

Current Approaches, Solutions and Practices in Conservation of Cultural Heritage

Editors

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PREFACE

The inception of the volume *Current Approaches, Solutions, and Practices in Conservation of Cultural Heritage* was motivated by the need to engage in a multidisciplinary discourse on conservation issues and incorporate recent experiences from various countries into a unified framework. The intent was to offer an examination of activities, replete with exemplary reflections on methodological choices and solutions adopted in the conservation of cultural heritage. Worth noting is the fact that, although it is challenging to fully anticipate the nature of submissions and how they will be assessed by the volume's evaluators when initiating a call for papers, in this particular case the proposed themes and case studies were discovered to harmonize seamlessly with the book's overarching objectives.

This volume comes to the forefront at a time when discussions on the integration of artificial intelligence (AI) in the realm of restoration are gaining momentum. This dialogue, intrinsic to the broader discourse on technological applications in the field, seeks to delineate the role of AI in conservation and restoration. It can now be stated that the application of AI in virtual restoration provides a platform for contemplating the reconstitution of artistic works, offering valuable reference points to deepen our understanding of artifacts and monuments. Concurrently, in the domains more closely related to conservation, an innovative approach has been initiated, aiming at developing algorithms capable of analysing changes in the appearance of artworks through image analysis and comparison, facilitating also the identification of alterations they undergo over time. Additionally, some contemporary research intends to support diagnostic investigations, employing AI to analyse surfaces and detect various forms of degradation. When appropriately directed, AI becomes a valuable asset in both the analysis and design phases of conservation or restoration interventions, providing new tools to explore the intricacies of the artworks. Nevertheless, the design of any intervention requires also a comprehensive reference point within the broader panorama of studies and research that integrate historical and critical aspects of restoration with both established and innovative practices, forged through the amalgamation of scientific knowledge and humanistic culture. Thus, the triad "Approaches, Solutions and Practices" appear in the volume as three closely interlinked elements of the discourse in taking stock of current strategies and methods employed in research and practical conservation interventions.

The adopted approach is inherently multidisciplinary, a characteristic shared by the group of curators comprising restorers, art historians, chemists and physicists. Their collaboration, rooted in diverse perspectives and experiences, underscores the collective effort towards the success of this book and its contribution to contemporary cultural heritage conservation. The foundational premise is a shared recognition that, in contemporary life, preserving cultural heritage is essential and that it must take into account the continual transformations in the environment and human life. Every material and intangible element of our past is its memory, and requires vigilant conservation for its future. Decision-making in conservation is then intricately linked to the experiences, culture, and relationships of those involved in designing and implementing conservation efforts. The focus on diverse approaches broadens the "investigative" field, encompassing reflections on work conducted by researchers and restorers across various time periods and locations where the problems of conservation find fertile ground to develop in order to safeguard the memory of the past and current human life.

Contexts are essential for understanding and acknowledging the testament of human activity, which in its turn requires preservation to reinstate its value, allowing perpetuation of its role in contemporary

PREFACE

society. Today's society is then encouraged to take a leading role in the valorisation process of cultural heritage through participatory actions, commencing with the attribution of value to both tangible artifacts and intangible cultural heritage (Faro Convention, 2013). In addition, contexts align with places of conservation, and ongoing climate changes must also be regarded in light of the continual evolution of parameters crucial to the preservation of cultural heritages.

The broad field of "investigations" provides innovative solutions for planning and executing actions to assess and monitor changes and interactions with the work. This includes scientific investigations studying material characteristics and degradation phenomena. The multidisciplinary approach emphasized in the book underscores the importance of considering both the appearance and subject matter of the artworks. Hence, it comes as no surprise to witness the involvement of interdisciplinary research groups that have formulated "solutions and practices" that include an understanding of the artwork from a critical historical viewpoint, encompassing aspects related to the execution processes and used materials, and that have simultaneously approached the subject from a scientific perspective, delving into the knowledge of physical and chemical characteristics of the materials and their transformations over time, while the development of tools and materials contributing to the enhancement of the restorer's work has also been considered in the different contributions integrating this book.

Interdisciplinary knowledge of cultural heritage contributes to preserving authenticity and integrity within its cultural context (Nara Document on Authenticity, 1995). In this sense, the term "conservation" in the title of the book is appropriate, since it encompasses all research and documentation activities that contribute to understanding cultural heritage, actions to protect artifacts (including restoration), and efforts to enhance their significance.

Editors

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APPROACHES

CHAPTER 1

UPDATING TRADITIONAL ETHICAL APPROACHES FOR THE CONSERVATION OF CONTEMPORARY ART

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Abstract

From the past to the present, experts have developed opinions and suggestions on protecting works of art sometimes prompted by negative consequences of past conservation practice. In response, ethical advice and practice was developed by practitioners and, through consensus, some of these have become de-facto ethical standards. The sector continuously returns to the need to establish common ethical standards to guide conservation practice in the protection of the works and support their transfer to the next generation. This article notes traditional ethical standards of respected institutes and theorists in Europe which were designed based on the conservation of classical works of art. The applicability of minimum intervention and recognisable practices of conservation is a debatable issue for professionals. As contemporary artists draw on a vast range of available materials, there are many transient and non-permanent materials and various conceptual approaches available for the construction of their artworks. The approaches currently adopted by many for the conservation of classical artworks might be appropriate for contemporary art, but, equally, the changing material and concept of the artwork might cause a rethink of traditional solutions. The article examines how these approaches match the challenges of contemporary art, which has revolutionized materials, techniques and even conceptions of art itself. We ask: does the artist's intent and the variety of materials and methods push the limits of current ethical approaches? In this context, we examine, with the use of case studies, whether conservators can apply ethical strategies such as minimum intervention and recognizability to the conservation of contemporary works of art.

Keywords: Conservation of contemporary artworks, ethics, artist's intent, minimum intervention, recognisable

1. Introduction

Ethical approaches to conservation were designed within the profession to provide basic frameworks to guide the conservation of classical artworks. These traditional approaches may not provide adequate guidance for the conservation of new artworks created under the influence of changing art movements. The reasons for this include: contemporary artworks can include conceptual elements that are immaterial and changing in form, that there is a different profile of materials and forms of construction in the creation of the art and there are radical new means of expression (Stigter, 2017). Contemporary artworks can be process-based and open-ended and represent more than tangible fixed objects (Stigter, 2017). The origins and applicability of ethical approaches defined in past centuries should be examined in the new context of contemporary artworks conservation.

In the later 20th century in Europe, approaches of minimum intervention and recognisable approaches gained hegemony and this is usually credited to the influence of Cesare Brandi. Brandi was an art historian and the director of the Istituto Centrale del Restauro between 1939 and 1961 (Muñoz-Viñas, 2005). According to Brandi, minimum and recognizable interventions are significant ethical elements for conservation practice. His motivation is to protect the artist's hand and the originality of artworks as much as possible. Although minimal intervention and recognisable practices were dominant thoughts in conservation in the 20th century in many national and regional traditions, their applicability to contemporary art conservation ethics has become arguable. This chapter discusses the applicability of traditional conservation ethics based on minimum intervention and recognisable approaches in contemporary artworks conservation. This discussion leads to additional questions as to how the artist's aims should be considered and how the transition of the conservator from a passive to an active role will develop our approaches and guidelines.

2. Approaches to minimal interventions and recognisability

The case for minimum intervention and recognisable interventions as an ethical practice is explained in Cesare Brandi's *Teoria del Restauro*, published in 1963. Brandi's (2005) conservation approach is informed by his perspective on the nature of art. He argued that the purpose of artwork should be a unique and special experience for each viewer and for a work to be described as 'art', aesthetic and historical values must be considered alongside an understanding of the artwork's integrity. This 'integrity' cannot be explained just as physical integrity, which describes the integrity of the materials that contribute the sum of the parts of artworks, but also the value integrity (Kaptan, 2009). To illustrate, words alone have no value,

whereas when the author brings them together to create a poem, words gain value (Brandi, 2005), and he applies this concept to the materials that make up the artwork. The materials that constitute works of art should not be considered separately from each other. They have indivisible integrity for the image that makes the artworks and therefore generate aesthetic value. Given this, the aesthetic value of artworks becomes a foremost decision-making criterion when undertaking conservation or restoration (Muñoz-Viñas, 2005). Consideration of aesthetic values led to the minimum intervention and recognisable conservation approaches suggested by Brandi (2005), where minimum intervention is the applied minimum limit of practices on the artworks where images or symbols do not change, and recognisable is where interventions to artworks can be recognisable by viewers or professionals (Brandi, 2005). Accordingly, it follows that interventions made to protect the works should be undertaken only where necessary on the material of the work and that the artist's hand should not be interfered with where possible. Brandi (2005) encouraged the conservator to ensure that interventions on artwork are recognisable to the extent that interventions can be noticed when examined closely and/or by professionals. This principle is offered as a significant approach to respecting the artwork, the artist's hand and minimising risk.

This century conservators have been challenged by changes in the perception of the value of artwork and in the nature of contemporary art creation, which has caused a fundamental shift in the paradigm of art conservation (Chyrkova & Yankovska, 2021). For example, the increasing use of deliberately ephemeral materials provides new challenges to conservators (Natali, 2008). Materials used by an artist might have conceptual properties that are formless or non-material (Stigter, 2017). What is the meaning of minimal intervention for conservation when the purpose of an artwork or a component of the artwork is to change and even disappear? Where artworks are ideas or performances, what does it mean to conserve them? Is it minimal to inhibit or enable change? Are changes built into artworks considered as deterioration and the subject of conservation, or as part of the value, in which case no intervention may be appropriate? Minimal intervention may not be an option for a material with a preservation horizon of days, weeks, or months. In a changing art movement, museum professionals must also be prepared to change and consider new approaches to managing the challenges in conserving the artworks, which often requires their active participation (Stigter, 2017; Giebelier et al., 2021; Lawson et al., 2019).

With the burgeoning of contemporary art forms that offer a personal perspective on political issues expressed through the art's form and content, the centrality of the artist's intention has become essential in art conservation. The artist's intent is important because the artwork

is a by-product and witness of a particular moment and era; it has historical relevance (Delagrange, 2021). With contemporary art, the inspiration and often the artists themselves, are available to help interpret that intent. This availability allows us to state, understand and challenge specific socio-cultural or ideological or political changes, creating awareness, stopping time and igniting the discussion (Delagrange, 2021). These social contexts were available to artists throughout history, and messages were made explicitly and embedded within classical artworks. However, for contemporary artworks, the artists or a close spokesperson is often available to articulate the intent, thus making it available specifically for conservation decision-making. Conservators can ask ‘what the artist means with the artwork’ by conducting and documenting a formal interview with them (Van Saaze, 2013, p. 54) or their representatives. These interviews will typically include information about techniques and materials used by artists and capture the meaning embodied in these artworks. Discussions about replacement and reconstruction should be undertaken to support the connection of meaning to tangible aspects. Such interviews are a chance to inform conservation decisions, but there remains a question about how much such interviews should impact the conservation process. Muñoz-Viñas a theorist and conservator, argues that artist’s intent is a weak approach to the conservation process. He argues that even if conservators conduct an interview with artists to learn the manufacturing technique of artworks, there may now be significant time passed between the interview and the making of the artwork, which may render it impossible for them to precisely remember all the materials, processes and techniques of manufacture (Reeves, 2015). Furthermore, the artist’s intent may change, either because of the artist actively changing their mind about the meaning or legacy value of the piece or through a developing consciousness about a piece that grows as it is engaged with. Therefore, although the artist’s interview is a valuable tool to inform conservation, it must be carefully managed and documented and sit within a larger decision-making framework (Giebler et al., 2021).

Early guidelines for ethical practice did not focus on, or prioritise, consultation with artists because the guidelines were created for conserving classical artworks long after the artist’s death. Therefore, with little guidance on how to consult, there is some evidence that conservators have in the past been reluctant to seek input on their work, especially on technical matters, or where advice was offered that appeared to conflict with what was felt to be professional ethics raising questions about how the conservators should negotiate that challenge (Henderson & Nakamoto, 2016). The combination of these challenges has led to a growing recognition within the sector that traditional conservation guidelines were inadequate, prompting calls for new ethical approaches (Ashley Smith, 2017). Thus, at least partially driven by the newly

revealed questions of contemporary artwork conservation, the necessity of reviewing and updating traditional conservation approaches and processes has become apparent (Opena et al., 2021). In practice, the rise of installation art has made artist consultation necessary and has prompted thorough reviews and guidelines (Lawson & Potter, 2017, Hölling, 2021). Conservators working with contemporary art have been revisiting the philosophy and ethics of conservation. For example, conservation staff in the Tate group of art galleries in the UK have worked to deliver considered and ethical conservation practices in consultation with relevant partners. In their publications, they have provided guidelines to practice which convey the conservators' skills and knowledge of materials, as well as innovative thinking, interdisciplinary collaboration, and ethics for a new operating climate (Lawson & Potter, 2017). This new operating climate challenges the comfort of well-accepted rules within the sector and reveals the need for more developed approaches to conserving contemporary artworks that can inform the profession well beyond contemporary art (Wain and Sherring 2021).

Moving beyond ethical approaches, which adhere strictly to rules of minimum intervention and recognisable practices, asks new questions of those conservators who have relied heavily on the Brandi model. It is necessary to expand common notions of authenticity, loss, and changing state being part of authentic art if we are to locate the recognisability of our intervention in multiple formats and integrate multiple and potentially changing or conflicting understandings of the meaning and authentic nature of the pieces on which we practice conservation.

3. Ethics and conservation

The field of philosophy known as ethics has been described as the study of behaviour (Edson, 1997). Another description is that 'ethics is a human activity' (Brown, 1990, p. 11). Ethics have an essential role in determining the limits of professional practice frameworks. Thus, determining ethics and their effect on professionals is significant for many fields. Clavir has described ethics as "*any and all sets of moral principles and values that govern individual and group behaviour*" (Clavir, 2002, p.26). In contrast, Edson (1997, p.5) describes ethics as geometric correctness, such as an $x=y$ mathematical equation. This ethical approach suggests that in the same situation (x) and should generate the same answer (y). Any behaviour that does not fit this method cannot be considered ethical. This rule-based or deontological approach to ethics may be helpful to warn that, for example, 'you shall not kill', but it offers less insight into conservation decisions. Furthermore, experiencing the limits of a rule-based approach may suggest to some practitioners that no universal code of professional ethics was possible for conservation, given the layers of nuance and variability implicit in our practice. Instead of a rule-based approach that focuses on inputs (the ' x ' that leads to the ' y '), an ethical code

could consider the outcomes as critical to ethical decision-making, situating ethical principles on the consequences of our actions. Such a system is problematic for conservation where the consequences of our decisions and actions may exist in an unknown future where the values with which cultural heritage and our acts upon it cannot be known. A virtue-based approach to ethics where we act according to our present-day virtues aligns more closely to Clavir's description, seeking instead to find universal virtues (moral principles) of our profession. Although a daunting prospect, conservation ethics should be determined by interdisciplinary and international debate as to what should guide our practice. Opening our values (implicit or explicit) to scrutiny and comment would support the professional position of conservation within the communities whose opinions we seek.

Ethics can be conceived of as the study of good and bad behaviour. When a rule-driven approach supports such a binary perspective this may create considerable pressures for every individual's behaviour to be perfect. Despite the allure of perfection, which may be strong amongst the conservation community, it is not credible to find an ethical code to determine all acts, practices and behaviours of professionals and guarantee a perfect outcome and set of consequences for every set of inputs. Simply acknowledging the multiple and changing perspectives on cultural heritage where the same tangible item may have different meanings to different communities exposes the impossibility of perfection. Guides to ethical practice can, however, support professional decision-making based on principles determined by our current virtues, which are defined by the society, culture, and necessity of the era. Thus, rather than seeking universal rules, we may attempt to uncover our ethical principles, which are discussed and determined by art historians, curators, owners, conservators, stakeholders, and others whose lives are touched by their relationship with cultural heritage (Clavir, 2002). It is valuable to note here that many lives are also shaped by their exclusion from the cultural heritage, so discussions on ethics should be as shaped by those who currently have no access to the cultural heritage as those who do.

Although his contemporaries discuss Brandi's strategies for the conservation of architecture and artworks, his contributions to the field undoubtedly have an important place for today's conservation. Brandi emphasised the importance of conserving the image and integrity of the artwork, as well as the approach to the uniqueness of the work, which emerges as a result of the human spirit and the emotional and mental state of the artist (Ersen, 2010). The conclusions of his ideas were to determine the goals of conservation to be to preserve the meaningful whole, the experience of an artwork, and to maintain the sense of the thing as it is found now and capture its whole life. How these ideas manifested in his writing might have been recog-

nizability and minimum interventions, but these were the conclusions of his ideas in practice rather than the theoretical platform. In critiquing the application of Brandi's philosophy, much of the critique applies to the blanket use of solutions without reference to the original impetus. The purpose of this chapter is not to offer a full philosophical review of the origins of Brandi's ideas and this is done elsewhere (Meraz & Magar Meurs, 2019). Instead, the impetus of the paper is to discuss the practical applicability of the conservation approaches that Brandi put forward which have a powerful hold in our sector by examining the continued relevance of the practical conclusions of his work and, in particular their manifestation as they have been taught to the lead author of this chapter.

3.1. A brief history of conservation ethics

It is common to trace the development of conservation and restoration practices back to the Italian Renaissance when artists were rediscovering the methods and creations of classical sculptors (Ashley-Smith, 2009). In many cases, mirror actions were undertaken by conservators in later centuries. These historic interventions do not fully align with what we consider to be a clearly defined conservation profession which only began to take shape in the middle of the 20th century (Ashley-Smith, 2009). One could argue that Alois Rigel and Camillo Boito are the originators of traditional conservation theory in Europe and that Cesare Brandi, Umberto Baldini, and Paul Philippot are just a few of the most well-known individuals who furthered the development of these ideas in their works (Belishki & Corr, 2019). These approaches have significantly influenced conservation traditions in many parts of the world and it is possible to track their influence on various national and institutional initiatives that attempt to scope out appropriate ethical approaches and methods. In reviewing the sector, it is interesting to reflect on who can and should identify ethical approaches and what should be considered within the scope and implementation of ethical conservation standards.

The development of ethics, as core to the practice of conservation, is strongly related to the development of conservation-restoration as a scientific discipline during the 20th century. Ethical codes evolved alongside the development of the philosophical, historical, and scientific bases for conservation intervention methods and techniques (Schadler-Saub, 2019), with ethical principles providing a framework for practice, techniques, and methods for the newly emerging class of professional conservators. Ethical principles continued to be revisited and rethought, and within traditional European conservation contexts, there were significant innovations between the twentieth century and the early twenty-first century (Schadler-Saub, 2019). A bedrock of European practice and influential worldwide were theories developed

by Brandi in 1963¹. As the ethical practice became embedded in an increasingly professional workforce, more formal and agreed guidelines were agreed upon and published. The ideas of many theorists influenced the sector, such as the work of the 19th-century writer John Ruskin (Niglio, 2013).

Ruskin based his approach on the restoration of architectural monuments claiming that heritage buildings are ‘corpses’ that could only be preserved rather than restored (Yazdani Mehr 2019). Ruskin thought that a heritage building’s material contained priceless traces of the past, anything great or beautiful in architecture has never been able to be restored; it is as not possible as raising the dead (Yazdani Mehr 2019). This soul, which can only be obtained by the hands and eyes of the workman, can never be recalled (Yazdani Mehr 2019). Ruskin argued that instead of attempting a process of restoration, the original aesthetic and physical integrity of heritage buildings should be conserved as faithfully as possible. Ruskin combined his ideals of decay and the patina of time with suggestions for minimal intervention and the idea of trusteeship (Orbaşlı 2017). In this way, he argued that viewers best experience heritage buildings by seeing the original material. Thus, a Ruskin-inspired approach to the conservation of artwork should entail stabilizing it, preserving its integrity and ensuring that its ‘true’ aesthetic is retained without altering the artist’s intent or losing significant historical information (Niglio 2013).

According to Nicola Hartmann, contemporary art has different levels of existence, so not only are the materials different from those selected in the past the very nature of existence is called into question (Hartmann 1977). Art is supported by its materiality, which would be the visible stratum of the work and a component of perceptible reality yet, there is also an interior stratum to art, and because its nature is immaterial, the viewer sees the art from this internal stratum (Llamas-Pacheco 2020). A conservation focus that is restricted to the material form of objects with a goal of preserving physical and aesthetic integrity that was effective in the 18th century has become problematic for contemporary artworks. Conservators have begun to draw attention to the shift in focus from tangible objects to intangible things (like ideas) and consider the implications for ethical practice. Some conservators argue that this transition requires an update to traditional conservation ethics (Grevenstein and Scharff, 2005, p. 296).

1 These publications revealing a period of focus on ethics with the following publications in the early 1960s: Cesare Brandi’s *Teoria del Restauro* (1963), the Murray Pease Report (1961 to 1963), and the Venice Charter (1964). This article acknowledges its focus is on ethical perspectives informed by European perspectives.

3.2. Defining conservation ethics

A precursor to much that shapes Euro-American perspectives on conservation ethics was a report produced in America by a committee on professional standards and procedures established in 1961 under the leadership of Murray Pease, resulting in the publication of what is commonly known as the Murray Pease report in *Studies in Conservation* in 1964 (Pease, 1964). The publication advocated for the adoption of ethical guidelines internationally and was ‘the first group of conservators in any country to have formulated its standards of practice in an explicit document’. The document was adopted in 1967 “*to express those principles and practices which will guide the art conservator in the ethical practice of his profession*” (AIC, 1994, p. I). Between 1964 and 67 the profession progressed their thinking from specific procedures or operations to the need for ethical principles to guide practice. This distinction is important, recognising that professional ethics guide decision-making processes supported by principles rather than ethics determining a specific measure (rule-based).

There are several internally agreed definitions of conservation ethics, and a selection of these are listed here in chronological order of their production (table 1). Some of the definitions reproduced below replace earlier versions, so a gap in the chronology does not necessarily mean that this definition work was not being undertaken, perhaps only indicating that earlier work has been superseded. Some of the documents listed do not identify the concept of conservation ethics but indicate the ethical practice that underpins their definition of conservation.

Table 1. A Chronological summary of some of the different institutions’ approaches to conservation and/or ethics is listed above.

Institutions	Publication date	Description of conservation ethics
Cesare Brandi 1963 (Brandi wasn’t considered an institution, but it was viewed as a point of the start).	1963	Brandi explained that conservation ethics should be based on conserving artworks’ aesthetic and physical integrity. His approaches to conservation ethics also include critical and philosophical perspectives.
The Venice Charter ²	1964	The Charter determined the limits of necessary interventions to the monuments and how conservators should be. Article 12: Replacements of missing parts must integrate harmoniously with the whole, but at the same time, must be distinguishable from the original so that restoration does not falsify the artistic or historic evidence (ICOMOS 1964).

2 The Venice Charter focused on the conservation and restoration of monuments and sites, was published in 1964.

E.C.C.O. [European Confederation of Conservator- Restorers' Organisations]	2002	Article 3: The conservator-restorer works directly on cultural heritage and is personally responsible to the owner, to the heritage and to society. The conservator-restorer is entitled to practise without hindrance to her/his liberty and independence (E.C.C.O. 2002).
ICOM [International Council of Museum]	2004	The museum should establish and apply policies to ensure that its collections (both permanent and temporary) and associated information, properly recorded, are available for current use and will be passed on to future generations in as good and safe a condition as practicable, having regard to current knowledge and resources.
ICOM-CC [International Council of Museums- committee for conservation]	2008	"All measures and actions aimed at safeguarding tangible cultural heritage while ensuring its accessibility to present and future generations ... All measures and actions should respect the significance and the physical properties of the cultural heritage item" (ICOM-CC, 2008 p. I)
ICOMOS	2014	The ICOMOS ethical principles specify the responsibilities of ICOMOS members and its bodies towards cultural heritage conservation and in connection with ICOMOS. Article 4-b: The ethical principles are not a doctrinal text: when necessary, the wording has been adjusted to clarify this.
ICOM [International Council of Museums]	2017	A basic requirement for museums is provided by the ICOM Code. It provides a set of standards for appropriate professional conduct, each supported by a set of guiding principles. All conservation procedures should be documented and as reversible as possible, and all alterations should be clearly distinguishable from the original object or specimen.
ICON [The Institute of Conservation]	2020	'Conservation is an approach to items of cultural heritage, which seeks to preserve their intangible and physical manifestations as evidence of the past for present and future generations to study and enjoy (ICON 2020, P.3).

These definitions, produced over decades, vary in origin and are influenced by national laws and originating institutions. However, it is possible to see most of them have similar core elements. In most cases, they suggest that conservation is concerned with their responsibility to future generations and to adhere to moral duties. The UK professional body for conservation, ICON, recently developed ethical principles and explained that they must 'specifically avoid dictating how those goals should be achieved' (ICON, 2020, p.2). Icon signalling that they are identifying the avoidance of a deontological or rule-based approach, offering instead thirteen general statements outlining the ethical treatment of cultural heritage objects. This broad approach recognises that conservators are professionals and should be free to use their professional judgment in decision-making. Nonetheless, even within the ICON codes are statements that, at the very least, are inspired in parts by traditional ethics, as this extract indicates:

“Actions should remain detectable.

Actions should allow future re-treatment and remain as reversible as possible” (ICON, 2020, p.6).

ICON also signals that tangible and intangible elements must be considered without at this time commenting on how to navigate between these. The worldwide concern for future use is also matched with detectability in the ICON statements, although the concept of minimal intervention is not present, replaced instead with twin concepts of considering no action and only enacting sustainable interventions. Ethical guidelines can provide frameworks for conservation practice which support different measures in appropriate contexts. So, when considering 20th-century artwork and its challenges, ethical frameworks should offer principles to guide practice. Where specific measures are described as ethical but are no longer sufficient, it is appropriate to move past them.

4. Conservation ethics a discussion

4.1. Value in conservation ethics

Ethical principles for conservation offer frameworks to support the protection of valuable objects for society raising the question: why do people prefer to conserve some objects more than others? Where does the value of objects lie and how is this value given? People attach value to an object for many reasons, such as culture, society, geography, religion, etc (Giombini 2019, Munoz-Vinas 2005, Frasco 2009). In the second half of the 18th century, Winckelmann wrote his noteworthy text on art history, fine arts colleges proliferated across Europe, and Baumgarten formally founded the independent discipline of aesthetics (Wicklemann 2006). Artworks and their materials start to have a value that is ‘eternalized’ by being removed from their historical context and made into museum exhibits for perusal as pure forms (Giombini, 2019). Determining the value of art also depends on a *“cultural group -often including, but not limited to, political, religious and spiritual, and moral beliefs”* (ICOMOS 1998), thus developments in conservation ethics are linked to wider social philosophical developments. The status of cultural heritage and its associated value are therefore philosophical concepts that conservators must address in determining their ethical approaches (Llamas-Pacheco 2020). Consensus on conservation ethics amongst professionals is therefore related to the adoption of such ideas in wider society. Whilst the impetus for ethical guidance is often the creation of a stable framework for practice, relevant socio-cultural, political, and scientific factors of each era shape the creation of guidelines or codes. Each generation creates a code that they hope will transcend time, but to date, no code that the authors are aware of has remained

unchanged. In this respect, it is important to aim for longevity but acknowledge that ethical approaches will be affected by time and context.

In the current literature, there are multiple perspectives on the major issues in contemporary art conservation (Chiantora and Rava 2013), but for this chapter, the scope is limited to a discussion of the impact of minimal intervention and recognisable approaches on the aesthetic of art. Brandi argued that conservation³ should be guided by the value inherent in the piece being treated and that conservation should be guided by the existing value of the piece as it is or was valued by its artist. In following his guidance, a conservator must consider the work's aesthetic and historical value and use this to guide decisions about interventions on the material form. Brandi's primary observation is that only the material of artworks can be restored, he states, 'Conservators must not intervene in the image, and if it is necessary to sacrifice the materials of artwork, the aesthetic value must be considered' (Brandi 2005, p.48). This holistic approach places the aesthetic rather than the materials of composition at the centre of the decision (Kaptan, 2009), framing an ethical approach on the basis that as long as the appearance of the artwork is not changed, the artwork's materials can be restored because the material serves the image in the artwork. According to Brandi, the artist tends to express and create something within themselves; they can only make it manifest outside of themselves by using material methods (Verbeeck, 2019); therefore, the materials are subordinate to the expression. The audience absorbs and recognises the 'something' that is the work through its materiality (Verbeeck, 2019), as the material serves as its carrier. Accordingly, one piece of the mosaic does not represent the artwork, but the stones capture the expression when the artist puts them together. Brandi's second guiding approach is the historical value of artworks. Art contains traces within its material form from its entire life: from the period when the artists made their artworks to the present day, contributing to its historical value.

Muñoz-Viñas (2005, p. 6) makes the case that 'aesthetic values are of the foremost importance' things to be considered when making conservation decisions. Whilst prioritising aesthetic concerns is critical where a primary function or component of the art is its aesthetic quality, the artist, in the context of contemporary art does not always create their work led by aesthetic concerns. At this point, understanding the meaning of the materials and techniques used becomes a prominent issue for conservators as these are at least the embodiment of the

3 It is valuable to note here that the terms conservation and restoration are used interchangeably and distinctly within the conservation profession. Restoration is sometimes associated with more direct intervention and replacement of missing elements; however, this association does not hold consistently, especially once translation from different European languages is concerned. Where an author uses the term restoration, it may refer to a more interventive aspect of conservation, but that is only a possible conclusion that a reading of the context should test.

artist's intent. When there is no chance to ask the artist about their intent in creating the work, a portion of the value of the artwork is represented by what they created with their own hands as an expression of their ideas.

4.2. Minimum intervention

In the second half of the 20th century, minimum intervention became a dominant phenomenon in conservation ethics (Villers, 2004), based on Brandi's 'minimum of needed intervention' (Brandi 2005). Since any intervention to the artworks may cause undesired changes to the objects, minimum intervention may be a solution to minimise risks. The minimal intervention strategy encourages the conservator to only carry out as much stabilization or restoration as the object absolutely and necessarily needs in an effort to lessen unexpected treatment consequences (Frasco, 2009). Limiting actions to the necessary: considering conservation before restoration; preventive conservation before interventive conservation; and not adding more material to the object than necessary, (Frasco, 2009) are necessary steps to achieving minimum intervention.

The term 'minimal intervention' may not always communicate clear principles for conservators as the term minimal describes a wide variety of values. It holds no universal sense; it does not mean 'rather little', 'quite little', or any other similar descriptions (Muñoz-Viñas, 2002). In the complete concept of minimal, we may theorise or feel that when we use the term minimum intervention, we are communicating the same ideas, but Muñoz-Viñas (2002) argues this is just an illusion because the concepts of intervention and minimal are exclusive, no intervention can be both. Even when the conservator intends to protect or maintain the artworks or historical objects, this term is an arguable principle because any intervention in the objects can cause a loss of historical value. Even the most commonplace techniques of interventive conservation defy the description 'minimal'. For example, removing a tarnished varnish layer on a painting is not reversible and results in the loss of some historical information. Such approaches are also affected by socio-cultural facts, such as the desire for the artworks to seem as it is believed that they were when they were first created, resulting in the removal of varnish layers, which have been thought of by others as valuable patina, to conform to a specific desired socio- cultural reality (Conti & Glanville, 2007).

The concept of minimal intervention is also temporarily bound. What may be considered the minimum necessary intervention in one period can appear drastic in another, following scientific development, which provides an alternative solution. To consider a medical analogy, whereas amputation may have been the minimum necessary to cure an infected limb in one era, a course

of antibiotics may be the minimal intervention in another. Accordingly, the concept of an appropriate minimal intervention depends on the era in which the decision is made. Since the options available and the cultural context changes over time, this will lead to different approaches. That said, the fewer interventions made by conservators, the higher the probability that the originality of the artwork will be conserved, as every intervention will have a non-reversible element and some possible negative consequences (Muñoz- Viñas, 2002).

According to Caple, *“the problem with minimum intervention is that it is not a complete statement. The minimum intervention to achieve what?”* (2000, p. 65). He asks what determines the conditions for minimum intervention and explains the problem with this example *“minimum intervention to preserve an object for 10 years standing outside in the rain is very different to the minimum intervention to preserve an object for a few days in a controlled internal environment”* (Caple, 2000, p. 65). Given this, a minimum intervention should be determined for a particular object over a given period of time under a specific set of conditions (Caple, 2000), further extending the concept of minimum intervention. Professionals must also factor in environmental conditions (global warming, pollution, vandalism, etc.) which can cause deterioration in the artworks and measures by which this deterioration can be mediated. Attempting to impose a framework of minimum intervention may not lead to the most logical decision pathway, and the minimal intervention approach may not be optimal for many artworks. Each artwork needs different solutions and interventions and a minimum intervention approach will differ between artworks guided by the resources and perceptions at the time of conservation. On examination, it seems that although pervasive in its use within the sector, the concept of minimum intervention has an inconsistent meaning and does not act as a unifying guide to ethical practice.

4.3. Reversible

When considering the practice of retouching a concept which often appears in discussions on ethics is reversibility. It is proposed that the materials used for retouching be reversible so that, in the future, the interpretations that the current restorer has suggested for the painting can be simply removed and replaced with new ones (Conti & Glanville, 2007). Methods to achieve this reversibility could include careful selection of pigment binder and solvent so that retouch can be chemically removed without impact on the original paint. For instance, when retouching an oil painting water-based pigment can be applied (watercolour) under-varnish so it can be removed without damage to the original paint layer on the painting. The intervention must be applied with reversible materials and the retouch may create a lighter colour (sotto tono) than the original image becoming recognisable from the original painting by the intervention technique, tone and colour (Ostrovcsa, 2020, p. 43). Another technique for reversibility is

using barrier layers providing a point of separation should an additional component need to be removed. The argument for these approaches is understandable given that in the past, instead of in-painting losses, some heavy-handed repair work involved over-painting where the original surface is hidden behind the additions to blend the repair. The resolution to this for professional conservators is careful in-painting where the conservator ensures that they restrict their actions to the areas of loss in the original paint layers, demonstrating a concern to preserve the authenticity and integrity of the artist's hand (Conti & Glanville, 2007).

4.4. Recognisable

The principle of recognisability was used in the conservation and restoration of artworks to preserve aesthetic integrity and help convey the value of artworks to visitors. Various approaches have been developed and implemented by conservation professionals to achieve recognisability. Brandi (2005) argued that all retouching interventions should be recognisable to counter any deterioration that negatively affects the aesthetic appearance of the artwork and disrupts its integrity. Such interventions should be sufficient to cover any deficiencies which disrupt the integrity of the artwork and to protect its historical meaning (Brandi 2005). A popular approach to creating recognisable retouching is to make an illusion for viewers whereby the intervention creates a form of integrity to unify the aesthetic, but when examined, it is apparent that it is not part of the original artwork. Visitors should be able to see differences between the original part of the artwork (artist's brush and drawing) and interventions which conservators have made.

Several suggestions exist for how 'in-painting' intervention can be applied. Conti and Glanville suggested three basic approaches; aesthetic restoration (invisible retouching and reconstruction through analogy), restoration as conservation (abstinence or an archaeological approach), and visible restoration (which complements the original while being easily recognisable) (Conti & Glanville, 2007). Based on experience, the authors believe that of these three approaches, aesthetic restoration is the more popular option for classical art in public collections in museums and galleries and potentially also with collection owners. This restoration intends to complete any gaps and accordingly, any past loss may go unrecognised by the viewer, who would be unclear as to any differences between the artwork of the original artist and the conservator's interpretation (Conti & Glanville, 2007).

Various techniques have been developed to enable restoration where a general audience can clearly distinguish between the original and in paint. One such technique is the *tratteggio* method of image reintegration (terms defined in AIC 2015) where the desired fill colour is created by adding repeated layers of delicate lines (Grenda, 2010). *Tratteggio* was created and improved in 1945-1950 at Istituto Centrale del Restauro and was inspired by Cesare

Brandi's philosophy of conservation. *Tratteggio* retouching reconstructs the image and makes it more readable while also making it obvious and recognisable to the viewer. Finding the distinguishing qualities of the desired hue and recomposing them by giving the appearance of a colour that reintegrates the image is known as a chromatic selection (Grenda, 2010). Colours from the chromatic selection are placed adjacently that when viewed from a distance provide the appearance of a unified colour. The colours are mixed in the eye rather than in a palette.

Full *tratteggio*-style retouching can be applied in two ways. The original *tratteggio* is *Riganto*: a system of vertical lines forms the colour (or pattern), which, when viewed from a distance, integrates the lacunae with the original *tratteggio* (Grenda, 2010). Another option is the *selezione cromatica* technique, where the alignment of the paint lines is not automatically vertical, but instead, the lines conform to the visual flow of the image (see figure 1). Another related technique is *astrazione cromatica* which was designed to be applied when there were more significant losses and there was not enough information about the original composition. The idea is founded on the supposition that neutral colour can be produced that harmonizes with the complete image and improves its ability to be reintegrated and understood (Grenda, 2010). The *astrazione* augments that neutral-toned fill with a limited pallet composed of primary colours and black, and combined with the toned fill, the intertwining lines create a vibrant colour screen (see figure 2).



Figure 1. The example for *selezione cromatica* in the Church of San Nicolas Obispo y San Pedro Martir, Spain. (Ostrovcska, I. 2020. Aesthetic integrations in the restoration process of mural painting. *Journal of Architecture Urbanism and Heritage*, 3(2), 37-44, p. 40).



Figure 2. The example of ‘astrazione cromatica’ of Madonna’s face. (Ostrovcska, I. 2020. Aesthetic integrations in the restoration process of mural painting. *Journal of Architecture Urbanism and Heritage*, 3(2), 37-44, p. 41).

By understanding the mode and philosophical routes of these approaches, their application to contemporary art conservation can be examined. The materials used to create contemporary works are more than just paint and canvas, so what criteria for practice should conservators use to preserve the aesthetic integrity of the work? Should new techniques for reintegration and intelligibility be developed in areas where losses are high, or can the aesthetic integrity of the contemporary artwork be achieved by re-use of materials that match the original? How is the ethical approach for traditional art conservation adapted to contemporary art conservation, can we identify a suitable approach to the aesthetic appearance that transcends variation in form?

5. The relationship between the conservator and the artist

5.1. Stakeholders

Contemporary art’ conservation has brought the necessity of collaboration to the forefront of the conservation discourse (Chiantora and Rava 2013). How can the interests of multiple stakeholders and their role in determining conservation decisions be negotiated? Miller argues that conservators should provide a balance between the artist’s intention and the obligations of institutions in terms of legal, ethical, and practical factors (Miller 2017). According to

Cotte, conservators “*aim to understand how the work is made, what the material is and the way it has been prepared, treated, manipulated, and materially transformed. Conservators tend to recreate the stages of making conceptually to gain a better understanding of the final work of art, how it conveys meaning and how it can best be conserved through time*” (Cotte et al. 2016, 108-9). In Cotte’s view, conservators are active participants in the conservation of the process of art manufacture as they take part in the experience by putting themselves in the artist’s shoes and thinking like an artist. As the conservators from the Tate describe, conservators have become ‘active caretakers of change’ (Lawson and Potter 2017), aware of the components, identity and perceptions of artworks.

5.2. Authenticity

Some conservators argue that artworks have a ‘true nature’, which is a concept that should be considered and examined alongside the term authenticity⁴. In the late 19th century the development of affordable and accessible (to some) scientific analysis enabled conservation laboratories to identify the composition of materials used by artists and to separate them from later interventions and added materials (Van Saaze, 2013). This formalized a technologically determined idea of following the artist’s aims as the basis of art conservation (Dykstra, 1996, p. 198). However, this preoccupation with material definitions of authenticity has been increasingly challenged within the profession in the early 20th century.

If a conservation ethic sits on the principle of not changing the nature of the object, and this is defined as “*the means by which the original and true nature of an object is maintained*” (Van Saaze 2013, p. 75) then evidence of an object’s origins, construction, materials, and manufacturing technology determine its essence. However, if the materials and techniques of artworks are of little concern for the artist’s intent then how should conservators respect the true nature or authentic elements of art? According to Clavir (1998), ethics should guide us to identify the conceptual integrity of cultural heritage: a concept that is not to be confused with original materials. If conceptual integrity and artist intent take precedence over ‘authentic materials and ‘original’ appearances then integrity can be seen to have moved from a material existence to an intangible one. This places artistic intent as an intangible quality with greater precedence in decision-making than material continuity. Llamas-Pacheco (2020) argues that in search of the truth of a work of art, we can distinguish between the identity and the essence of a thing, and determines that if we ask ‘what’ the art is the “*essence relates to the main and necessary qualities of the work of art*”, (2020 p.489). Whilst defining the truth of any work is

4 Authenticity is a term that includes different discussions and approaches; a full discussion of all interpretations and their implications is beyond the scope of this paper.

a huge challenge we can, as conservators, aim to try to gather interpretations of the work both from the artist and from those who interact with the work (Llamas-Pacheco, 2020).

5.3. Artists intent

Artists' intent, the use of ephemeral materials and novel techniques and the conceptual intention of the artist have all challenged traditional practices developed for conserving classical artworks. The materials used by contemporary artists, such as plastic, human and animal by-products, ephemeral, synthetic, replicas, living, etc., may cause unpredictable consequences and prove new challenges (Chiantora and Rava 2013, Soulioti and Chatzidaki 2022, Hölling, 2021, Bharti, 2023) compared to the comparatively well-researched materials of classical artworks such as tempera, oil painting, canvas or paper. The positive opportunity to interview artists helps conservators learn about the materials, techniques and intention of their artworks which may guide preservation strategies ideally as part of the process of acquisition of the artwork. Conservators can obtain information about the artist's surviving artworks that can assist in the conservation process, but this means that conservators must also recognise and respect the artist's intent and integrate this into their conservation strategy (Natali, 2008). A challenge related to the artist's intent arises when conservators do not have the opportunity to interview the artist. In this case the artist's intention could be known to exist but not to be available. Furthermore, sometimes artists want to change their artwork, which can cause a dilemma for those who regard the originality of the artwork as being located within its material construction at the point of origin. The artist's intent must also sit in the context of other perspectives including those who own or interact with the work. Given this, working with artists in the conservation process may be a nuanced process. Any simplistic default or preservation 'zeal' must be carefully managed, and a lazy default to 'ethics' as an excuse to ignore this information should be avoided.

While artists are well-positioned to describe the artwork's techniques and materials, they are not always experts in materials and conservation practices. Therefore, advice given by artists to the conservators is a platform to begin to determine conservation practice, but conservators must integrate this vital input with their specialist technical knowledge, their ethics and a concern for the pragmatism of operating in the public sphere. For example, the artist Anya Gallacio prefers work with ephemeral materials (salt, flowers and sugar), and Tate Britain asked the artist to make a site-specific sculpture in their gallery. The artist intended to use ephemeral materials to express her ideas and mentioned: *"I want to work with landscape and oak and sugar beet are both familiar elements, symbols from very different British landscapes"* (Davies & Heuman, 2004, p. 32). One of her proposed works involved pouring 1.5 tonnes of boiling sugar and glu-

cose directly on the gallery floor so that visitors could walk on the resulting sugar carpet. The gallery staff identified that these materials were hygroscopic and unstable and could cause pest attacks and dust. In collaboration with the artist they reviewed several methods and techniques to find a solution that respected the artist's vision but did not threaten the care of other parts of the collection. Eventually, the artist agreed that the nature of the sugar, the scale of the project and its interactions with decay and experience could all be adapted. Conservators reviewed and recommended the least tacky sugar substrate, selected and applied a sealant to protect the sugar surface from incoming moisture whilst keeping the glass-like surface in place and agreed that the work would be produced on pallets rather than directly on the floor (Davies & Heuman, 2004). The conservators, Davies & Heuman, noted that these quite drastic alterations were possible because the artist was very pragmatic: Gallacio stated that *"This is not about simply illustrating an idea... it is to do with having an idea about certain materials and putting them together and seeing what they do. That's what excites me. You must accept that things will change"* (Davies & Heuman, 2004, p. 33). In this case, the original materials, construction, and interactions with the visitors regarding the smell of sugar and its inevitable decay during the display were problematic for the conservators. All the adaptations described conflicted with the artist's intention, who wanted to show the physical transformation of the materials. In their paper, the conservators reflect on their practice and question whether their impetus to preserve the artwork for the future clashed with the artistic vision of the now. The artist's desire to explore physical changes was directly in conflict with conservation training to preserve materials. Most contemporary art is concerned with its effects now, no matter the repercussions, whereas conservation is about conserving art for the future. Additionally, it can be best to take a backseat and allow the artist to focus solely on their work (Davies & Heuman, 2004).

This case demonstrates how conservators changed the form and experience of a piece of art and represent a core challenge of consultation when input is sought but the stakeholder's perspective is overruled by conservators based on a perceived technical or ethical necessity (Henderson & Nakamoto, 2016). If the artistic input is subverted have the conservators become gatekeepers based on the enactment of apparent ethical principles which respect techniques of conservation even above the philosophical spirit of the creators of pieces that they aim to preserve? How do conservators navigate a pathway through an artist's intent for the now and their belief that their ethical duty is to save artworks for the future?

Is it appropriate or indeed even ethical to question artists about the philosophy that went into their creation, the tools and methods employed to make it, before interfering with their own work (Natali, 2008)? Or should ethics focus more clearly on asking questions about the

artwork to understand the artist's creative path? Protecting the aesthetic and historical value of artworks and inhibiting material deterioration are no longer sufficient guides, not least when artists want their work to decay or when they place higher importance on a notion than its material expression, which can clash with a preservation zeal (Wharton, 2005). An approach must be developed that can consider how the artist's intent can be integrated into conservation decision-making with technical considerations, the input of multiple stakeholders and ethical standards. If conservation requires a choice between protecting material or the artist's intention how can professionals unpick this dilemma?

6. A new approach to ethics?

Contemporary art movements and innovative artistic methods have led to a reevaluation of conservation, how it affects cultural objects and the responsibilities of conservators and other stakeholders (Marçal, 2019, Bharti, 2023). The 1990s saw a notable expansion in discussions on the field of conserving contemporary art (Marçal, 2019). Various interests, methodological strategies, and newly applied philosophical approaches affected the development of contemporary art's conservation (Bauerova, 2010).

Many materials and methods entered the artist's work during the second half of the 20th century. The social and historical connotations of chosen materials and the expression of the material's iconography have widened the artist's selections and integration of non-traditional painting materials (Hummelen and Scholte 2021). Changing art movements and artists' intentions have caused the need to refresh and revisit our ethical approaches to conservation. In conserving contemporary art, the improved relationship with artists has changed conservation practice. For example, if working with multiple iterations of a display of contemporary art that each consists of several frequently changeable elements, the conservator will benefit from the opportunity to develop a fuller understanding of the artists' intent and how that evolves and is applied in each specific context perhaps adapting to restrictions of space, equipment or changing components (Sterrett, 2009). In this respect, the role of the artist has been extended beyond creating artwork and in some contexts it has become engaged with museums or collectors in decisions about conservation and access.

Those who are developing the field of contemporary art conservation have looked to other disciplines for new perspectives with a resulting innovation in conservation methods (Marçal, 2019). Collaborating with professionals who have different backgrounds is as significant for understanding the meaning of material beyond the physical object to uncover issues related to value, artist intent and what the material represents (GCI CIMCA 2008). Contemporary art

conservation makes the challenges of interdisciplinarity in describing the meaning and nature of the subjects of our work and the uncertainty of future developments impossible to ignore. However, the lessons of interdisciplinarity, collaboration and the rejection of rigid frameworks can apply across the profession (Soulioti and Chatzidaki 2022). As a result, working with multidisciplinary perspectives and professionals with different backgrounds has become a common theme in making conservation decisions for contemporary artworks.

According to, Muñoz-Viñas (2005), contemporary conservation theory uses adaptable criteria and makes adjustments to meet the needs of its subjects. However, theory can be exploited or even abused when making important decisions because these criteria are subjective. So, the authority of the conservator should be implemented wisely and with caution, and all relevant variables should be evaluated as accurately and honestly as possible (Muñoz-Viñas, 2005). Additional protection lies in the process of documentation and accountability, which is vital in the process of conservation. In respect of this, contemporary conservation ethics should include informed and flexible perspectives and applications for conservators. Whilst in the early periods of conservation, decisions were made by those who considered themselves experts, such as conservators, archaeologists, and art historians, today, the conservation process respects other relevant expertise and involves different stakeholders such as artists, visitors, and originating communities, in the conservation of artworks. Of course, professionals should be listened to, and other stakeholders will undoubtedly be impacted by their views, but this should be conducted in a climate of mutual respect and carefully managed power relationships, and this can be described as ‘negotiating conservation’ (Muñoz- Viñas, 2002, p.30). Complex issues such as the artist’s intention in the work of art, the meaning attributed by the curator and the meaning that the work acquires after it is displayed to visitors can be preserved in the view of these negotiations and based on ethical standards. As Rubio and Silva claimed:

“the need to collaborate to acquire, display and maintain increasingly obsolescent and rapidly changing artworks is forcing contemporary art museums to create new interdisciplinary spaces and practices that are blurring the boundaries traditionally separating conservators, curators and artists and are fuelling new dynamics of position-taking and struggles” (Miller 2017, p.1).

Traditional conservation ethics have been focused on preserving the artworks’ original material and physical aspects. In contrast, today’s conservation ethics have noticed a shift in attention from the tangible to the intangible aspects of an artwork (Lawson & Potter, 2017). The materials and techniques used by the artist to reveal their intention have become a complex issue in contemporary art conservation. The purchase of art can mean ‘buying an idea’ rather than buying objects. An example of this is *Comedian* by Italian artist Maurizio Cattelan. This artwork is a

piece of humour, criticism and ironic work of art for the contemporary art market. Emmanuel Perrotin described this artwork as a double entendre, a symbol of global trade, and a traditional technique for humour (O’Neil 2019). Cattelan bought an ordinary banana from the local market and paid \$0.30, but it sold for \$120,000 (O’Neil 2019). A simple material conceptually serves the artist’s intention and becomes art. This highlights the significance of understanding the artist’s aim as an important place in conservation approaches. Instead of preserving the original banana just because it was placed there by the artist, the artist’s idea can be preserved. The conservator should have technical knowledge that is both implicit and explicit, as well as high training in the sciences, history, and arts, as well as effective communication skills (Muñoz- Viñas, 2005), ensuring a complete understanding of the methods and materials employed (Lorusso et al., 2009).

7. Case study (bird boxes in Cardiff National Museum)

Conserving the artist’s hand in the original material is one of the priorities for conservation. However, there are many more challenges for the conservation decision-making process which can be illuminated by the case of contemporary art. We propose a thought experiment with a fictionalized case study scenario based on a real contemporary art object on display in Amgueddfa Cymru-National Museum Wales, Cardiff. The artwork that is the subject of this experiment is the ‘Unlliw’, made by Carwyn Evans and installed at the National Museum Cardiff (figure 4). The bird boxes in the piece respond to the housing policy from the local authority in Wales, to build the 6500 new houses. In response Evans made 6500 boxes to represent this decision, explaining, ‘because there were no restrictions on the new housing... is it for the local population or to entice a new population?’ Evans focuses his argument on the inevitable shift brought on by such a development and the legacy of the Welsh language, culture, and scenery. In an interview with him, he explained his intent with these words: ‘Adar i’r unlliw yr hedant i’r unlle’ [Birds of a feather flock together] (Translated by Gwern Cemig Jones). When he installed the artwork, he described this process accordingly:

“All the cardboard sections are by the factory, and I used the same factory back in 2002, and subsequently, I have to fold up all those kinds of shapes together and glue them together with hot glue. I worked flat out for about 2 weeks just to get this work ready with a few hours of sleep every night, and then half an hour to install” (YouTube, ‘Unlliw’ explained, Amgueddfa Cymru- Museum Wales, 2012).

Unlliw translates from Welsh to the English word ‘monochrome’, underlining the essential uniformity of the works. Given that both the number of boxes and their uniformity is critical to the artwork’s meaning and could be understood to transcend the individual elements how might the conservators respond in a fictitious case where one or more boxes are damaged? In

this thought experiment imagine that the artist is interviewed, he did not identify a desire for a slowly degrading housing stock but instead expressed a wish to retain the specific number and uniform nature of the bird boxes. In such a case with an appreciation of the meaning and message of this project and the uniformity of the boxes, then damage to a box is likely to prompt replacement. Such replacement might ideally be undertaken through the production of the boxes from the original factory aiming to add boxes that are perceived to be authentic in terms of their colour, shape, and size, although manufactured at a different time and context. Replacing a damaged bird box with a newly made copy in matching materials would not look like a traditional minimum intervention approach, and neither would the intervention be recognisable. A dogmatic application of minimal intervention and recognisability would lead to a rejection of the conceptual integrity or essence of the work that carried the artist's intent into the visitor experience. This presents an ethical dilemma if your ethical approach is based on instructions and habits of practice but does not if your ethics are developed through a reflexive and shared process.



Figure 3. Original artwork, 'Unlli' by Carwyn Evans at National Museum Wales in Cardiff. (Photographed by; Ece Erman in Landscape Gallery at the National Museum of Art, 5 January 2023).

Conservators and their work frequently deliberately minimise the visible impact of conservation treatment, making it only apparent upon careful inspection (Sweetnam & Henderson, 2021). An alternative approach has been the proposal that the intervention is deliberately visible on the object and can even be thought of as a contribution to the journey of the life of the object (Sweetnam & Henderson, 2021). Is this a possible or even applicable idea for contemporary art conservation, and how does this integrate into ideas about conservation utilising minimal and recognisable approaches? Is there any scope to ask, 'Why not paint it pink?' (Sweetnam & Henderson, 2021, p. 1).

To develop the thought experiment with the Unlliw artwork. Imagine that during reinstallation in the museum, some of the boxes are lost or damaged; could different colour boxes signal their replacement? In this case, conservation would become part of this artwork's journey. How then to approach the essence of the art, the artist's intent, and a desire to reflect that process of loss and capture it in an honest and readable way? Are there any circumstances (perhaps related to how the loss occurred) where the replacements would be vivid such as bright pink (figure 5)? Might other circumstances related to the loss be responded to in more subtle ways, detectable to a careful viewer so that the replacement birdboxes are one tone darker or lighter than the colour of the boxes used in the artwork (figure 6)? Or could the boxes have the same colour and shape but different surface textures (figure 7)? Each of these ideas experiments with the recognisability of conservation interventions. A more subtle approach may create an unconscious assumption in most viewers that this was part of the artist's work, an invisible replacement would remove the loss even from the object's story and the bright pink event would call attention to it. An invisible replacement could remain detectable by a careful marking on a non-exposed surface edge or the use of fluorescent security markers, rendering it detectable to museum staff but invisible to the public. If we imagine different possible agents of change: slow decay under gallery lights; accidental wetting and mould due to poor cleaning practices; theft by young political activists seeking to extend the cause by carrying the bird box back to the housing site; a future artistic project that sought to distribute the birdboxes amongst galleries to signify alternative futures would each suggest the same response? The suitability of the conservation approach cannot be informed from an examination of conservation canon alone, it requires a culturally considered ethically informed, participatory, case-by-case discussion.



Figure 4. Representation of the recognisable intervention in the illustration program. (Photographed by; Ece Erman in Landscape Gallery at the National Museum of Art, National Museum Wales in Cardiff, 5 January 2023).



Figure 5. Designing the boxes that can be added to the work in a less conspicuous colour illustration program. (Photographed by; Ece Erman in Landscape Gallery at the National Museum of Art, National Museum Wales in Cardiff, 5 January 2023).



Figure 6. A version designed in the illustration program with a different surface texture application approach. (Photographed by; Ece Erman in Landscape Gallery at the National Museum of Art, National Museum Wales in Cardiff, 5 January 2023).

8. Conclusion

Contemporary conservation ethics and the decision-making process for contemporary artworks should involve multidisciplinary perspectives and people with different backgrounds. Instead of using strict rules and language, opening conservation decisions to the discussion is a more relevant approach to effective contemporary conservation ethics. It may be necessary for conservators to obtain information from people with new and different fields of

expertise, diversifying significantly whom we need to seek advice from to support ethical and informed practice (Garcia Celma, 2021). Traditional conservation solutions such as minimal intervention and recognisability, which have represented the dominant approach in the conservation of artworks (especially for paintings), should be recognised as strategies, not ethical principles and should be opened to discussion. A practice described as ‘minimal intervention’ does not make a case for today’s challenges and is insufficient to reflect conservation goals in the twenty-first century, particularly within the framework of an active museum purpose (Villers, 2004). Strict rule-based approaches may cause negative consequences for conservation decision-making and should be replaced by discussions held on a case-by-case basis.

A careful and bespoke approach need not be considered an abandonment of ethics but a different application of ethical practice. Principles can be developed shared and recorded that have guided conservation decisions. Ethical conservation may lead to the materials and display style of an artwork being changed in collaboration with artists, conservators, and curators and facilities managers. As seen in the example of the sugar carpet idea for ‘Now the Day is Over’, the artist’s idea may evolve into a different dimension with the participation of conservators as stakeholders. We can conceive of ethical relationships between the artist and the conservator with the conservator sometimes becoming an active participant in the creation process.

In the chronological review of ethical guidance, we noted that Icon changed their wording of an ethical approach from ‘recognisable’ to ‘detectable’ intervention. This subtle but significant shift allows for a greater range of solutions that could vary from a discrete but documented replacement of components through subtle visual cues to an approach where the intervention is a very conscious visual reminder of the life story as written in the work. In each of these options, conservation may be detectable in a distinct way whilst consistently protecting the aesthetic whole of the work.

Materials used by artists might be ephemeral or conceptual, challenging the concept of authenticity. Authenticity is understood by many to represent the continued forward protection of material elements, however, if authenticity is understood as a truthful alignment of how something is perceived and how it was intended, then other solutions become possible. Authenticity may also be understood to be consistent with the essence of the work imbued into it by the artist. Working ethically with these multiple perspectives requires a reflective conservation practitioner to identify and acknowledge their own perspectives on authenticity and open this to scrutiny and examination in the light of multiple perspectives. Successful ethical conservation practice might be defined either by the values used by the conservators

to devise their strategies or by the outcomes and consequences of their decisions, but in either situation, the conservators should acknowledge the time and context affecting those decisions.

Minimal intervention is an arguable ethical principle for the conservator. Devising an ethical approach depends on the artwork, the resources, the partners' views, the socio-political climate, and the development of technological possibilities. A contemporary artwork which used ephemeral or changing materials in its creation challenges past implementations of a minimal intervention approach. Where an artist focuses on the meaning rather than the materials, and the materials are subordinate to the artist's intent and aesthetic concern, they could be considered entirely replaceable, with the ethics satisfied through documentation. Interviewing artists and others, where available, can and should guide conservators to find the integrity of the piece and frame the possible conservation options and practices.

The ethical approach of minimal intervention and recognisable practices may vary in their form and implementation as seen by the output of the conservator's work. The application of conservation techniques can vary, but the inputs should be consistent considering the views of others and the limitations of the time and technical possibilities. Therefore, ethical rules designed for conserving classical artwork cannot be replicated simply as practical applications. Instead, the diversity of contemporary artwork encourages the conservation profession to embrace a greater diversity of inputs and approaches, to set aside the dogmatic replication of practice based on an obsession with the continuation of tangible elements and to return their ethical frameworks to issues of preserving the meaning of our cultural heritage.

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References

- American Institute for Conservation, [AIC], (1994). Code Documents: American Institute for Conservation of Historic and artistic works. Historical background: code of ethics and guidelines for practice; commentaries. American Institute for Conservation, [AIC], (2015) *Tratteggio*. Available at: <https://www.conservation-wiki.com/wiki/Tratteggio> [Accessed: 18 January 2023].
- Amgueddfa Cymru-Museum Wales, (2012). ‘Unlliw’ explained. Available at: <https://www.youtube.com/watch?v=beqNOygxppk> [Accessed: 9 January 2023].
- Ashley-Smith, J. (2009). The Basis of Conservation Ethics. In: Richmond, A., Bracker, A., & AL (Eds.), *Conservation: principles, dilemmas and uncomfortable truths* (pp.6-21). Taylor & Francis Group.
- Ashley-Smith, J. (2017). A role for bespoke codes of ethics. In *ICOM-CC 18th Triennial Conference Copenhagen Preprints*, (pp.1-8). Paris: ICOM.
- Bauerova, Z. (2010). A Critical Reflection on Czechoslovak Conservation-Restoration: Its Theory and Methodological Approach. *Conservation: Principles, Dilemmas and Uncomfortable Truths*. In: *Conservation* (pp.113-124). Routledge.
- Belishki, S., & Corr, S. (2019). Reflection on conservation-restoration practice today. A European perspective, *Ochrona Dziedzictwa Kulturowego*.
- Bharti, S P. (2023) Conserving and Exhibition New roles and emerging issues for the conservation of contemporary art *News in Conservation* (pp.12-18). Available at: https://www.iiconservation.org/system/files/publications/journal/2023/b2023_2.pdf [Accessed 14 April 2023].
- Brandi, C. (2005). *Theory of restoration*. Istituto centrale per il Restauro Nardi Editore.
- Brown, M. T. (1990). Working ethics: strategies for decision making and organisational responsibility. San Francisco and Oxford: Jossey-Bass Published.
- Canadian Association for Conservation of Cultural Property. [CAC], (2000). Code of ethics and guidance for practice. Ottawa: The Canadian Association for Conservator of Cultural Property.
- Caple, C. (2000). Conservation Skills: Judgement. *Method and Decision Making*. London and New York: Routledge.
- Chiantora O., and Rava, A. (2013) Conserving Contemporary Art: Issues. *Methods, Materials*.
- Chyrkova, N., and Yankovska, D. (2021). The Ethics of Conserving Modern Art. *Baltic Journal of Art History*, 21.
- Clavir, M. (1998). The social and historic construction of Professional values in conservation. *Studies in conservation*, 43:1, 1- 8.
- Clavir, M. (2002). Preserving what is valued: Museums, conservation and First nations. (p. 73-75) Vancouver: UBC Press.
- Conti, A., & Glanville, H. (2007). *A History of the Restoration and Conservation of Works of Art*. Routledge.
- Cotte, S., Tse, N. & Inglis, A. (2016). Artists’ interviews and their use in conservation: reflections on issues and practices. *AICCM Bulletin*, 37(2), 107-118.
- Davies, L., & Heuman, J. (2004). Meaning matters: collaborating with contemporary artists. *Studies in Conservation*. 49(sup2), 30-33.
- Delagrang, J. (2021). Why is contemporary art important? Introduction: the importance of contemporary art explained. *CAI Gallery*. Available at: <https://www.contemporaryartissue.com/why-is-contemporary-art-important/> [Accessed: 14 April 2023].
- Dykstra, S. W. (1996). The artist’s intentions and the intentional fallacy in fine arts conservation. *Journal of the American Institute for Conservation*, 35(3), 197-218.

- E.C.C.O. (2002). Professional Guidelines. Published by: *The European Confederation of Conservator-Restorers' Organizations*.
- Edson, G. (1997). *Museum Ethics. Theory and practice*. London and New York: Routledge.
- Ersen, A. (2010). Cesare Brandi 1906-1988 ve Restorasyon Teorisi. *Restorasyon ve Konservasyon Çalışmaları Dergisi*, (7), 3- 11.
- Frasco, L. (2009). The contingency of conservation: changing methodology and theoretical issues in conserving ephemeral contemporary artworks with special reference to installation art. *Undergraduate Humanities Forum 2008-09*. 2009.
- Garcia Celma, M. (2021). Supporting decision-making when conserving contemporary art: a model for identification and categorisation of stakeholders. *Journal of the American Institute for Conservation*, 60(2-3), 161-174.
- GCI CIMCA [Conservation Issues of Modern and Contemporary Art] Meeting. (2008). Museum of Modern Art: New York.
- Giebler, J., Sartorius, A., Heydenreich, G., & Fischer, A. (2021). A Revised Model for Decision-Making in Contemporary Art Conservation and Presentation. *Journal of the American Institute for Conservation*, 60(2-3), 225-235.
- Giombini, L. (2019). Artworks and Their Conservation A (tentative) Philosophical Introduction. *Aesthetica Edizioni*.
- Grenda, M. (2010). Tratteggio retouch and its derivatives as an image reintegration solution in the process of restoration. Case study: restoration of a 20th century lithograph film poster by Stefan Norblin. In *CeROArt. Conservation, exposition, Restauration d'Objects d'Art* (No. EGG1). Association CeROArt asbl.
- Grevenstein, A., and Schraff, M. (2005) [1999]. Introductions Texts in Training Conservators of Modern Art. In *Modern Art: Who Cares?* edited by Hummelen, IJ. and Sille, D., 296-299. London: Archetype Publications.
- Hartmann, N. (1977). *Estetica*. Universidad Nacional Autonoma de Mexico.
- Henderson, J., & Nakamoto, T. (2016). Dialogue in conservation decision-making. *Studies in Conservation*. 61(sup2), 67-68. Hölling, H. B (2021). *Object, Event, Performance: Art, Materiality, and Continuity Since The 1960s*. Bard Graduate Center.
- Hummelen, Y. and Scholte, T. (2021). Collecting and archiving information from living artists for the conservation of contemporary art. In *Conservation of Easel Paintings*. (pp.38-46). Routledge.
- ICOM-CC. (2008). International Council of Museum Committee for Conservation. Terminology to Characterise the Conservation of Tangible Cultural Heritage
- ICOM (2004). Seoul and Museum Development in Korea: Retrospect with Global Perspectives.
- ICOM (2017). Code of Ethics for museums. *International Council of museums*.
- ICOMOS (1964). The Venice Charter for the Conservation and Restoration of Monuments and Sites: Venice ICOMOS.
- ICOMOS, A. (1998). Code on the ethics of co-existence in conserving significant places.
- ICOMOS. (2014). *Review of the 2002 Ethical Commitment Statement Proposal for the Adoption of the ICOMOS Ethical Principles*. Report by the Merged Working Group.
- ICON (2020) Institute of Conservation. Ethical Guidance: Principles of Conservation. Available at: <https://www.icon.org.uk/resource/icon-ethical-guidance.html> [Accessed in: 04.05.2023].
- Kaptan, C. (2009). *Tuval Resmi Restorasyonunda Yanlış Uygulamalar ve Önermeler* (Doctoral dissertation, Marmara University (Turkey)).
- Lawson, L., Finbow, A., & Marçal, H. (2019). Developing a strategy for the conservation of performance-based artworks at Tate. *Journal of the Institute of Conservation*, 42(2), 114-134.

- Lawson, L. & Potter, D. (2017). Contemporary art, contemporary issues-conservation at Tate. *Journal of the Institute of Conservation*, 40(2), 121-131.
- Llamas-Pacheco, R. (2020). Some Theory for the Conservation of Contemporary Art. *Studies in Conservation*, 65(8), 487-498.
- Lorusso, S., Natali, A. & Volpe, F. (2009). The traditional, the innovative, the ephemeral: conception, realisation, intervention in contemporary art. *Conservation Science in Cultural Heritage*, 9, 170-214.
- Marçal, H. (2019). Contemporary art conservation. Reshaping the collectable: *When Artworks Live in the Museum*.
- Meraz, F., & Magar Meurs, V. (2019) Cesare Brandi (1906 to 1988): his concept of restoration and the dilemma of architecture *Conversaciones*, 7, 160-174.
- Miller, Z. (2017). Low-level Conflict in Contemporary Art Conservation Research. *NACCA [New Approaches in the Conservation of Contemporary Art]*.
- Muñoz-Viñas, S. (2002). Contemporary theory of conservation. *Studies in Conservation*. 1-239.
- Muñoz-Viñas, S. (2005). *Contemporary theory of conservation*. Routledge.
- Natali, A. (2008). Some considerations on conservation and restoration in contemporary art. *Conservation Science in Cultural Heritage*, 8(1), 187-197.
- Niglio, O. (2013). John Ruskin: The Conservation of the Cultural Heritage.
- O'Neil, L. (2019) One banana, what could it cost? \$120,000- ifit's art. Available at: <https://www.theguardian.com/artanddesign/2019/dec/06/maurizio-cattelan-banana-duct-tape-comedian-art-basel-miami> [Accessed: 23 March 2023].
- Opena, M., Singer, M. & Müller-Wüsten, D. (2021). Introduction to the Special Issue on Contemporary Art Conservation. *Journal of the American Institute for Conservation*. 60:2-3, 67-68.
- Orbaşlı, A. (2017). Conservation Theory in the 21st century: slow evolution or a paradigm shift? *Journal of Architectural Conservation*, 23(3), 157-170.
- Ostrovcsa, I. (2020). Aesthetic integrations in the restoration process of mural painting. *Journal of Architecture, Urbanism and Heritage*, 3(2), 37-44.
- Pease, M. (1964). The Murray Pease Report, *Studies in Conservation*, 9:3, 116-121
- Reeves, H. (2015). Zero to Now: The contemporary art conservation problem. MA Final Project Visual Arts Administration. New York University.
- Schadler-Saub, U. (2019). Conservation ethics today: are our conservation-restoration theories and practice ready for the 21st century? Introductory notes to some central issues. *Protection. Of Cultural Heritage*, (8), 291-300.
- Soulioti, A. M. & Chatzidaki, M. (2022) Double Trouble: Replicas in Contemporary Art and Their Impact in Conservation Decision-making, *Studies in Conservation*, 67:1-2, 21-29.
- Sterrett, J. (2009). Contemporary museums of contemporary art. In: Alison Richmond, and Alison Brackett. *Conservation: Principles, Dilemmas and Uncomfortable Truths* (pp.223-228). Routledge.
- Stigter, S. (2017). A behaviour index for complex artworks: A conceptual tool for contemporary art conservation. Paper presented at the ICOM-CC 18th Triennial Conference Preprints. Copenhagen: 4-8.
- Sweetnam, E. & Henderson, J. (2021). Disruptive conservation: challenging conservation orthodoxy. *Studies in Conservation*. 67(1-2), 63-71.
- Van Saaze, V. (2013). Key Concepts and Developments in Conservation Theory and Practice. In *Installation Art and the Museum: Presentation and Conservation of Changing Artworks*. (pp.35-60). Amsterdam, Holland: Amsterdam University Press.

- Verbeeck, M. (2019). Brandi and the restoration of contemporary art. One side and the other the Teoria. *Conversaciones*, (7).
- Villers, C. (2004). Post Minimal Intervention, *The Conservator*, 28(1), 3-10.
- Wain, A. & Sherring, A. (2021). Changeability, Variability, and Malleability: sharing perspectives on the role of Change in time-based art and utilitarian machinery conservation, *Studies in Conservation*, 66:8, 449-462.
- Wharton, G. (2005). The challenges of conserving contemporary art. *B. Altshuler. Collecting the New: Museums and Contemporary Art*, 2005, 163-178.
- Winckelmann, J. J. (2006). *History of the Art of Antiquity*. Getty Research Unit Publications.
- Yazdani Mehr, S. (2019). Analysis of the 19th and 20th-century conservation key theories in relation to contemporary adaptive reuse of heritage buildings. *Heritage*, 2(1).

CHAPTER 2

DETECTION AND DIAGNOSIS IN THE CONSERVATION OF CULTURAL PROPERTIES

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Abstract

Interventions in the field of conservation are more similar to the field of medicine, as the treatment is decided in accordance with the patient. As in medicine, every cultural property in the field of conservation that needs intervention should be treated according to its current state. In interventions to be made to a work or monument in a conservation area, the aim is either to determine the existing risks and to prevent problems (maintenance and preventive conservation), or to eliminate the problem (active conservation and restoration). For this reason, research and examinations are done first that enable one to recognize the artifact or monument, determine its construction and material properties, and gain complete knowledge of the types of problems or deteriorations, as well as the factors or sources that are the cause. Evaluations are made according to the determinations, and then the diagnosis obtained. The experienced methods are reviewed, and then the most accurate treatment is determined. The experiences gained in the field of the conservation of cultural assets, together with technological developments, have enabled problems and solutions to be determined more easily. However, deficiencies and faulty restoration practices still necessitate a reexamination of the process to be followed in the protection, repair, and work phases. This study discusses the stages of detection and diagnosis in the conservation of cultural property, from first contact with an artifact to the treatment process, and thus questions how to create a resource for similar research that will be carried out by conservation professionals.

Keywords: Conservation, restoration, documentation, determination, diagnosis

1. Introduction

The thought that no similarity exists among each cultural property in a conservation area obliges one to carry out the relevant interventions carefully. For success with problem solving, one must firstly identify the object or monument whose value is to be preserved; characterize the material, construction techniques, workmanship, decorative features; and determine the exact type and source(s) of the problem before evaluating tried-and-tested treatment methods and finally making an intervention decision in line with all these determinations.

On one hand, recent increases in experience in the field of protection has allowed the problem and solution to be determined more easily, while on the other hand, ongoing criticisms necessitate reexamining the process.

This study aims to contribute to similar studies from conservation professionals by addressing the stages of detection and diagnosis that should be followed from one's first encounter with an artifact until the end of the treatment process in the field of cultural property protection.

2. Studies on detection and diagnosis

Conservation interventions should be based on evidence obtained through research and investigation in a scientific discipline.

When intervening with an object or monument, the questions one should usually ask oneself are “what, why, and how does one intervene?” The short answer to these involve a process that starts with a qualified examination of the work and ends with the implementation (Figure 1).

On-site inspection is the primary phase of the conservation process. This stage examines the characteristics of the artifact, the materials that have been used, the elements of workmanship, the types of deterioration, and the factors causing it. After the primary determinations and observations, comprehensive studies are carried out as needed through an interdisciplinary study at this stage.

The second stage documents the data. All stages actually perform documentation alongside the work. This can be done separately by each expert involved in the work, can be used together, or combined later. This stage collects the written, photographic, and graphic documentation, as well as archaeometric studies, information forms, reports, and other professionally published scientific studies; if these are missing, they are prepared in this stage.

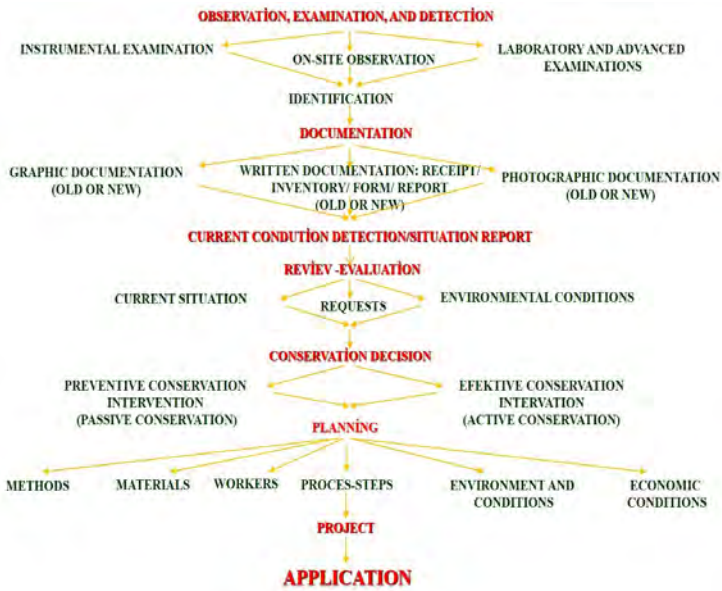


Figure 1. Process to be followed in conservation (adapted from Şener, 2011, p. 887).

At the end of the second stage, one can now move on to a report study. As a matter of fact, the current conservation status can be determined, as preliminary data about the work will have been accessed through the determinations obtained from the examination.

The next stage of the process evaluates the data and determines the interventions the work will need alongside the current challenging conditions based on the preservation status of the work, production techniques, and requests for its conservation. The evaluation is concerned with making decisions regarding how the next step will carry out the conservation. In fact, the intervention decisions to be made may be for preventive conservation, as well as for both effective and preventive conservation.

The next stage involves planning and projecting the decisions that have been taken. This stage takes into account the construction techniques, current state, current legal procedures, and internationally accepted principles in accordance with the features of the object or monument and determines the intervention methods and application stages.

A perception may occur that the conservation process outlined above is carried out in successive stages. However, in order to be perceived more easily, all the separately mentioned studies constitute parts of a whole, and one should not forget that a series of studies also occur in practice that are generally carried out side by side or that progress one after the other.

2.1. Recognizing cultural property

The concept of cultural property corresponds with the answer to the question of what needs to be conserved, from among the questions in Figure 2 in order to understand the conservation process.

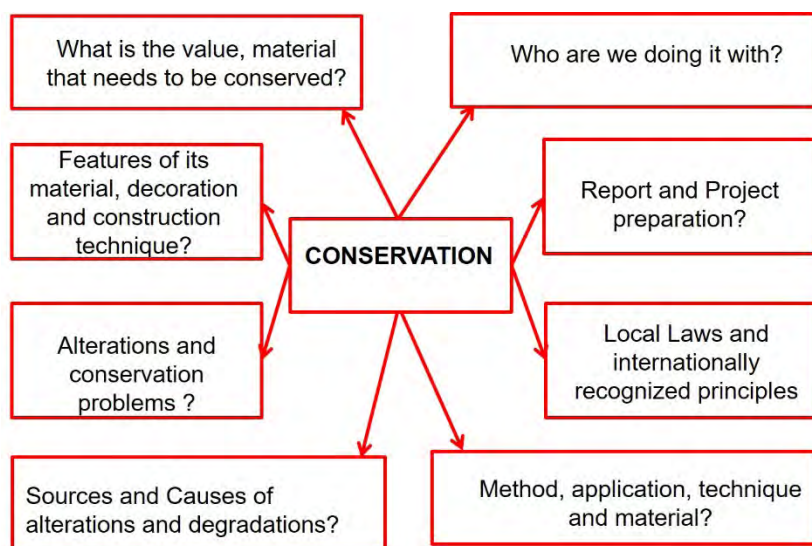


Figure 2. General components of the conservation process.

While distinguished historical monuments and movable works of art are prioritized regarding what is worth conserving, the concept of a “monument and its surroundings” drew attention in 1931 with regard to Carta del Restauro (Ahunbay, 2011, pp. 148–149). The definition in the Venice Charter of 1964 (2022, pp. 201–202) states the concept of historical monument to cover urban and rural settlements that have witnessed a certain civilization, an important development, or a historical event. This concept is emphasized to include not only works of art, but also simpler works that have gained cultural meaning.

The scope of the valuables to be protected was expanded with the decisions taken at the UNESCO meeting held in Nairobi in 1976 (Ahunbay, 2011, pp. 157–163). Historical and architectural (including traditional) areas are defined as open areas containing groups of buildings, structures, and archaeological or paleontological sites whose archaeological, architectural, prehistoric, historical, aesthetic, or sociocultural values are recognized. Prehistoric areas, historical cities, old urban neighborhoods and villages, or homogeneous monumental

groups were given as examples and stated to be among areas with very different qualities that should be protected. Continuing with definitions, environment was defined as a place that statically or dynamically affects the perception of these areas or is directly connected to these areas by spatial, social, economic, and cultural ties or that have been created by humans. Historical environments were stated to exist everywhere as part of people's daily environments, to represent the living existence of the past that created them, and to provide the necessary diversity in life for responding to diversity in society. In addition, one should take into account that historical environments have gained a valuable humane dimension and that, although the destruction of historical environments is not an economic loss, they are cultural assets whose loss would cause social discomfort. These have been emphasized to be the responsibility of every citizen and to be an obligation that only public authorities themselves can fulfill. Cultural properties are accepted as being worth protecting today and are examined in two main sections: movable and immovable cultural properties (Ahunbay, 2011, p. 22).

Immovable cultural assets are defined as monuments and protected areas. Monuments can occur in the form of large complexes formed by a single building or building groups and are accepted to be able to reach city-wide, country-wide, and eventually even continent-wide in size. The concept of a site is a natural or man-made product with properties that need to be preserved, or a combination of the two. Places where an important historical event took place are called historical sites. Areas with ruins from prehistory to the end of the Industrial Revolution are called archaeological sites. Locations that have streets, neighborhoods, and areas in a city that have preserved their harmony, order, architectural integrity, and equipment are called urban sites. Site complexes have been defined as a rural site with an area containing at least two protected zones (Ahunbay, 2011, pp. 22–28).

The process for protecting cultural assets starts from the moment they are registered. In Türkiye, the protection of movable and immovable cultural assets and the decision to intervene with them are taken under the supervision and control of the Ministry of Culture and Tourism. Registration of immovable cultural assets and interventions on them are provided with the approval of the Regional Board for the Protection of Cultural Heritage in accordance with the principal decisions taken by the High Council for the Protection of Cultural Heritage.

Conservational interventions take place through the preparation and approval of projects to be submitted to conservation committees for a single monument or protected areas according to the procedures determined regarding the principal decisions taken by the High Council. Comprehensive reports are prepared for both monuments and the interventions that are required in the projects (Ersen et al., 2009).

2.1.1. Determining the characteristics of cultural property

This defines the stage in which all the features of the work are recorded by specifying the name, place, and area of the work for the purpose of identifying the cultural property. Its scope expands according to the nature of the work to be examined.

For conserving architectural monuments, the monuments are referred to as they are commonly known (e.g., Istanbul Hagia Sophia Mosque). If the monument is unknown, the period (e.g., Parion Roman Bath) from when it originated, the person who built it (e.g., Ankara Caracalla Bath), its location, and building type (e.g., Çatalhöyük-North Shelter, B5) are used to identify it (Figure 3).



Figure 3. Ankara Caracalla (Roman period) Bath (photo by Sener, 2015, Ankara, Türkiye).

The second important step regarding the features of an artifact involves its dating. Dating consists of important basic data on this topic, such as inscriptions, written sources, and archaeological finds, as well as reports and scientific studies that have been prepared on the work. Studies from such researchers as ancient historians, numismatists, and epigraphs are also important in dating, as well as research and studies from historians, archaeologists, and art historians.

Another important stage in examining a work involves examining the material, construction, and decorations of the work. This stage emerges from studies and reports (e.g., documentation and restitution) that include extensive research into the structural dimension.

Historians, archaeologists, art historians, and specialized professionals working on the history of architecture make efforts to determine the characteristics of a work according to the period and type of construction. In fact, a classical archaeologist for a Roman temple, an archaeologist working on pre- or protohistory for a mud-brick house uncovered in a neolithic mound, and an art historian for a late Ottoman period house with wall paintings can be requested to make reports.

Survey and restitution studies are organized by an architect in Türkiye. However, reports prepared by geologists, architects, or civil engineers can be used to illuminate the grounds and static conditions of architectural elements. A historical report is required to describe a property's historical process. An art history-archaeology report is required to determine its place with regard to production techniques, material usage, period, and the like. Archaeometry and geology reports are prepared for materials, their types, and their characteristics. The works of all these expert groups are evaluated together, after which comprehensive projects are prepared.

The measurement of a building using classical methods or technological methods such as laser scanning facilitates the preparation of survey, restitution, and restoration project studies. Such methods enable precise measurements to be obtained with fewer mistakes; plan, section, and facade views to be created; and a clearer simpler understanding of the materials, workmanship, and deterioration to be determined, as well as the type of intervention to be processed on them using figures with colored delineations.

Determinations regarding identifying cultural assets vary in terms of being able to recognize many features such as construction, use, periodization, materials, decoration, and workmanship.

2.1.2. Determining the material properties

This involves identifying the original materials used in the construction and/or decoration of the work, as well as determining any additions and changes related to its use and repairs. While these identifications enable one to determine the original material type and diversity in the work, these also provide data for use in understanding the deterioration formations in these materials and in choosing the methods and materials for conservation interventions.

Determining the materials used in the construction and decoration of a building allows the identification of both original and later additions in the masonry, building elements, and any cladding. For example, when determining the use of two different types of stone in the stone cladding of a building exterior, a detailed examination reveals that the damage had been filled in with different types of stone and the repairs to have been made from materials similar to the original (Figure 4).



Figure 4. Reintegration applications using a type of limestone similar in color and texture during the 20th-century repairs (bottom) in place of the tuff stone used in the original construction of the Abdülaziz Hunting Lodge (top) during the reign of Ottoman Sultan Abdulaziz (1861-1876; photos by Sener, 2022).

Examinations of the material are also used to identify conservation problems. In fact, when examining the sedimentary stone types used in the building, the siliceous, carbonate, or clayey structure of the components allows one to understand the causes of wear in order of least to most impactful (Figure 5).



Figure 5. Advanced erosion of clayey sedimentary stones in a mosaic exhibited in an open area (Antakya Museum, Hatay, Türkiye; photo by Şener, 2009).

Detecting the material properties also facilitates intervention decisions. For example, in a floor mosaic where marble and limestone tesserae were used alongside terracotta tesserae, an effective finding occurs that requires limiting mechanical cleaning methods due to the presence of the terracotta tesserae, which is easily eroded.

2.1.3. Determining production techniques and work characteristics

This covers the determinations of all the features of the construction, production, and workmanship phase of a structure or portable object. The determinations to be made enable one to identify the features that need to be preserved by determining the materials used, workmanship elements, and decoration features in the original construction. In fact, when examining a sculpture, detecting the traces of tools such as chisels, work hammers, grooved chisels, and flat chisel determines the construction and workmanship stages of the original monument and the elements that are to be preserved in future repairs (Figure 6).

In a building decorated with wall paintings, determination made regarding the carrier, the plaster layers and the type of paint used on the plaster, as well as the decoration style, the wall painting technique (e.g., secco, fresco), any graffiti, and writing as belonging to one period or a later one can be used to determine the original construction, usage periods, period additions, and changes (Figure 7).

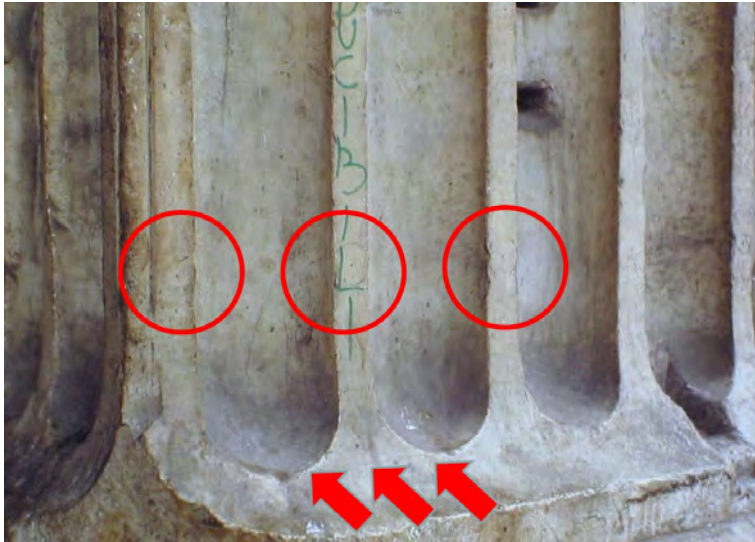


Figure 6. Temple of the Pantheon in Rome. Circular lines (red circle) by which the groove width of the compass is determined for carving the grooves in the marble columns and straight lines (arrows) that determine the lower border of the groove as drawn with a hard tool (photo by Şener, 1992).

Determining the paste material, glaze mixture and quality, production processes and faults, underglaze lining and paint, glaze decorations, and the material used in the decorations with regard to a glazed ceramic provides an understanding of the original construction and craftsmanship. This also influences intervention decisions for the diagnosis and protection of the types of data obtained regarding damage. This may require more detailed studies on the deterioration and also play an important role in selecting the methods and materials to be used in the intervention.



Figure 7. Vazelon Monastery (Trabzon, Türkiye), used from the Byzantine period until today. Right: Straw-added plaster material, which becomes visible thanks to spillage, and putty paints that have been embossed on the surface. Left: Notch marks on the wall painting showing the construction of new plaster over previous plaster (photos by Şener, 2022).

The data obtained on construction and production techniques and craftsmanship enable the exact determination of losses and damage when determining the types of deterioration and how the deterioration mechanisms affecting them have occurred. One example of this is the determination of paint loss and the amounts in an original wall painting or the fading traces of workmanship (e.g., chisels, drills) on a marble work.

Revealing which original elements (value) are to be preserved enables the identification (cleaning and purifying) of the original and subsequent period supplements, as well as unqualified attachments.

When a partial replacement decision is made in order to eliminate the damage to the cut stone of a masonry building, the original construction and the type, dimensions, and

workmanship of the stone are determined. Determining these will affect the decision of what kind of method and workmanship will be adopted when one desires to make a change compared to the original.

2.1.4. Detecting periodic annexes and interventions

The construction of some monuments continues over centuries, such as in medieval cathedrals. This construction process can contain period additions and stylistic features. Changes may occur in the floor coverings, wall decorations, or other building elements of a gothic church that have survived from the Middle Ages or that belong to later usage periods.

Similarly, architectural remains can be seen unearthed during archaeological excavations that for example show a structure that was built in the Hellenistic period, used in the Roman period, abandoned after being used in the Byzantine period, and then left underground, as well as the differences in the structures and decoration elements of the periods (Figure 8).



Figure 8. Sultan Kulliyi II (Edine, Türkiye) from the Beyazıt rule (1484-88). The first-period wall paintings on the domed cover in the portico belong to the 15th century (right), while the wall paintings on the left belong to the late Ottoman period (18th-19th centuries; photos by Şener, 2009).

When approaching the present, the separation of period annexes from restoration interventions becomes even more complex. Of course, the annexes of the period are as valuable as the original structure in terms of historical process and should be preserved. However, the multiplicity of interventions in monuments leads to an increase in issues related to identification and diagnosis. Especially in buildings that are still in use but whose function has changed, extensive renovations that show the same construction and workmanship as the original in their repairs increase the difficulty of recognizing elements such as original and later-period additions and renovations. The determinations regarding this issue should be identified by making use of detailed observations and technical studies.

2.2. Detecting conservation issues and deterioration

This covers the examinations and research regarding identifying the changes, deteriorations, and damage that has occurred in a work according to the original features (Figure 9).



Figure 9. Seljuk period (13th century) Kubadabad Great Palace Building (Beyşehir, Konya, Türkiye). Even from one's initial observations of the building, the stages of structural loss can be observed on the walls and around the door openings (photos by Şener, 2011).

The studies begin with the initial observations to be made by conservation professionals and the recording of said determination. A studied work possessing composite-mixed materials and problems can turn into much more comprehensive studies with the participation of professionals from conservation and different professions such as archeology, art history, anthropology, architecture, civil engineering, archaeometry, biology, physics, chemistry, and geology. In fact, the problems and their causes should be clarified in all their dimensions through comprehensive examinations and documents, as well as from reports based on these and that are to be carried out separately or jointly by all these experts.

Detecting deterioration issues determines the need for one or more different conservation experts according to the type of artifact. For example, when a valuable item to be protected is a monument, the diversity of materials such as the architectural whole, mosaics, wall paintings, and processed stones requires the involvement of multiple field experts, each reporting on their own field of expertise. Conservation professionals' experiences facilitate the precise identification and classification of deterioration and its causes.

The list and study forms for the types of deterioration should always facilitate the employees in a field study of a work. Checking dictionaries on conservation problems (e.g., ICOMOS-ISCS,

2008; Şener, 2012; Illustrated Glossary, 2013; Glos, 2015) that have been prepared by national or international studies according to the type of material to be protected, deterioration sheets, or templates help facilitate recordings of what has been detected.

The types of deterioration, their distribution throughout the work in terms of quality and quantity, their relations to the material and other deteriorations are determined in the reporting to be made. Irreversible damage and reversible changes are identified. While all these determinations are recorded in writing, things such as photographic documentation, drawings, figures, tables, and mappings that have been prepared with symbols and colors on the drawings are added to the report.

Detecting the source and causes of deterioration may require the participation of scientific experts and comprehensive technical and scientific studies when necessary, as materials, construction techniques, usage, and environmental factors may vary as much as external factors (e.g. as in material determinations). Detections provide a thorough understanding of the damage and reveal any ongoing or future protection risks. All the data obtained here guide intervention decisions.

Deterioration of movable objects or a monument and determining their causes constitute the basic diagnosis with regard to determining intervention decisions and implementations (Figure 10). For example, the restoration decision that requires partial braiding for reinforcement is made in order to eliminate a problem such as a unit material loss in the braid. For the problem of surface loss caused by salt crystallization due to water absorption and frost, a restoration decision such as desalination followed by imitation reintegration can be made. However, because these decisions will not be sufficient, iother intervention decisions may also be required, such as creating a drainage system or cleaning the earthy fillings around a building in order to prevent possible risks and future deterioration.



Figure 10. Medieval bath structure in Ahlat. The surrounding earthen fill, the exposure of the tops of the walls and the effects of the continental climate cause further structural losses in the building remains (photo by Şener, 2015).

One important factor in deterioration formations involves previous faulty restoration interventions. Faulty repairs can also involve either alterations or renovations to the original construction and decorative features with the performed restoration, as well as improper material selections that lead to new deteriorations in the original material and ornament. For example, repairing grouting with cementitious mortar on a stone wall that has been poured with joint mortar causes salt crystallization and new wear and loss-type deterioration formations in the repaired and even original sections, necessitating the removal and cleaning of these fillings with a new intervention.

2.3. Technical reviews, analysis, and laboratory reviews

This covers the observations, technical studies, and research on cultural assets, from age determinations to identifying the types of construction and ornamental materials and understanding the deterioration and deterioration mechanisms. Most of the various professions and scientists take part in such studies based on the types of materials (Figure 11).



Figure 11. Repair project for Bodrum Torba Monastery Mosaics (Torba, Bodrum, Türkiye). Mosaic sampling studies in cooperation with conservation expert and archaeometric specialist (photo by Şener, 2006).

The factors causing ruin to a monument are investigated in a study before they are repaired. For example, the conservationist monitors the condition of a monument at various times under seasonal variables (e.g., sun, snow, and rain, temperature changes), observes how

it is affected by these conditions, records its deterioration, investigates the factors causing these, and continues their studies. After examining the monument sufficiently, the conservationist can make a diagnosis and attempt to find remedies. An improper intervention may occur when identifying the work, the causes of damage, and the deterioration process doesn't happen first. A diagnosis that is not made correctly may result in the procedure being far from serving its purpose, the deterioration continuing, and the damage growing, as well as other new problems arising (Ahunbay, 2011, p. 38).

A wide variety of examinations can be made regarding detections. For the example of stone, the material and type can be identified, the binder aggregate content and mixing ratios for mortars and plasters determined, and the paint colors and tones used for wall paintings noted. In addition, the type and cause of corrosion can be determined with regard to metals, or the static strength with regard to building elements.

In a work, an art historian, archaeologist, or architect makes a preliminary assessment by observing anomalies and differences in construction and material usage. However, in order to confirm these determinations, one may need to take samples in the field and carry out archaeometric examinations of these in a laboratory environment. In fact, these types of examinations can determine details such as period additions, renovations, and restoration interventions in use.

Reviews also provide an understanding of the mechanisms of degradation. For example, detailed examinations of a material are able to determine the porous material structure of a stone to allow water absorption, water absorption to cause salt crystallization and frost formation (due to the stress and pressures on the material), and the stone to then chip and defoliate (Torraca, 1988, pp. 30–36). Thanks to studies carried out on this subject, the surface area of stone has been determined to increase hundreds of times through crumbling formations, especially in stone works exhibited in open areas, and other deterioration formations increase in a chain with the existing ones. (Lazzarini & Tabasso, 1986, p. 26).

Observations and examinations may be prior to intervention decisions, as well as necessary for controlling the actions taken during an intervention. Measurements for humidity or temperature changes in a work exhibited indoors or outdoors are used to prevent new deteriorations caused by environmental factors, as well as to observe changes in the microclimate environment.

Color measurements made with sensitive devices contribute to identifying the paints in a wall painting, the tessera-stone types in mosaics, and also the variations in surface cleaning due to precise measurements made before and after a repair.

2.4. Determining methods and materials in conservation: tests and preliminary trials

While the definitive diagnosis of a material and its deteriorations is carried out as a result of the examinations and research, the determination of the intervention decisions is usually made according to previous experiences. While interventions are currently determined according to the needs created by the damage, the methods and materials that are determined for the application have been tried and tested.

For example, determining the original mortar mixtures, binder and aggregate ratios during the analysis phase in conservation applications allows a decision to be made on mortars with similar properties to the original in the repair. However, the obtained data only provides the diagnosis. In practice, preliminary trials are made for a decision. When the mortar is desired to resemble the original, experiments and strength tests can be applied to determine similarities regarding strength and weakness, color and tone differences, and texture differences due to the aggregate-binder mixture.

When selecting the materials for reinforcement and surface protection that can be used for problems such as chipping on the surfaces of stones, mortars, and plasters, trials are made on materials (samples) similar to the original. Properties such as absorption depth, adhesion and cohesion, reversibility, and transparency of the material that were determined for consolidation applications are reviewed, and decisions are made according to the obtained results (Figure 3).



Figure 12. Experiments for monitoring the absorption levels of known consolidation types in building stone tuffs in Tagar Church (Cappadocia, Türkiye) within the scope of the Emergency Response Training Project on Murals carried out by Turkish, Italian, and Japanese conservation experts between 2017-2019 (photo by Şener, 2018).

Different cleaning methods are also attempted for cleaning contamination problems on a material's surface. A harmless, economical, and easy-to-apply method or application can be

selected according to the original material in which the pollutant is located based on existing alteration and degradation types. Experiments can also be made to increase the impact of a chemical method by adjusting ratios.

2.5. Detections while preserving and repairing

Detection and diagnosis are often requested to be completed prior to intervention. Based on the state of the monument or artifact, however, detection works also continue during and after the interventions that take place.

In this regard, one may encounter new findings such as identifying a door by plaster scraping in repair applications on a wall whose opening was covered with stone and plastered and that had been unable to be determined before the project phase.

In the mosaics unearthed by archaeological excavations, one can encounter layers of tessellatum from previous periods of use in a lacuna, whose earthy filling was cleaned during the restoration work (Figure 4). In such a case, one needs to make a new intervention decision and review the implementation decisions while the implementation is ongoing.



Figure 13. In 2017, the tessellatum layer of a previous period was revealed during the cleaning of earthen fill in lacunae during the restoration carried out on the central nave floor mosaic of Ölüdeniz Church (Fethiye, Muğla Türkiye; photo by Şener, 2017).

3. Conclusion

Monuments, protected areas and movable cultural assets are documents of human life with their historical, social, cultural and artistic features. They must be protected for their local, regional, national, and universal value (Ahunbay, 2011, p. 8). Diagnostic studies on

the protection of cultural assets have recognized the importance of “accurate and detailed documentation” of the material properties of the work, construction techniques, deterioration and causes, and conservation and repair practices (Ersen et al., 2009, p. 16).

The original construction and decoration features of a work are to be fully comprehended to reveal data about different usage periods, which is then used to identify material and mass additions, renovations, or repair interventions that have occurred during the historical process up to the present.

One determines how to classify the types of deterioration and their causative factors in order to allow a full determination to be made regarding damage. The effects of the determined restoration interventions are to be determined, the correct implementations to be applied, and problematic implementations to be sorted out and perfected.

The degree of an intervention and the protection methods are determined using a prepared report or conservation project. These studies are used as scientific documents during the construction and inspection phase. In the applied interventions, one can check the materials and scale of the details. In conservation practices, faulty repairs are avoided by using the necessary guidance, thus preserving the documented value of a work. A long-term care program and protection plan are also to be determined (Ersen et al., 2009, p. 16).

References

- Ahunbay, Z. (2011). *Tarihi Çevre Koruma ve Restorasyon*, (6th ed.) [Historic Environment Protection and Restoration]. İstanbul, Turkey: Yem Yayın.
- Ahunbay, Z. (2022). *Kültür Mirasını Koruma İlke ve Teknikleri*, (3th ed.) [Principles and Techniques of Conservation of Cultural Heritage]. İstanbul, Turkey: Yem Yayın.
- Ersen, A, Güleç, A., Alkan, N. (2009). Konservasyon Raporunun Önemi, İçeriği ve Hazırlanma Adımları [Aim, Context And Preparation of a Conservation Report] *Restorasyon ve Konservasyon Çalışmaları Dergisi*, (2), pp.3-16. İstanbul, Turkey: FSF Matbaacılık
- Glos, E., (2015). *European Illustrated Glossary of Conservation Terms for Wall Paintings and Architectural Surfaces*, Series Publications By Horneman İstutute, Volume 17, Edited by A. Weywe, P.R.Picazo, D. Pop, J. Cassar, A.Özköse, J.M.Vallet, İvan Srsa, Petersberg, Germany: Michael Imhof Verlag GmbH&Co.KG, Retrieved from: <http://openarchive.icomos.org/id/eprint/1706/1/2015ewag.pdf>
- ICOMOS-ISCS, (2008). İllustrated Glossary on Stone Deterioration Patterns, Monuments and Sites XV, Champigny/Marn, France: Retrived from: https://openarchive.icomos.org/id/eprint/2097/1/georgian_glossary.pdf
- İlke Kararı 660, (1999). *Taşınmaz Kültür Varlıklarının Gruplandırılması, Bakım ve Onarımları*, [Policy decision:660: Grouping, Maintenance and Repairs of Immovable Cultural Heritage],T.C., Kültür V.Bakanlığı, Kültür ve Tabiat Varlıklarını Koruma Yüksek Kurulu,Toplantı tarih ve karar no: 660 ve 5.11.1999, Retrieved from: <https://teftis.ktb.gov.tr/TR-263743/660-nolu-ilke-karari-tasinmaz-kultur-varliklarinin-gruplandirilmasi-bakim-ve-onarimlari.html>

- Illustrated Glossary, (2013). *Illustrated Glossary, Technician Training for the Maintenance of In Situ Mosaics*, Editing by Livia Alberti, Elsa Bourguignon, Ermanno Carbonara, Thomas Roby, and Juana Segura Escobar – Getty Conservation Institute/Institut National du Patrimoine, Tunis, Los Angeles, USA: Getty Conservation Institute. Retrieved from https://www.getty.edu/conservation/publications_resources/pdf_publications/pdf/illustrated_glossary_2014.pdf
- Lazzarini, L.-Tabasso, M.L., 1986. *Il Restauro Della Pietra*, [The restoration of the stone], Padova İtaly: CEDAM-Casa Editrice Dott.Antonio Milani.
- Torraca, G., 1988 *Porous Bulding Materials, Materials Science for Architectural Conservation*, 3th Edition, Rome, İtaly: ICCROM Tecnical Notes.
- Şener, Y.S. (2011), Basic criteria for the conservation of mosaics, *Paper Presented at the 11th İnternational Colloquium on Ancient Mosaics, Mosaics of Turkey and Parallel Developments in the Res of the Ancient and Medieval Word: Questions of iconografy, Style and Technique from the Beginnings of Mosaic until the Late Byzantine Era*, in M. Şahin (Ed.), October 16th-20th, 2009, (pp. 873-882), Bursa Turkey: Ege Yayınları.
- Şener, Y. S., (2012). Arkeolojik Alanda Taban Mozaiklerinde Karşılaşılan Bozulmalar, [Deterioration of Floor Mosaics in the Archaeological Site] *Türkiye'de Arkeometrinin Ulu Çınarları, Prof. Dr. Ay Melek Özer ve Prof. Dr. Şahinde Demirci'ye Armağan* (ed: A. A. Akyol-K. Özdemir), [To honour of Prof. Dr. Ay Melek Özer and Prof. Dr. Şahinde Demirci, Two Eminent Contributors to Archaeometry in Turkey], pp.329-344, İstanbul,Turkey: Homer Kitabevi
- Yönetmelik, (2012), *Kültür Varlıklarını Koruma Yüksek Kurulu Ve Kültür Varlıklarını Koruma Bölge Kurulları Yönetmeliği*, [Regulation of the High Council for the Protection of Cultural Heritage and Regional Boards for the Protection of Cultural Heritage]. retrivied from: <https://teftis.ktb.gov.tr/TR-264568/kultur-ve-tabiat-varliklarini-koruma-yuksekk-kurulu-ile-koruma-kurullari-yonetmeliği.html>

CHAPTER 3

THE WRITTEN WORD AND ITS MULTIPLE ROLES IN CULTURAL HERITAGE

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Abstract

The written word is a means of communication that has been with us through millennia in very different forms, from scientific reports to drama pieces, novels, and other forms of register. Concerning its role in cultural heritage (CH), the written word plays several different roles. In this chapter, we plan on examining three roles this form of register can play in the context of CH: firstly, as one of the examples of a possible cultural artifact, and therefore as an object of research; secondly, as the basis of research in matters regarding cultural heritage as the preliminary and mandatory step of literature review and, finally, as one of the possible mechanisms used in the conservation and preservation of cultural heritage. We will begin with an introduction and a reflection on the concept of CH, passing through several definitions, the difference between tangible and intangible artifacts, and how the written word is placed in these two categories. We'll show not only how it's a very nuanced element of cultural heritage, by the multiple roles it plays and its multiplicity inside each of the parts, but also how the written word is present in every single part of the process of conservation, making possible for future generations to understand where they come from.

Keywords: Cultural Heritage, Literature, Literary Artifact, Preservation, Conservation, Tangible, Intangible

1. Where does the written word fall in the concept of Cultural Heritage?

One quote from Paulo Garcez Marins, a Brazilian historian, with a Ph.D. in social history, comes to mind when thinking about cultural heritage. His phrase dates from June 2020, around the time when statues and other monuments were being destroyed because of their connection with the history of racism and violence in Europe, the United States, and Brazil. The quote went along the lines of “Destruir uma estátua não resolve, é preciso discutir a memória.” and then continued by saying “os monumentos são importantes para a reflexão do passado” (Uol, 2020). I want to start with this last part since reflecting on the past is an intrinsic part of cultural heritage.

There are quite a few definitions of cultural heritage (CH). One practical and immediate way to describe it would be: what past societies and cultures left to future generations, an “inheritance” of sorts. UNESCO defines it as “our legacy from the past, what we live with today, and what we pass on to future generations.” (Cultural Heritage, 2022). Lyndel V. Prott and Patrick J. O’Keefe in the volume *International Journal of Cultural Property* say, “cultural heritage consists of manifestations of human life which represent a particular view of life and witness the history and validity of that view”. One of the most recognizable representations of cultural heritage are archeological sites, or physical monuments, also identified by the two authors as examples of CH since human-built structures are “clearly accepted as important evidence of the past to be preserved” (Prott & O’Keefe, 1992, p.307). Along with historical buildings and sites, we can also look at paintings preserved in museums or other forms of artwork, even music. For instance, listening to an opera (maybe Vivaldi) can certainly send you back a few centuries or have that past brought back to you.

These forms of cultural heritage previously identified are called **artifacts**¹, mechanisms of representation of a specific culture or society. An opera is an artifact of a given time and given space, made within a specific society. But so is a statue, like *Capitoline Brutus* (dated around the 4th to early 3rd centuries BC), or a building like *Il Colosseo* in Rome. Given the two very different attributes of these artifacts, two categories were created to distinguish them: **tangible and intangible artifacts**.

Vivaldi’s opera is an intangible artifact, something we can’t touch. So are the stories passed from generation to generation and specific traditions from a particular society. Or even the language. *Capitoline Brutus* and *Il Colosseo* are tangible artifacts, touchable, able to be

1 The term was borrowed from archeology, where an artifact is an object recovered from an archeological site.

seen, and, for these reasons, their perception is more immediate. Using the previous example, it is known almost worldwide, that *Il Colosseo* dates to Ancient Rome and represents a part of their way of living. But not so many people might know that in the Portuguese language, a lot of words start with “al” because they come from the Arabic language, from the time when the arabes conquered Iberian peninsula by defeating the visigoths in the Battle of Guadelete in 711 and settled there (Collins, 1983, 151). The words that remained and were adapted into the current Portuguese language are intangible artifacts².

It’s important to note that these two types of artifacts weren’t always treated equally. Using the words of the 1994 Report of the World Commission on Culture and Development, “the intangible had for long been an ignored heritage” (Munjeri, 2004, p. 13). For a few decades, this has been a long-standing situation and the reason for overlooking intangible artifacts is given by Professor Ralph Pettman, who clarifies that the concept of heritage is, most of the time, seen as a place, as a thing – a visible thing – and so the visible takes precedence over the immaterial, and what cannot be touched (Munjeri, 2004, p. 13).

The case has, since then, developed into a different one. The rightful value is now also given to folklore, tradition, the evolution of language, and especially to memory. The work UNESCO has been developing around the preservation and conservation of CH and their definition of the two categories reflects this shift in mentality and it can be seen in their definition of the phenomenon:

Cultural heritage includes artefacts, monuments, a group of buildings and sites, museums that have a diversity of values including symbolic, historic, artistic, aesthetic, ethnological or anthropological, scientific and social significance. It includes tangible heritage (movable, immobile and underwater), intangible cultural heritage (ICH) embedded into cultural, and natural heritage artefacts, sites or monuments. The definition excludes ICH related to other cultural domains such as festivals, celebration etc. It covers industrial heritage and cave paintings.

(Cultural Heritage | UNESCO UIS, n.d.)

With this considerably new valorization of intangible artifacts, where does the written word and its content fall in the wide-encompassing range of cultural heritage? As we’ll see next, written registers can be very fluid artifacts, by its formal textures and different supports alone. Beyond that, it can also play multiple individual roles or, sometimes, all of them at once. This fluidity makes the labeling of written records into just one category extremely complex. Moving forward, we’ll see how the written word can be an object of study in CH and still acquire different forms, as the following:

2 For more on this subject, consult Nascentes, A. (1932). *Dicionário Etimológico da língua portuguesa*. Francisco Alves.

- a) a cultural artifact
- b) a primary step in the research of another artifact in the form of a “literature review”
- c) the means of preservation and conservation of cultural heritage through historic documents and translation.

Starting with the first role, written registers as a cultural artifact, we’ll start by exploring the notion of how these records can be perceived as an object of study in CH. We’ll do this by observing several examples of the various forms these artifacts can present themselves, like a recently found book collection, the language aspect, and a few of the narrative works of Italian writer Antonio Tabucchi and how they can be considered cultural artifacts themselves. From there, we’ll try and place these examples into the two categories we identified previously: tangible and intangible artifacts.

Next, we’ll focus on the written word as the basis of research and analyze a very important step in every investigation called a literature review. We’ll start with a quick introduction of what a literature review consists of and identify three different scopes in which they can be developed. After considering the significance of this step in cultural heritage, we’ll follow by presenting an example of a possible investigation done about the *Basilica di San Lorenzo*, a monument set in Florence, and the different forms a literature review could take in this scenario, as well as what particularities this overview might have.

Finally, we’ll look at written registers as a mechanism for the conservation and preservation of cultural heritage. Firstly, the attention will be on the registration into written word as a form of conservation of cultural and historic elements. Here, we’ll also reflect on translation and the conversion of a text into another register as a different form of preservation. Lastly, we’ll look at the example of the ancient library of Alexandria to show the importance of these institutions in the preservation of cultural artifacts.

1.1. Written word as a form of cultural heritage – the object of study

A few days ago, there was some news in a local newspaper that caused some reflection on the topic of this chapter: the library of Bruno Schröder, a mining engineer, had been discovered in Germany upon his death. Over seventy thousand books were discovered in his “secret” library, which he had built to accommodate his passion. After the property manager tried to sell the collection at an auction and failed, the books sit again in their very own library. The news propelled the following thought: for anyone wanting to study Bruno Schröder, now or in the next decades, his library might be a very good place to start. There are very interesting

questions that arise from this collection alone. What books did he collect? What genre? From what years? Was there a particular time that interested him? What does this say about Bruno Schröder? What does this collection say about the society he lived in? What were the most popular interests at that time? The list could go on. The answers to these questions would rely heavily on these written records.

Studying a specific language also relies heavily on written registers. Taking the example of the evolution of Latin to Portuguese or even to Italian, given that we are talking about a process that took centuries, oral records might be impossible to find. The researcher might better place her/his luck on different written records spaced along a very extended timeline and study them, compare them. Here we can look at personal letters from different individuals, or even parchments, the first manuscripts, codexes, or even printed books (the birth of the press in the fifteenth century gave an immense upgrade to literary works). Even to investigate the oral aspect of the evolution of the language, one of the ways to get an answer would be through the register made by the individuals of the time, of the stories told to the children, for instance, the language in which they did it. How did the king of the time, or other authority power, communicate their laws to the people, and in what language? The answers would inevitably be in the written register.

Observing these two situations alone (a lot more could've been given) we see how the written register plays an important role in CH and here, with these different forms, we are in the presence of a tangible artifact. Artifacts because the collection assembled by the mining engineer represents not only his interests but also those of the society and the community he lived in. Tangible because it can be touched, seen, and handled. So are the records consulted by the different researchers for their investigation of the transformation of Latin to Portuguese/Italian, they can all be maneuvered, handled, and seen and they are artifacts because they're registers of the life, the habits, and other aspects of the life of a given society and at given time.

Let's think for a moment about the writer Antonio Tabucchi. Antonio Tabucchi (1943 – 2012) was an Italian (and from 2004, Italo-portuguese) academic, translator, and writer. His love for Portugal and the Portuguese literary culture are represented in his work as a translator as he, alongside his wife Maria José de Lancastre, was one of the main translators of Fernando Pessoa in Italy, as well of Alexandre O'Neill and other Portuguese and Brazilian writers. He used his words not only to write novels and short stories but also to speak up about the problems facing the Italian people for decades. He did this by writing for different newspapers and

magazines³. While consulting these articles and reading them, we get a sense of Tabucchi and Italy during those years. We have “almost” direct contact with the past through the writer’s words. One day, one might resort to Tabucchi’s many articles to understand the social and political problems that the Italian peninsula was facing at the time. Another artifact through the written word.

There is, however, another side to literary artifacts, more subtle, more nuanced. And another side to the author’s work as well. Born during the second world war, the writer has a very complex relationship with history and even with memory (his individual or collective one). In this regard, Claudio Milanesi observes that history was used by Tabucchi to show the constant evil in humankind (Milanesi, 2007). That is certainly the case of his first novel, *Piazza D’Italia* (1975), which “nell’ampio arco cronologico di quasi un secolo, la saga della famiglia di anarchici toscani, raccontata in *Piazza d’Italia*, diventa *exemplum* per la Storia di tutta l’Italia” (Rimini, 2007). Tabucchi uses his first literary work to represent the war for the unification of the peninsula, called *Risorgimento*, and the adventures of Garibaldi, one of the key people in this enterprise.

Why is this book so important when talking about CH? *Il Risorgimento* took place for almost six decades in the nineteenth century (1815 – 1870), meaning Tabucchi wasn’t yet alive at that time to experience it. The representation present in his novel doesn’t come from his own personal and individual memory, but from one even more complex: the collective memory of the Italian people that he shares by being part of the community. His book is an excellent example of how memory and literature can come together to form a cultural heritage artifact.

Most memories connected with cultural heritage fall into the category of collective memory. This distinction between individual and cultural memory comes from the development of the field of memory studies. This area of study developed with the second world war and the horrors of the holocaust, with the creation of books, articles, diaries, the discovery of letters, and other literary records from survivors that recounted their time in captivity. Since then, the connection between memory and culture has been seen as the key to interdisciplinary research, encompassing areas from history, sociology, literature, etc (Erll & Nunning, 2008, p. 1). From this development and connection between disciplines, memory was categorized into two different types: individual memory and, as we saw earlier, collective memory.

Individual memory is connected with our personal experiences and recollections and, ultimately, helps form our identity. While they’re individual memories, they are created in

3 These articles were then published in a compilation book entitled *L’oca al passo* (2006) published by Feltrinelli.

a collective context and by external factors, which means they're not fully individual. On a collective level, memory has a symbolic value, as one given memory can't be remembered the same way by every member of a given community. The concept refers to practices, institutions, and media used by different social groups to build a collective past (Erll & Nunning, 2008, p. 7). This is the memory Tabucchi uses within his first novel.

But *Piazza D'Italia* isn't the only case of the writer's use of memory. His deep connection with Portugal, its people, and its history is present furthermore in the so-called *Portuguese Trilogy*, composed of the novels *Requiem* (1991), *Sostiene Pereira* (1994), and *La testa perduta di Damasceno Monteiro* (2004). The second novel has also a connection with CH. The story, set in the year 1938, has as background the dictatorship of Salazar but also Italian fascism and even the Spanish civil war. Calling again on the memories of the Portuguese people, Tabucchi represents reactionary moments and episodes of violence and torture used by PIDE, calling the attention of the reader to the past, once again.

With these two novels, we are in the presence of a collective memory, which Tabucchi had contact with and then represented in the pages of his book. The memory used and brought back to life in these two novels are intangible artifacts of not only Italian but also Portuguese and even Spanish history. By "putting" these memories in his pages, Tabucchi turns his works into intangible artifacts themselves, because it's the memory embedded in those pages that makes them artifacts. Not exactly tangible because they can't be touched and might not be perceived by everyone. Furthermore, the importance Tabucchi gives to the past is the same given to intangible artifacts as they are "those against which we measure our present and plan our future" (Rainey, 1978, p.115).

Regarding intangible artifacts, we can also look at traditions, knowledge, social practices, memories, and other examples. We'll find most of their practices documented in literary works, either by journal entries, diaries, narrative works, articles, or other forms of written registers. An example of this is the book *Eva dorme*, by the Italian author Francesca Melandri. While reading the novel, we pass by several linguistic words and phrases in German, showing the intangible reality of bilingualism in the region of Alto-Adige in Italy.

Language can be seen as an intangible artifact as well. The register in which we communicate is a living cultural element of our past because, as we saw earlier, our language has been developing for centuries but in it are still embedded elements of that development and of that history. Those elements can't be seen, of course, but they are present, nonetheless.

1.2. The written word as the base of research – literature review

It may not be so perceptible but written registers, in any form, are present in every research conducted and in every area of study. Before beginning any investigation there's a mandatory first step that consists of making an overview of everything that was written and created about the topic. This step "shows the reader what is known about a topic, and what is not yet known, thereby setting up the rationale or need for a new investigation, which is what the actual study to which the literature review is attached seeks to do" (Denney & Tewksbury, 2013, p.218). As stated by the quote, this step is called a literature review.

A quick search on google will come up with thousands and thousands of results of literature reviews on the most different topics, from climate change to mechanical engineering, mathematics, social sciences, and the list could go on. But why is this mandatory phase so important? Denney and Tewksbury answer this question quite clearly, by saying:

Primarily, literature reviews force a writer to educate him/herself on as much information as possible pertaining to the topic chosen. (...) Second, literature reviews demonstrate to readers that the author has a firm understanding of the topic. This provides credibility to the author and integrity to the work's overall argument. And, by reviewing and reporting on all prior literature, weaknesses and shortcomings of prior literature will become more apparent.

(Denney & Tewksbury, 2013, p.219).

From the investigation standpoint, the importance given to literary review is well established by the previous quote. A literature review sets a foundation where future research can be built and simplifies the work going forward. However, not every literature review is created for the same purpose. As Knoph states in his article, there are three different contexts in which this overview can be conducted: it can be produced to create a state-of-art article or text, in which the objective of the text would be to do a critical review of what has been done until that moment, to identify positive and negative points. Secondly, it can be the "preliminary stage in a larger research project" meaning that it's normally required for a thesis, a dissertation, or even for grant proposals in which the researcher aims to show how his/her proposed theme is a valid option and what it'll add to that specific field. Finally, it can be also part of a finished research report. This context involves "building on and revising the literature review completed at the proposal stage" to show how the conclusions of the project relate to what has been written before (Knopf, 2006, pp. 127-128).

While reading all the interesting nuances that a literature review can undertake, much like a chameleon, it does arise the question of how this phase of research plays in the context of CH and the particular significance of this step. For this chapter, we tried to find a few articles

that would speak on the subject, but the research didn't yield many results. One could assume since the importance of a literature review has been greatly established in academic circles that there isn't a need to specify it for the context of CH. However, there are some attributes of the literature review on cultural heritage that must be considered and reflected on.

A quick look on Google shows us that the terms "cultural heritage" and "literature review" are extremely linked. Looking at some of the articles that immediately come forward we can conclude that most of these literature reviews are done in the context of the first type identified by Knopf before, with the scope of becoming a state-of-art article. However, the second one, a preliminary state of a larger research project, is also one of the most common scopes of a literature review.

While conducting any research related to CH, being that of an artifact recently found or some other element, the literature review done in academic circles about the artifact or the society in which it was found, will be one of the first things to be consulted. The researcher will resort to the document to try and answer the question "what was said about the artifact so far?". This overview will include every – or the most significant – development made in an academic context and over a systematization of the information. Thus, this literature review will fall into the second context and serve as a preliminary step.

However, this overview may come up empty – or nearly empty – if the researcher is developing a study about an artifact that no one has had any contact with or hasn't focused on yet. The investigation that the researcher will embark, on will necessarily have the same attributes as a literature review and obtain the form of a state-of-art article. Let's take the example of an architectonic artifact, like the *Basilica di San Lorenzo* in Florence (figure 1).

This monumental building is an important part of Florence's cultural heritage as one of the great artworks born during the Italian Renaissance, a period where the city produced a great number of works of art, from paintings to sculptures and architectonic buildings. Naturally, this building and its history have been studied for centuries from several different angles and its history has been greatly established. That is not to say that discoveries cannot be made, and new artifacts cannot be found.

A historian or an art historian, or any other researcher, who was looking to study this imponent building would first resort to academic records, in form of articles, monographs, art-history volumes, and other types of academic knowledge, once again to answer the question "what has been established about the basilica so far?". However, if the researcher has in his/her hands a newly found artifact that hasn't been studied yet, the results might not answer the artifact and his connection with the basilica.



Figure 1. Basilica di San Lorenzo, central nave designed by Brunelleschi (1425–1442)

In this case, the historian might need to go back and look at the records of the building, in form of architectonic plans, artist's drawings, and maybe the letters of the family who commissioned the work, in this case, the Medici Family. Maybe they'll find records of payment to Brunelleschi for directing the works and to other artisans. They may even find some letters to a priest or even to the Pope (we cannot forget that the Medici bank held for a long time the papal accounts) and their replies about consecrating the works and the finished basilica. All these records – literary records because we are talking about the register of the written word – would necessarily be consulted in search of a mention or even a connection with the artifact being studied.

While compiling this information, a state-of-art article might be born, where is the researcher himself/herself that is trying to answer the question stated before. For instance, a literature review focusing on a particular aspect of Brunelleschi's work at the basilica would inevitably include not only academic records but also these and other artifacts. The importance of this kind of record can be perceived, remaining in the art-history domain, in any compendium of this area. These compendiums offer a very detailed history and state-of-art of the works of art included in the volume. Those texts include several mentions of letters, plants, materials lists, and sometimes other letters containing other curious aspects of the works and the work of art itself that may inspire future research.

Once again, written word records present themselves as an extremely nuanced element of cultural heritage. Even as the basis of research and as a preliminary element, we see how it can take three different forms as the preliminary step of a literature review. Through the examples given before, we saw how the same investigation can cause the same overview to play different roles, depending on being a new and yet-to-be-studied artifact or one that has an already established background. Whatever the form it takes, we saw how essential this step is, not just by propelling a careful reflection about the artifact and the circumstances that surround it but also by making it possible for new investigations to be born.

1.3. The written word as a means of preservation and conservation

We saw thus far how written registers can be objects of study and simultaneously the starting point of research (in the form of a literature review) in matters of cultural heritage but now we'll see how this format plays another role, extremely related to written word records as an artifact.

As Gorman (2013) states in his article, writing was invented millennia ago and from that time until now there are uncountable records that represent the thoughts and the evolution of mankind throughout time. The creation of these written records, which greatly increased with the creation of the codex (what we now call the book), was extremely important for the dissemination of knowledge since “the existence of these texts and, increasingly, other manifestations of the human record, led to a community of learning that transcended national boundaries centuries (...)” (Gorman, 2013, p. 479).

The importance of Gorman's text goes beyond the significance of the invention of writing. It states that written records are essential for the conservation of the knowledge inside of them, identified by the author as the best format for the preservation of human records (Gorman, 2013, p. 481). We can call on the examples given before to demonstrate this. If we refocus our attention on the artifacts identified earlier, like letters, possible plans, commission contracts, drafts of possible paintings of future buildings, etc, we quickly see that it was the registration of these pieces of information that made possible for this data to be compiled and studied, sometimes in tandem, and different connections to be made between them. If these records didn't exist, if the information had been passed only orally, a study about the work made in the *Basilica di San Lorenzo* wouldn't have been possible, since there wouldn't be any records available to study, and any information to pass on.

As stated by Mahmud, Ampera, and Sidiq, “The word preserving is defined as the act or activity of keeping something in an existing and usually satisfactory condition” (Zulkifli Mahmud et al., 2019, p.11). The idea of preserving tangible artifacts might be more immediate

than the one called for intangible artifacts. The solution that seems to be working for centuries is the preservation through the act of documentation, not just by pictures (and here rises again the importance of photography and painting) but also by words and literature. And thus, the written, and its various elements, also acquire the role of preservation of CH's artifacts.

A language, by itself, has the role of naming an object, an idea, a concept, or even a behavior in a community, and those same terms will become a cultural product of the society in which they were created. The cultural elements authors choose to insert in their works and "how they are presented through words to the same community with the same language" can be seen as an act of preservation. But so can be the way used to transmit "cultural elements to other communities with different languages without decreasing the detail of information given in the source language text" (Zulkifli Mahmud et al., 2019, pp.11-12). And this is how translation becomes essential to CH.

In an example given before, we saw how literary artifacts are extremely important to understand the evolution of a language, but this can also be extended to any historical aspect. If we take into consideration the enormous number of records concerning the second world war, we'll quickly see that these documents will appear in very different languages, from Italian to German, English, Spanish, Portuguese, Russian, and the list goes on. How could these records be understood by someone who does not understand the source language? And how can these documents be preserved in the case the originals are or were destroyed? Although making copies is also a solution to this last problem, translation presents itself as another possible solution to both.

Translation is "an act of reproducing various kinds of texts including religious, literary, scientific, and philosophical texts in another language and thus making them available to wider readers" (Zulkifli Mahmud et al., 2019, p.11). Following our example, the war records are going to be translated into the target language of the research team so it can be understood and studied by all. Furthermore, in case of the destruction of the original, the possible existence of translations into various languages will ensure that the records are preserved, and the knowledge can be accessed and passed on.

That is not to say that all problems are fixed with a translation. The process has quite a few challenges and trying to convert elements specific to a determined culture into another register is still one of the biggest questions in the field. Nevertheless, translation is still a very important step forward in the preservation of literary records but also the dissemination of knowledge to a wider audience.

This last aspect, the transmission of knowledge, it's a very intrinsic part of cultural heritage. As Gorman puts it:

“The term ‘cultural heritage’ contains within it a clear implication – that of onward transmission. The word ‘heritage’ means something transmitted by or acquired from a predecessor. In order for that generational transfer to take place, the item of cultural heritage must be recorded and preserved. Something that has only transient existence – a dance, the singing of a bard, a religious ritual – cannot be transmitted (i.e. cannot form part of a heritage) if it is not described or recorded in some manner that ensures the accurate transmission of the event.

(Gorman, 2013, p. 486)

One of the greatest disasters for humankind was the destruction of the library of Alexandria, established around the year 3 BC. The library was part of a larger research compound called *Mouseion*, a dedication to the goddesses of art, the Muses (Murray, 2009, p. 17). The extraordinary building encompassed countless parchments of universal knowledge, from scientific, to artistic, literary, and medicinal, all in the same building. Although the exact number is impossible to calculate, sources say it held between forty thousand to four hundred thousand parchments and other manuscripts. The building suffered many attempts of destruction, starting with the one propelled by Julius Caesar's troops during the siege of Alexandria, around 48 BC.

Sources vary in setting the scale of the destruction, some stating the whole building was destroyed and others affirming that just part of it collapsed. The second colp dates from 385 to 412 AC and the third in 640 AC. Through many reconstructions, either total or partial, the original aspect of the building is now impossible to know or even imagine. Its true dimensions are impossible to calculate and the same can be said about the amount of knowledge lost.

That's where the importance of libraries lies: the conservation of knowledge. Although literary records are conservation methods themselves, they must also be conserved. Like the example set by the library of Alexandria, all libraries hold important records of human life and knowledge. Regarding the role of libraries, Gorman states that the primary concern of these buildings is the messages that constitute the human record, and because of that “the library is seen to be a part of the general context of the history of human cultural” (Gorman, 2013, p. 482).



Figure 2. Ruins of Celsus' Library in Ephesus, built c.400 after Alexandria's Library

To keep libraries at the forefront of the conservation endeavor, Gorman suggests they should ally themselves with other institutions “based on communities interest” like archives, museums, art galleries and institutes, research institutes, other societies and even performing groups. This cooperation between them would aim to “achieve common goals, especially the overarching goal of the organization, preservation, and onward transmission of the human record and the cultural heritage that it embodies” (Gorman, 2013, pp. 487 – 488).

A library is a crucial complex for the preservation of the knowledge acquired through centuries and the history of humankind. Losing these buildings and their content, as it happened in Egypt with the loss of the Library of Alexandria, would be a loss for all humanity. The knowledge preserved in the ancient codexes and now in books plays an important part in CH, as they represent a given time's behaviors, ideas, and concepts. Translating these artifacts is another form of preserving them by creating another record of a given artifact, in the case the first and original one may be lost or destroyed.

Conclusion

There's no denying the importance of the written word in cultural heritage. This form of documentation has been present in human life for millennia and has accompanied every single development of mankind. The written word also has a pre-history, before the invention of parchments, letters, codexes, and their evolutions to books, newspapers, and so forth.

Written registers of information started in different parts of the world at different times: in Mesopotamia about 3200 BCE, in China about 1250 BCE, and in Mesoamerica around 650 BCE. At this time, these communities were already capable of “devising a system of graphic symbols to represent the sounds of language” that enabled them of communicating in other forms other than oral and register different data about their history (Bazerman et al., 2008, p. 8).

These artifacts are the object of study of cultural heritage. As we saw in the first part of the chapter, how this type of records is a multifaceted artifact that can play different roles at the same time. This is very perceptible in the distinction made between tangible artifacts and intangible ones.

Other than being an artifact, the written word also plays a part in cultural heritage research, taking place in a mandatory step called a literature review. After reflecting on the importance of this research element, we focused on the example of possible research conducted about a newly found artifact of the *Basilica di San Lorenzo* and observed the many forms a literature review could obtain in this regard. From there, we reflect on the many different forms this same overview could take and on the importance of this element to set the stage for new investigations.

But also in the conservation of cultural heritage does the written word plays its role and a significant one of that. As we saw in the third part of this chapter, the documentation of information, in various forms, allows for the preservation of the knowledge being registered. This is true for literary records and for other forms of documentation, like photography. Another mechanism of conservation is through translation, which can make knowledge available globally but also of preserving the same knowledge in another register. To make sure these records are preserved, libraries and other buildings dedicated to preserving literary records (or any other records) become crucial to cultural heritage.

There’s no denying that written records are quite everywhere regarding cultural heritage. In this chapter, we showed a little of the complex ability of the written word to change itself into playing multiple parts in the process, in the center as an artifact, in the background as a literature review, and at the forefront of the preservation effort. It can even adapt itself to become a tangible or intangible artifact. A more interesting and curious artifact would be hard to find, and we hope to have shown the astonishing ways in which the written word can be approached from the cultural heritage standpoint.

References

- Collins, R. (1983). *Early Medieval Spain: Unity in Diversity, 400-1000*. Palgrave Macmillan.
- Cultural heritage | UNESCO UIS. (n.d.). <https://uis.unesco.org/en/glossary-term/cultural-heritage>
- Cultural heritage. (2022, July 21). UNESCO. <https://en.unesco.org/fieldoffice/santiago/cultura/patrimonio>
- Denney, A. S., & Tewksbury, R. (2013). How to Write a Literature Review. *Journal of Criminal Justice Education*, 24(2), 218–234.
- Erard, M., & Schmandt-Besserat, D. (2008). Origins and Forms of Writing. In C. Bazerman (Ed.), *Handbook of Research on writing: History, society, school, individual, text*. Routledge.
- Erl, A., & Nunning, A. (Eds.). (2008). *Cultural Memory Studies: an international and interdisciplinary handbook*. De Gruyter.
- Gorman, M. (2013). The wrong path and the right path: The role of libraries in access to, and preservation of, cultural heritage. *New Library World*, 108(11/12), 479–489.
- Knopf, J. W. (2006). Doing a Literature Review. *PS Political Science & Politics*, 39(01), 127–132.
- Milanesi, C. (2007). Tabucchi, la storia e l'impegno, da Piazza d'Italia a L'oca al passo. *Italies*. <https://doi.org/10.4000/italies.3722>
- Munjeri, D. (2004). Tangible and Intangible Heritage: from difference to convergence. *Museum International*, 56(1–2), 12–20.
- Murray, S. (2009). *The Library: An Illustrated History*. Skyhorse Publishing Company Incorporated.
- Nascentes, A. (1932). *Dicionário Etimológico da língua portuguesa*. Francisco Alves.
- Prott, L., & O'Keefe, P. (1992). 'Cultural Heritage' or 'Cultural Property'? *International Journal of Cultural Property*, 1(2), 307–320.
- Rainey, G. R. (1978). Intangible Artifacts. *Childhood Education*, 54(3), 115–117.
- Rimini, T. (2007). La cine(biblio)teca di Tabucchi: il montaggio di Piazza d'Italia. *Italies*. <https://doi.org/10.4000/italies.3726>
- Uol. (2020, June 11). “Destruir uma estátua não resolve, é preciso discutir a memória”, diz historiador. 11/06/2020 - UOL Notícias. <https://noticias.uol.com.br/ultimas-noticias/rfi/2020/06/11/destruir-uma-estatu-nao-resolve-e-preciso-discutir-a-memoria-diz-historiador.htm>
- Zulkifli Mahmud, E., Ampera, T., & Isnaeni Sidiq, I. (2019). Preserving Culture through Literary Works and Their Translations. *PROCEEDING Conference on the Environmental Conservation through Language, Arts, Culture and Education (CECLACE 2019)* 1(1), 11–15.

CHAPTER 4

MUSEUM EXHIBITIONS: INNOVATIONS FOR THE CONSERVATION OF BOOKS AND OBJECTS FOR DISPLAY

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Abstract

Conservation of museum collections for exhibitions is a complex collaborative process between curators, conservators, and exhibition designers, whose principle objective, in realization of the curator's narrative, is attaining the finest display of museums' and on loan artworks. The present essay discusses book and paper objects exhibited in museums from the conservator's perspective, and describes a selection of significant to the history of the *Art Institute of Chicago* examples of books and objects from the museum special collections conserved for display at: *Van Dyck, Rembrandt, and the Portrait Print, Ireland: Crossroads of Art and Design, 1690–1840, Ghosts and Demons in Japanese Prints, What May Come: The Taller de Gráfica Popular and the Mexican Political Print*, and *Beauty and the Book: 19th and Early 20th Century Folios on the Decorative Arts*. The essay also reflects on aspects of conservation treatment before, during, and after exhibition display, case design, construction of custom cradles and supports, environmental requirements for exhibiting books and papers, lighting, security, and exhibit monitoring practices.

Keywords: Conservation and restoration, museum exhibitions, book and paper conservation for exhibitions, custom cradles and supports, environmental requirements

1. Introduction

Created equally as a museum and as an academic institution, the *Art Institute of Chicago* was founded in 1866 by a group of artists named the *Chicago Academy of Design*. A few years later, the *Chicago Academy of Fine Art* was established in 1879, following certain organizational developments. Shortly thereafter, the name was changed to the *Art Institute of Chicago* in 1882. (Figure 1)



Figure 1. The Art Institute of Chicago in the 1900s.
Credits: The Art Institute of Chicago

The museum and academy moved in 1893 into the present building on *Michigan Avenue*, which houses the museum. Boston architects Shepley, Rutan, and Coolidge originally designed this structure for the *World's Columbian Exposition*. The principal *Allerton* building of the museum complex was constructed on the rubble of the 1871 Chicago fire. John Maxon (1916–1977), the Vice President for Collections and Exhibitions at the Chicago Art Institute, dedicated a monograph published in 1983 to the history of the museum. In this monograph titled *The Art Institute of Chicago*, Maxon stated that “The trustees decided to profit from the World’s Columbian Exposition in 1893 by cooperating with the managers of the exposition in the building of a hall for the World’s Congresses, which, at the end of the exposition, would revert to the trustees of the Art Institute for their permanent use”¹ (Maxon, 1983).

¹ For further details of the museum architecture, administration and establishment of the first museum collections of paintings, sculptures, prints and drawings, oriental art, textiles, primitive art, classical and decorative arts, see Maxon, John. *The Art Institute of Chicago*, Thames and Hudson, London, UK, 1983, p. 8.

The *Art Institute of Chicago* is located in *Grant Park* and is considered one of the oldest and largest art museums in the world. The museum features thousands of artworks spanning over five millennia of human creativity and showcases its permanent collections of nearly 300,000 artworks through numerous special exhibitions. Its encyclopedic collections of iconic artworks by Seurat, Monet, Cezanne, Toulouse-Lautrec, Caillebotte, Gauguin, Degas, Van Gogh, Van Dyck, Picasso, Dali, Miro, Magritte, and Hopper are augmented by a profusion of contemporary paintings, sculptures, photographs, installation art, and new-media design from every significant art movement from 1950 to the present. Represented artists include David Hockney, Jasper Johns, Cindy Sherman, Eva Hesse, Ellsworth Kelly, Bruce Nauman, Gerhard Richter, and many others.



Figure 2. Documentary photographs of the *Ryerson and Burnham Libraries* in the 1900s
Credits: *The Art Institute of Chicago*

As a research institution, the *Art Institute of Chicago* encompasses a conservation and conservation science department and five conservation laboratories. It also accommodates the *Ryerson and Burnham Libraries*, one of the largest art history and architecture repositories in the United States, which contains books and paper material from all historic periods. These collections include extensive holdings of literature on 18th- to 20th-century architecture as well as 19th-century paintings, prints, drawings, and decorative art. The compilations also contain diaries, personal correspondence, work files, photographs, sketchbooks, transcripts, and memorabilia of various artists and architects. (Figure 2)

The first conservation department at the museum was founded in 1956. Today, the museum employs more than thirty conservators who specialize in all conservation-related disciplines. The museum's book conservation laboratory was established in 1983 to preserve, conserve, care, and restore the collections of the *Ryerson and Burnham Libraries*.



Figure 3. Present-day *the Art Institute of Chicago*
Credits: Malina Belcheva

As a book and paper conservator my responsibilities at the *Art Institute of Chicago* were focused on research, conservation, restoration and documentation of conservation treatment on rare and special collections books, maps, manuscripts, exhibition design and preparation of books and paper materials for installation. During my conservation practice, I created a variety of exhibition cradles and supports for books and papers for display in the museum's beautifully designed exhibition galleries. (Figure 3, 4 and 5)



Figure 4. Galleries in the Modern Wing of the museum
Credits: Malina Belcheva. Courtesy of the *Art Institute of Chicago*

2. Guidelines for display

The general requirements for displaying bound materials in the museum's galleries include:

- If possible, books and pamphlets should be displayed horizontally or at an angle, preferably not higher than 45°. This display is recommended to prevent damage to objects during exhibitions.
- Books and other bound paper materials on exhibit should be fully supported to avoid straining their binding structures.
- Books displayed open should be exhibited in an open position that is comfortably allowed by the particular historic binding.
- Most books will not lie flat when opened and should not be forced into an open position that could damage their bindings.

The museum observed two main principles for book installations:

First, conservators were asked to design cradles that would not cause any structural damage to the books on display.

Second, the exhibition cradles should be unobtrusive to museum visitors and thus enhance their perceptions of the exhibition design.

It was crucially mandated that no paper-based material should be exhibited permanently or for a long period of time.



Figure 5. Photograph taken during conservation treatment of *Galerie Royale de Costumes: Costumes Espagnols*, Publisher Aubert & Cie, Paris 1852, collection of the Art Institute of Chicago
Credits: Malina Belcheva. Courtesy of the Art Institute of Chicago

3. Installation of books and paper materials

The conservation treatment and safe display of exhibited books and papers essentially require conservators to evaluate and determine the condition of objects before installation. Thus, the optimal design of the exhibition cradles and supports takes into account the fragility of the artwork. The primary responsibility of the conservator in creating exhibition cradle designs is to preserve the integrity of the objects on display.

In this context, the principal factors to consider include:

- the **physical condition** of the object
- the **type of binding** (for bound materials)
- **size**
- **weight** (it is problematic to create cradles and supports for small or oversized items)
- **flexibility of the bookbinding structure**
- **preferred opening** of the book or other bound material

These aspects are essential to the process of designing an exhibition.

Different historic binding structures present discrete challenges:

The display of tight-bound volumes, re-bound material, artists' books, historically inflexible bookbinding structures, bridle paper, and leather bindings is complex. Also problematic is an array of materials such as single-leaf pieces, uneven or wrinkled parchment, and lightweight or heavyweight bindings. A wide open book in an exhibition vitrine benefits museum visitors who can better observe its aesthetics and absorb its beauty in its entirety. However, displaying a unique book fully open can damage its binding structure. Notably, books with flexible spines are very rare from a historical perspective, and manuscripts with deteriorating bindings require special attention when they are considered for display because their open position would be perilous to their future preservation. For example, French-bound volumes printed around the 18th and early 19th centuries have tight-back bindings. Their firmly pressed (hammered) text blocks render these volumes difficult to showcase in an open position. In fact, such texts should no longer be fully opened, even for consultation, viewing, or reading.² Consequently, exhibition mounts and cradles should be designed to completely support varied book structures and must be distinctively created from acrylic sheets, Vivak, Plexiglas, cardboard, or museum boards in a range of thicknesses suited to the particular art object. In addition, the mounts or cradles should be encased in textiles, papers, and assorted artists' materials for decorative purposes.

2 For further information see: Peachey, Jeffrey. (2013) "Beating, Rolling, and Pressing: The Compression of Signatures in Bookbinding Prior to Sewing" in *Suave Mechanicals: Essays on the History of Bookbinding*. Editor: Julia Miler, Vol. 1, The Legacy Press, MA, USA.

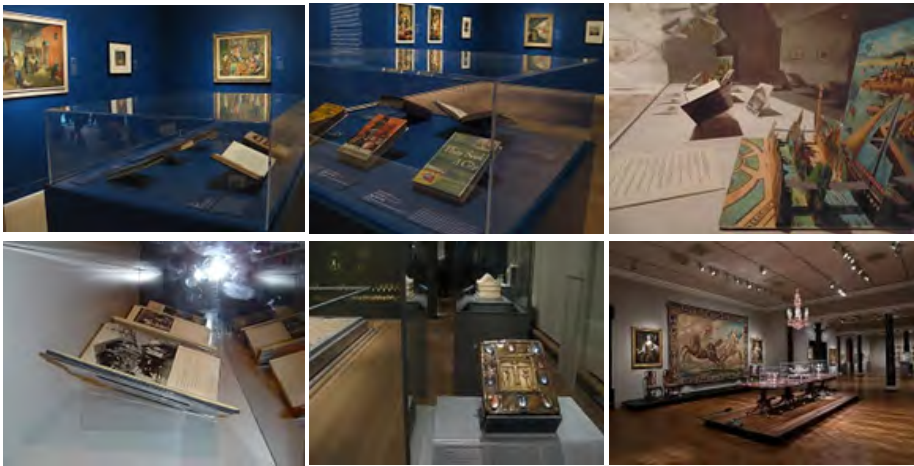


Figure 6. Exhibition supports and cradles designed by the author for the museum galleries
Credits: Malina Belcheva. Courtesy of the Art Institute of Chicago

This essay discusses the exhibition design and preparation of unique cradles and supports for books, graphic artworks, and objects presented at the galleries of the Art Institute of Chicago. These exhibits include *Van Dyck, Rembrandt, and the Portrait Print, Ireland: Crossroads of Art and Design, 1690–1840; Ghosts and Demons in Japanese Prints, What May Come: The Taller de Gráfica Popular and the Mexican Political Print; and Beauty and the Book: 19th and Early 20th Century Folios on the Decorative Arts*. (Figure 6)

4. Considering the aesthetics of display

4.1. Conservation of books and papers for display

Conservation treatment and exhibition cradle design for Cuauhtémoc (1960) by Adolfo Quinteros exhibited at What May Come: The Taller de Gráfica Popular and the Mexican Political Print

The exhibition of the graphic print *Cuauhtémoc* selected for *What May Come: The Taller de Gráfica Popular and the Mexican Political Print* was challenging from the conservator's perspective. More than 100 artworks from the Art Institute of Chicago collections of *Taller de Gráfica Popular*³ group prints, curated by Diane Miliotes were displayed at *The Jean and Steven Goldman Prints and Drawings Galleries*. (Figure 7)

3 Founded in 1937 by Leopoldo Méndez, Luis Arenal, and American-born Pablo O'Higgins, the *Taller de Gráfica Popular* emerged and evolved in the crucible of antifascist and leftist politics in Mexico during *World War II*. This milieu shaped the workshop's dedication to a collective printmaking model, also influencing its productions. These creations were aimed both at "the people" and discerning collectors, a strategy necessitated by the era's quickly changing political tides. See: Miliotes Diane. (2014). *What May Come. The Taller the Grafica Popular and the Mexican Political Print*. The Art Institute of Chicago, Yale University Press, Canada. The Art Institute of Chicago holds one of the most significant collections of *Taller de Gráfica Popular* graphic prints in the United States.

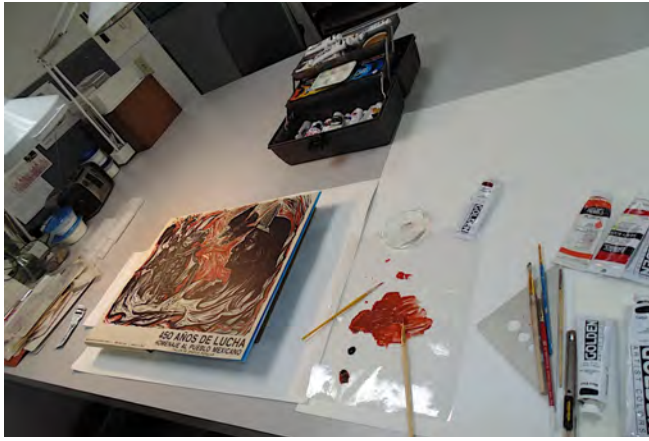


Figure 7. Photograph taken during the conservation treatment of Adolfo Quinteros' *Cuauhtémoc* (Mexico, 1960) from the collection of the Art Institute of Chicago
Credits: Malina Belcheva. Courtesy of the Art Institute of Chicago



Figure 8. Leopoldo Méndez, *What May Come, Mexico*, 1945, collection of the Art Institute of Chicago
Credits: The Art Institute of Chicago

The *Taller de Gráfica Popular* workshop created thousands of prints between 1937 and 2010, including linocuts and lithographs ranging from ephemeral leaflets and newspapers to political posters, luxe portfolios, and printed books. *Taller de Gráfica Popular* artworks were designed to be accessible to a broad audience. Their explicit realism in depicting Mexican political life around the time of *World War II* made them politically engaging, affordable, and visually compelling.⁴ (Figure 8)

4 Ibidem.

Adolfo Quinteros (1928–1994) created the linocut gravure titled *Cuauhtémoc*⁵ in 1960. This piece portrays Aztec resistance to the Spanish conquistadors. Printed on cream cardboard using letterpress in red and black ink, this work constituted the cover of *450 Years of Struggle: Homage to the Mexican People*.⁶ This luxe album⁷ comprised a collection of 146 finely printed folio-format graphics on colored paper. Created by twenty-five Mexican artists, the graphic works were dedicated to the Mexican War of Independence of 1810, the Mexican Revolution of 1910, and the Nueva Rosita miners' strikes in the 1950s. Figure 9 shows *Cuauhtémoc*, in which the artist depicts the entrancing Aztec legend of the *Descending Eagle*. Quinteros adhered to the principles of *Taller de Gráfica Popular* that “art must reflect the social reality of the times.”⁸ Hence, he symbolized the significance of the last Aztec ruler Cuauhtémoc, “one who has descended like an eagle,” visually implying the fierceness and determination of the Mexican People in times of war. (Figure 9 and 10)



Figure 9. Adolfo Quinteros, *Cuauhtémoc*, Mexico, 1960, after undergoing conservation treatment, collection of the Art Institute of Chicago

Credits: Malina Belcheva. Courtesy of the Art Institute of Chicago

- 5 Cuauhtémoc is also known as Cuauhtemotzín, Guatimozín or as Guatémoc, the last Aztec Emperor who ruled from 1520 to 1521.
- 6 Taller de Gráfica Popular. (1960). *450 años de lucha: Homenaje al pueblo mexicano (450 Years of Struggle: Tribute to the Mexican People)*, Taller de Gráfica Popular, Mexico City, Mexico.
- 7 In the collection of the *Ryerson and Burnham Libraries*, a gift from the Art Institute of Chicago curator Mark Pascale in memory of Dr. Margaret Burroughs.
- 8 The declaration outlined the *Taller de Gráfica Popular* group's intention to collectively create work that would engage with contemporary issues and events, “serve the people,” contribute to Mexican culture, oppose reactionary forces, and establish solidarity with progressive international movements. Murphy, John. (2014). *Collective Brilliance*. Review of *What May Come: The Taller de Gráfica Popular and the Mexican Political Print*; *What May Come: the Taller de Gráfica Popular and the Mexican Political Print*, by Diane Miliotes. *Art in Print*, 4(4), 50–51. <http://www.jstor.org/stable/43045715>.



Figure 10. Conservation treatment and exhibition cradle design for *Cuauhtémoc* from the portfolio cover of *450 Years of Struggle: Homage to the Mexican People*
Credits: Malina Belcheva. Courtesy of the Art Institute of Chicago

Captivated by the supreme influence of Quinteros' graphic art, the curator of the exhibition intended to display its portfolio cover in an open position. Originally, the artwork was extended and folded along the front, spine, and back cover of the portfolio. This structural characteristic complicated the conservation treatment and the creation of the cradle design. The exhibition installation for *Cuauhtémoc* proved challenging because the preliminary conservation treatment proposal initially envisioned preparations to display the object completely open, albeit only during the exhibition. The piece would later be restored to its original state.

Consequently, the conservation treatment began as usual with dry cleaning of the object with a volcanic sponge and *Staedtler Mars eraser crumbs*, followed by controlled humidification of the central spine fold of the cover. Next, pigment abrasions and paper losses were consolidated. The portfolio cradle support was finally created.

The paper and pigments were tested for permanence, and their stability was confirmed before the artwork was subjected to conservation treatment.

4.2. Conservation treatment outline and cradle support preparation

The oversized artwork titled *Cuauhtémoc* from the portfolio *450 Years of Struggle: Homage to the Mexican People* was prepared for display.

The paper object was dry cleaned, humidified, unfolded, repaired with lightweight *Japanese tissue* applied to infill paper losses, and retouched along the spine line with acrylics. Graphic work toning was consolidated using *Klucel G*. The custom cradle design required the construction of an additional cardboard insert, which was created of a two-ply off-white museum board. A cardboard box was inserted for the firmness of the object during display. It was created to replace and fill in the thickness of the graphic works of the artist and was positioned on a Plexiglas cradle along with the portfolio cover at a 45° elevation in accordance with the exhibition planning aesthetics (see Figure 11).

The portfolio cover was re-conditioned after the exhibition closed. It was humidified and repaired along the spine. The final conservation treatment provided complete flexibility in opening and closing the soft portfolio cover, which was restored to its original state of being folded back around the collection of graphic prints. The additional protective enclosure of the custom-made drop-spine box was completed to further conserve the artwork and ensure its longevity.

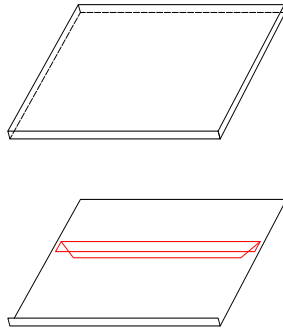


Figure 11. Graphic drawing for the exhibition cradle design for *Cuauhtémoc*
Credits: Malina Belcheva

*Conservation treatment and exhibition cradle design for the album **Fifty-two Plates Engraved from Portraits by Van Dyck and Others, 16th–17th Century** presented at **Van Dyck, Rembrandt, and the Portrait Print** exhibition at the Art Institute of Chicago.*

Aesthetically closer to the cradle designed for Adolfo Quinteros' artwork is the exhibition support of the album *Fifty-two Plates Engraved from Portraits by Van Dyck and Others, 16th–17th Century*⁹ prepared for display at *Van Dyck, Rembrandt, and the Portrait Print* exhibition at the Art Institute of Chicago. This custom-bound album comprises a collection of fifty-two intaglio prints by Van Dyck (1599–1641) along with portrait designs completed and executed by various artists between 1620 and 1641. Received at the museum as a gift by the American lumber magnate William Goodman (1848–1936), an unknown art collector compiled and assembled the collection of graphic prints from the *Iconography series* by Van Dyck in a folio album (see Figure 12, 13, 14 and 15). Preliminary conservation research revealed the absence of documentation or archival records for this museum acquisition, except for indirect correspondence and personal memorabilia related to the *Goodman Family Archive*¹⁰ preserved at the *Newberry Library* in Chicago. The album was selected for inclusion in the exhibition *Van Dyck, Rembrandt, and the Portrait Print* by Victoria Lobis, the museum cura-

9 *Fifty-two plates Engraved from Portraits by van Dyck and Others, 16th–17th Century*. Album of fifty-two portrait prints, Art Institute of Chicago, Chicago, USA.

10 *Goodman Family Papers, 1795–2003, Bulk, 1880–1995*, Midwest. MS. Goodman Family, Newberry Library – Modern Manuscripts, Newberry Library, Chicago, USA.

tor of prints and drawings, Prince Trust Curator at the *Art Institute of Chicago*. The book and paper conservation laboratory of the museum received it for conservation shortly thereafter.



Figure 12. Vivak book cradles custom designed for the exhibition titled *Van Dyck, Rembrandt, and the Portrait Print* Credits: Malina Belcheva. Courtesy of the Art Institute of Chicago



Figure 13. Selected books prepared for the exhibition titled *Van Dyck, Rembrandt, and the Portrait Print* Credits: Malina Belcheva. Courtesy of the Art Institute of Chicago



Figure 14. Unobtrusive cradles uniquely designed to completely support album structures using minimal material. Book cradles created according to the curator's specific preferences for the opening of the books
Credits: Malina Belcheva. Courtesy of the *Art Institute of Chicago*



Figure 15. A close-up photograph of the album spine, tail, and front cover before the conservation treatment
Credits: Malina Belcheva. Courtesy of the *Art Institute of Chicago*

4.3. Album examination and conservation overview

The first conservation examination of the album binding, text block, and graphic works concluded multiple prior conservation and restoration campaigns. As there were no conservation records at the museum documentation, the time period of the preceding conservation treatments was difficult to be determined. Observations of the binding condition revealed a range of materials applied on the binding covers, spine, and endsheets of the volume implemented by previous conservators during the stabilization of the album structure, its rebinding, and text block repair.

The album included a selected collection of fifty-two of the one hundred cataloged prints of Van Dyck. Their authenticity was confirmed during the latest conservation treatment by the identification of the personal marks of the artists and printers and the paper watermarks corresponding to their production between 1620 and 1641. The album was privately bound with a central Cambridge Panel tooled in gilt in accordance with the representative English style of the late 16th to 17th centuries.

As consequence of the existing repairs, and changes to the album binding structure, for over a period of more than three hundred years, the conservation examination defined the album condition as: *primary*, containing characteristic features related to the original, also first intended binding, and *secondary*, regarding to binding modifications implemented during prior conservation treatments.

Comprehensive technical examination of the album binding, details of the conservation treatment, and in-depth research, including commentaries on Van Dyck's *Iconography series* and identification of his graphic works could be studied in the following publications by the author of this essay: "Remboitage of a Binding: Authenticity and Conservation of Fifty-two Plates Engraved from Portraits by Van Dyck and Others, 16th–17th Century",¹¹ and "Conservation Consideration and Sequence of Treatment for Fifty-two Plates Engraved from Portraits by Van Dyck and Others, 16th–17th Century."¹²

11 Belcheva, Malina. (2021). "Remboitage of a Binding: Authenticity and Conservation of Fifty-two Plates Engraved from Portraits by Van Dyck and Others, 16th–17th Century." *Conservation, Exposition et Restauration d'Objets d'Art Journal*, no. 12, Association CeROArt, Liège, Belgium. Retrieved from <http://journals.openedition.org/ceroart/7138>.

12 Belcheva, Malina. (2021). "Conservation Consideration and Sequence of Treatment for Fifty-two Plates Engraved from Portraits by Van Dyck and Others, 16th–17th Century" in *Book Conservation. One Philosophy - Many Interpretations*. Editors: Georgios Boudalis, Patricia Engel, Elissaveta Mousakova, Flavia Pinzari, Joseph Schiro and Jedert Vodopivec Tomazic, Verlag Berger Horn, Wien, Austria, 257–273.



Figure 16. Photograph of the front cover and spine of the album after conservation
Credits: Malina Belcheva. Courtesy of the Art Institute of Chicago

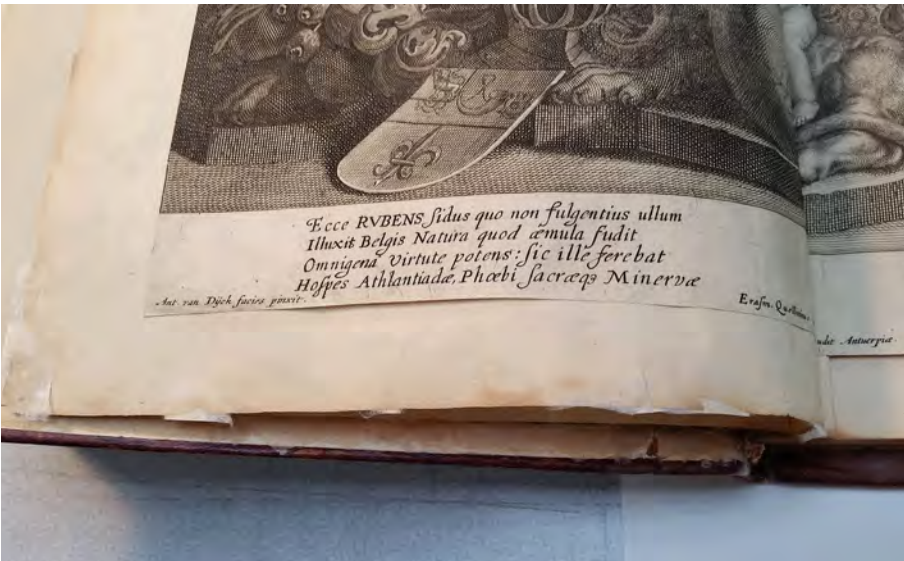


Figure 17. The album during conservation, a close-up of the conservation consolidation of the text block using Tangucho Japanese handmade papers. Visible are Van Dyck graphic prints finely adhered by the collector on their four corners on the verso of the album leaves
Credits: Malina Belcheva. Courtesy of the Art Institute of Chicago

This complex conservation treatment encompasses consolidation and reconstruction of the binding losses, preceded by a compositional analysis of the original and secondary binding materials. Based on extensive conservation studies, stabilizing the album condition enhanced the flexibility and solidity of the binding and successfully integrated historical repairs with contemporary conservation materials. After the conservation treatment, an exhibition cradle was uniquely designed and custom-made using acrylic sheets of Plexiglas to fully support the folio album during the exhibition display.¹³ (Figure 16, 17 and 18)

The graphic diagram displayed in Figure 18 shows the design of the exhibition cradle drawing for the album of intaglio prints by Van Dyck for the exhibition *Van Dyck, Rembrandt, and the Portrait Print*.

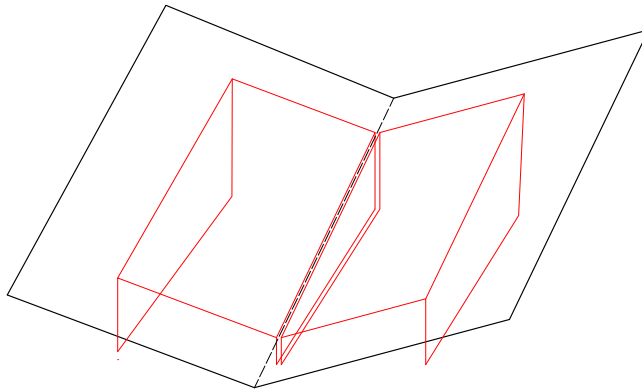


Figure 18. Graphic depicting the exhibition cradle for the folio album *Fifty-two Plates Engraved from Portraits by Van Dyck and Others, 16th–17th Century*
Credits: Malina Belcheva

4.4. Custom design of exhibition supports

*Conservation treatment and exhibition cradle design for the **Ghosts and Demons in Japanese Prints** exhibition at the Art Institute of Chicago*

The historic binding structures of Japanese manuscripts allow a full opening for display during exhibitions. Thus, Plexiglas cradles and supports were designed and created for the *Art Institute of Chicago*'s collection of rare Japanese art books selected for display at the exhibition *Ghosts and Demons in Japanese Prints*.

¹³ Detailed description of the conservation research and treatment can be consulted at Belcheva, Malina. (2021). "Remboitage of a Binding: Authenticity and Conservation of Fifty-two Plates Engraved from Portraits by Van Dyck and Others, 16th–17th Century." *Conservation, Exposition et Restauration d'Objets d'Art Journal*, no. 12, Association CeROArt, Liège, Belgium. Retrieved from <http://journals.openedition.org/ceroart/7138>

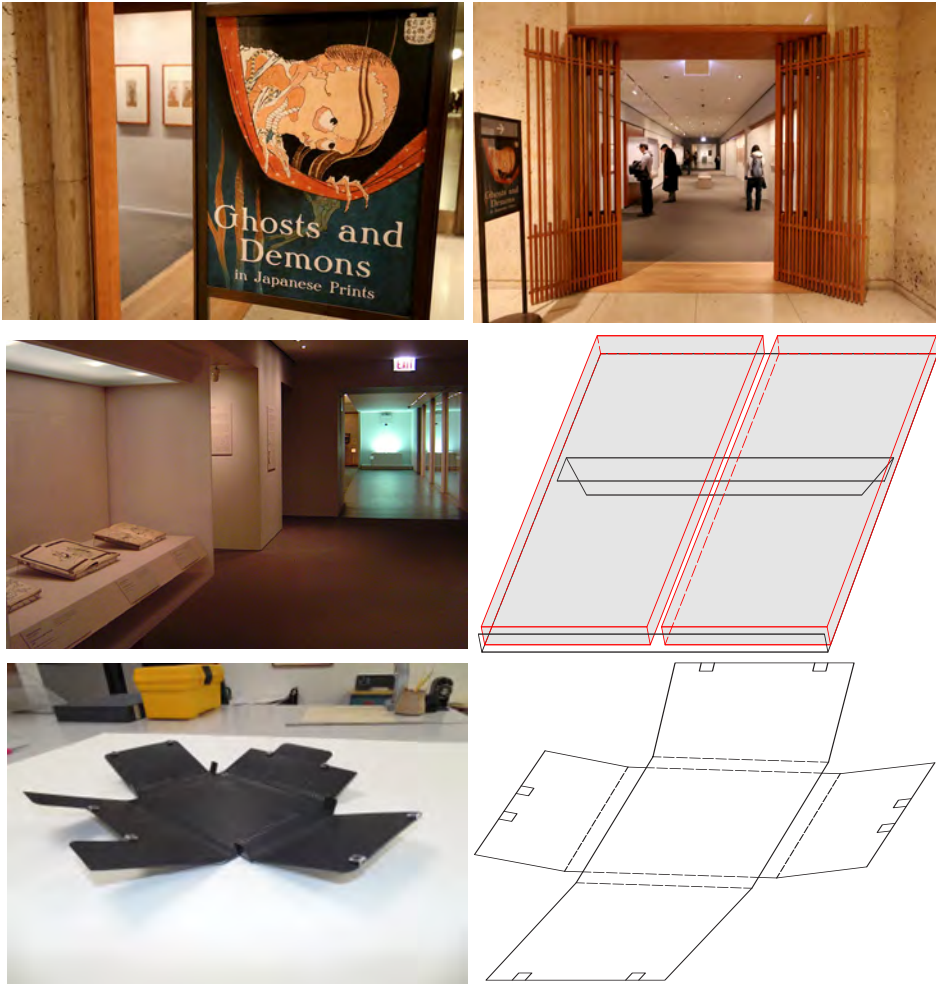


Figure 19. Conservation treatment and exhibition cradle design for the *Ghosts and Demons in Japanese Prints* and *Provoke* exhibitions at the Art Institute of Chicago
Credits: Malina Belcheva. Courtesy of the Art Institute of Chicago

Photographs from the exhibition vitrines of the museum *Japanese Art Galleries* show well-balanced cradles created for the full opening of Japanese bookbindings. The cradles were custom-made from Plexiglas sheets cut to the exact size of the book covers and creased on a metal bending machine (Figure 19).

Stub-bindings denoted the prevailing style of Japanese bookbinding. Both four- and five-hole bindings were common during the Edo period. The four-hole binding style originated from Chi-

nese bookbinding, whereas five-hole bindings were influenced by Korean bookbinding.¹⁴ Text blocks naturally lie flat because the stub-binding holes (usually four or five) were pierced along the spine and the binding thread was sewn through them to connect and compose the binding.

Traditionally, Japanese bindings were printed on handmade paper only on one side. They were folded with the printed text and images on the outside. The fold itself composed the fore-edge of the book, whereas the cut edges were positioned at the binding edge. Therefore, every page of the book was double-leaved and formed an open-ended fold. The covers of the books were made of handmade paper, layers of paper and pasteboard, fiber backed with paper, or fabric-wrapped boards. The text block paper was handmade and produced using long kozo fibers. Therefore, the text blocks were soft and flexible, and it was unnecessary to strap the volumes for display.

*Conservation treatment and exhibition cradle design for oversized folio albums presented at the **Beauty and the Book: 19th and Early 20th Century Folios on the Decorative Art** exhibition at the Art Institute of Chicago*



Figure 20. Overview of the exhibition titled *Beauty and the Book: 19th and Early 20th Century Folios on the Decorative Art* Exhibition at the Art Institute of Chicago
Credits: Malina Belcheva. Courtesy of the Art Institute of Chicago

14 See: Jacobson, Emily. *Cradles for Bound Japanese Books*, Folger Shakespeare Library. <https://www.folger.edu/sites/default/files/Jacobson-Cradles-for-Bound-Japanese-Books.pdf>



Figure 21. The sequence of preparing an exhibition cradle using a foam board covered for aesthetics with the same Japanese Silk textile utilized for the vitrine base layer.

Credits: Malina Belcheva

Important from the conservator's viewpoint is the exhibition design of the supports constructed from a foam board for the oversized folio album collection of decorative art books presented at *Beauty and the Book: 19th and Early 20th Century Folios on the Decorative Art*. The photographs that follow depict the gallery view of the exhibition and the exhibition supports covered with Japanese silk. (Figure 20 and 21).

The author has published extensive research findings and details about the conservation treatment of *The Psalms of David. The Victoria Psalter* album binding created by Owen Jones

in 1861, and published by the author at *Unveiling Secrets of the Trade: Owen Jones and the Relievo Art of The Psalms of David*, and at *Innovative Design and Experimental Structures in Victorian Design Binding (1800–1900)–Technology and Conservation of Relievo Papier-mâché Binding by Owen Jones for The Psalms of David (The Victoria Psalter)*.¹⁵

Conservation treatment and exhibition cradle design for a historic gold leaf presented at Ireland: Crossroads of Art and Design, 1690–1840 exhibition at the Art Institute of Chicago



Figure 22. Gold leaf display next to period reproductions of Trevor Lloyd's Irish bookbinding and Philip Maddock's personal finishing tools
Credits: Malina Belcheva. Courtesy of the Art Institute of Chicago

Figure 22 depicts the exhibition installation of an unusual museum object, a gold leaf¹⁶. A single gold leaf was taken from a historic gold leaflet book and displayed in an acrylic vitrine. The gold leaflet book belonged to collector and exhibition patron Philip Maddock.¹⁷

- 15 Belcheva, Malina. (2022). "Unveiling Secrets of the Trade: Owen Jones and the Relievo Art of The Psalms of David" in *Suave Mechanicals: Essays on the History of Bookbinding*. Editor: Julia Miler, Vol. 7, The Legacy Press, Ann Arbor, MI, USA, 78–108, and Belcheva, Malina. (2022). *Innovative Design and Experimental Structures in Victorian Design Binding (1800–1900)–Technology and Conservation of Relievo Papier-mâché Binding by Owen Jones for The Psalms of David. The Victoria Psalter* (in Bulgarian), St. Kliment Ohridski University Press, Sofia, Bulgaria. 464 pp.
- 16 *Mechanical Production. Gold Leaf Restoration and Gilding with Gold Leaf* by Giusto Manetti Battiloro. Florence, Italy; <http://www.manetti.com/>
- 17 Maddock, Philip. (2015) "Irish Bookbinding" in *Ireland: Crossroads of Art and Design, 1690–1840*, Edited by William Laffan and Christopher Monkhouse with the assistance of Leslie Fitzpatrick, The Art Institute of Chicago, UK, p. 200–205.

Curated by Christopher Monkhouse and Leslie Fitzpatrick, the *Ireland: Crossroads of Art and Design, 1690–1840* exhibition at the *Art Institute of Chicago* dedicated the central part of ten *Regenstein Hall Galleries* to the art of bookbinding. Ireland’s finest craftsmanship was presented by an array of forty 18th-century bindings by Parliamentary Binder, John Baskerville, Hugh Maffett, Samuel Watson, Boulter Grierson, Joseph Leathley, and Abraham King. This exhibition also showcased exquisitely crafted period reproductions of Irish bookbindings by Trevor Lloyd.

Unaware of the unstable properties of the gold leaf produced for bookbinding, the exhibition curators planned its installation in a didactic vitrine. Several factors should have been considered for the successful realization of this unusual installation. The gold leaf lightweight and extremely delicate; characteristics incited the decision the leaf to be underlined with Japanese tissue for additional stability and thickness, through which it adhered to the vitrine surface. The installation outline and sequence of treatment and preparation of the gold leaf for display are published by the author in “A Gold Leaf Installation,” an essay that includes commentaries on the selection of adhesives and experimental processes for the gold leaf underlining technique (see Figure 23).

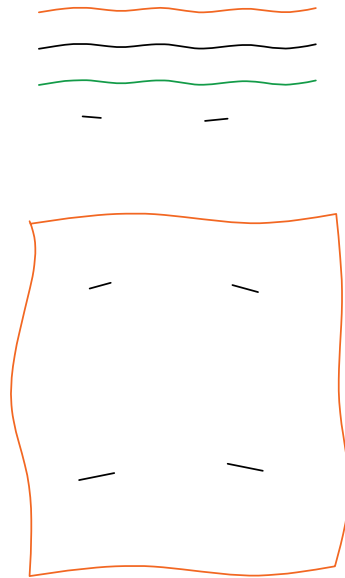


Figure 23. Graphic depicting the exhibition support of the historic gold leaf for *Ireland: Crossroads of Art and Design, 1690–1840*

Credits: Malina Belcheva



Figure 24. Close-up view of bookbindings created by Parliamentary Binder, John Baskerville, Hugh Maffett, Samuel Watson, Boulter Grierson, and Joseph Leathley
Credits: Malina Belcheva. Courtesy of the *Art Institute of Chicago*



Figure 25. Installation of *Le Antichita Romane* at *Demesne Gallery* featuring a frontispiece engraved by Giovanni Battista Piranesi with a view of a punch bowl racing trophy designed by William Williamson II and engraved by Daniel Pomarede
Credits: Malina Belcheva. Courtesy of the *Art Institute of Chicago*

5. Case construction and display conditions

The essential requirements for constructing exhibition vitrines for the display of books and paper materials stipulate that:

Materials for the construction of exhibition vitrines should be tested before installation. PH-neutral cloth, paper, adhesives, and sealants should be used. Fabrics should be tested for “off-gassing.” The selection of materials for the construction of exhibition vitrines is vital because the substances used could increase the aging rates of the displayed artworks if proven unsafe for them.

The **temperature and humidity** in the exhibition vitrines must be controlled, observed, and recorded during the exhibition.

Documenting the exhibited book and paper objects is an important facet of the exhibition process.

Air conditioning and humidification or dehumidification are considered necessary to protect collections from environmental changes. **Silica gel**¹⁸ may be added to the exhibition vitrines to ensure local control of humidity to the desired RH.

Light levels must be maintained as low as possible in the galleries. All light is damaging. Therefore, low levels of lighting must be ensured in areas where paper materials are exhibited. Most collection materials can be displayed without any visible fading for three to four months at 50 to 150 lux. Lower light levels are mandated for light-sensitive materials such as watercolors, photographs, and prints. Materials without color (printed text, black and white photographs, carbon black ink manuscripts, etc.) can be exhibited at up to 150 lux.¹⁹

Exhibition vitrines should be enclosed, sealed, and composed of materials that will not damage their contents. Some exhibition vitrines can be fitted with ventilation systems or undersurface compartments designed to hold silica gel to partially control humidity.

Barrier sheets should be prepared for every displayed object and placed between the object and the vitrine surface. This protective layer may be composed of polyester films such as Mylar or a polyethylene foam sheet that can protect the exhibited objects from harmful acid transfers from one material to another. (Figure 24, 25 and 26).

18 See: Weintraub, Steven. (2002). *Demystifying Silica Gel - Cultural Heritage*. The American Institute for Conservation of Historic & Artistic Works, Objects Specialty Group Postprints, Volume 9. 169–194.

19 See: American Institute for Conservation. *Exhibition Standards and Guidelines*; Canadian Conservation Institute. *Display Methods for Books*. CCI Notes 11/8 (1994).



Figure 26. Photograph taken during the preparations for the exhibition titled *Ireland: Crossroads of Art and Design, 1690–1840*. The museum display case was designed by *Goppion Technology*. Credits: Malina Belcheva. Courtesy of the *Art Institute of Chicago*

6. Exhibition documentation

Condition reports and proposals for the conservation treatment of objects considered for exhibition should contain a brief comprising

- the **bibliographic information**
- the **provenance of the object**
- the **physical characteristics of the object**, including a description of its present condition

If the object is a book, the condition report should include details such as the type of binding, binding cover, attachment process, sewing, text block structure, and support or backing.

The conservation treatment proposal should include considerations for cleaning, consolidation, treatment, housing, construction of cradles, supports, and specific conditions for display. The proposal should conclude with recommendations for future preservation: for instance, advice for digitization and guidelines for future exhibitions. The suggestions should specify requirements for aspects such as page opening and book display angles. (Figure 27 and 28).



Figure 27. Preparing condition reports for the exhibition titled *Ireland: Crossroads of Art and Design, 1690–1840*
Credits: Malina Belcheva. Courtesy of the Art Institute of Chicago



Figure 28. An overview of the exhibition *Ireland: Crossroads of Art and Design, 1690–1840*
Credits: Malina Belcheva. Courtesy of the Art Institute of Chicago

7. Publications and presentations by the author

The author has published and presented selected reference materials at conferences held at the *American Institute for Conservation* (AIC, USA), the *Institute of Conservation* (ICON, UK), and the *Dubrovnik Research Library International Conference* (Dubrovnik, Croatia). These presentations and publications entailed advanced research on the conservation of books and objects and the preparation of exhibition cradles for exhibits in museums:

Belcheva, Malina. (2022). *Unveiling Secrets of the Trade: Owen Jones and the Relievo Art of The Psalms of David*. Suave Mechanicals: Essays on the History of Bookbinding, Vol. 7, The Legacy Press, Editor: Julia Miler, Ann Arbor, MI, USA, 78-108.

Belcheva, Malina. (2022). *Innovative Design and Experimental Structures in Victorian Design Binding (1800-1900) – Technology and Conservation of Relievo Papier-mâché Binding by Owen Jones for The Psalms of David. The Victoria Psalter*. (In Bulgarian: *Иновативен дизайн и експериментални структури във викторианската книга (1800–1900) – технология и реставрация на релефен дизайн подвързия на Оуен Джоунс за “Псалмите на Давид. Псалтир на Викториа”*), “St. Kliment Ohridski” University Press, Sofia, Bulgaria, 464 pp.

Belcheva, Malina. (2021). *Remboitage of a Binding: Authenticity and Conservation of Fifty-two Plates Engraved from Portraits by Van Dyck and Others, 16th - 17th Century*. Conservation, Exposition et Restauration d’Objets d’Art Journal, no. 12, Association CeROArt, Liège, Belgium. <http://journals.openedition.org/ceroart/7138>

Belcheva, Malina. (2018). *A Gold Leaf Installation*. ICON News. The Magazine of the Institute of Conservation, Issue 77, Institute of Conservation, Taylor & Francis Group, London, UK. 32-33.

Belcheva, Malina. (2017). *A Novel Conservation Treatment Developed for the Restoration of The Psalms of David Relievo Papier-mâché Binding Designed by Owen Jones*. Annual Conference - Treatment 2017: Innovation in Conservation and Collection Care, American Institute of Conservation of Historic and Artistic Works National Conference, Presentation and poster for the conservation of the book “The Psalms of David,” American Institute for Conservation of Historic and Artistic Works, Chicago IL, USA. DOI: 10.13140/RG.2.2.35437.59361

Belcheva, Malina. (2012) *Beauty and the Book: 19th and Early 20th Century Folios on the Decorative Arts*. The Art Institute of Chicago, Ryerson & Burnham Library, Chicago, IL, USA. DOI: 10.13140/rg.2.2.36158.48966, <<https://archive.artic.edu/ryerson/beauty-book/>>

8. Exhibitions at the Art Institute of Chicago

Van Dyck, Rembrandt, and the Portrait Print, Curator Dr. Victoria Lobis, <https://www.artic.edu/exhibitions/2281/van-dyck-rembrandt-and-the-portrait-print>

Ireland: Crossroads of Art and Design, 1690–1840, Curator Christopher Monkhouse, <https://www.artic.edu/exhibitions/1768/ireland-crossroads-of-art-and-design-1690-1840>

What May Come: The Taller de Gráfica Popular and the Mexican Political Print, Curator Diane Miliotes, <https://www.artic.edu/exhibitions/1906/what-may-come-the-taller-de-grafica-popular-and-the-mexican-political-print>

Beauty and the Book: 19th and Early 20th Century Folios on the Decorative Arts, Curator Dr. Malina Belcheva, <https://archive.artic.edu/ryerson/beauty-book/>
(Figure 29)



Figure 29. Documentary photograph taken from the entrance of the *Art Institute of Chicago* in the 1900s
Credits: *The Art Institute of Chicago*

9. Reference materials

Additional information on protecting paper and book collections during exhibitions and materials on the subject may be consulted at

American Institute for Conservation. Exhibition Standards and Guidelines. https://www.conservation-wiki.com/wiki/Exhibition_Standards_%26_Guidelines

Canadian Conservation Institute. Low-Cost Plastic/Aluminum Barrier Foil. *CCI Notes 1/9* (2010). <https://www.canada.ca/content/dam/cci-icc/documents/services/conservation-preservation-publications/canadian-conservation-institute-notes/1-9-eng.pdf?WT.contentAuthority=4.4.10>

Canadian Conservation Institute. Display Methods for Books. *CCI Notes 11/8* (1994). <https://www.canada.ca/content/dam/cci-icc/documents/services/conservation-preservation-publications/canadian-conservation-institute-notes/11-8-eng.pdf?WT.contentAuthority=4.4.10>

NEDCC. Preservation Leaflet 2.2 Monitoring Temperature and Relative Humidity 2012. <https://www.nedcc.org/free-resources/preservation-leaflets/2.-the-environment/2.2-monitoring-temperature-and-relative-humidity>

NEDCC. Preservation Leaflet 4.10 Matting and Framing for Works on Paper and Photographs, 2019.

<https://www.nedcc.org/free-resources/preservation-leaflets/4.-storage-and-handling/4.10-matting-and-framing-for-works-on-paper-and-photographs>

Jean Tétreault. Products Used in Preventive Conservation – Technical Bulletin 32, Ottawa: Canadian Conservation Institute.

<https://www.canada.ca/en/conservation-intitute/services/conservation-preservation-publications/technical-bulletins/products-used-preventive-conservation.html#a3a>

Websites

NEDCC: Preservation Leaflets Section 2 (Environment) <https://www.nedcc.org/free-resources/preservation-leaflets/overview>

National Park Service: Museum Handbook Chapter 4 (Museum Collections Environment) <https://www.nps.gov/museum/publications/MHI/chap4.pdf>

Library of Congress Collections Care: Limiting Light Damage from Display and Exhibition <https://www.loc.gov/preservation/care/light.html>

South East Museum Development Programme: Environmental Monitoring <http://southeastmuseums.org/conservation-advice-environmental-monitoring>

Minnesota Historical Society: Getting a Handle on the Museum Environment <http://www2.mnh.s.org/about/publications/techtalk/TechTalkMarch1999.pdf>

NEDCC: Preservation 101 Section 2 – The Building and Environment <https://www.nedcc.org/preservation101/session-2>

American Museum of Natural History: Light, Ultraviolet and Infrared <http://www.amnh.org/our-research/natural-science-collections-conservation/generalconservation/preventive-conservation/light-ultraviolet-and-infrared/>

Connecting to Collections Care: Webinars and Forums www.connectingtocollections.org

10. Conclusion

The rapid development of exhibition design offers unique opportunities for museum conservation practices. This conservation essay presented an exclusive behind-the-scenes view of continuously growing possibilities for exhibition installations. It thus constitutes a written record of the considerations and decisions mandated to undertake the conservation treatment of books and objects for display. The author offered written and photographic documentation of accomplished conservation treatments to reveal the multidisciplinary functioning of museum exhibitions. This record provides the reader with an exceptional perspective on some of the most significant exhibitions held at the *Art Institute of Chicago*. In so doing, it intends to inspire contemporary discussions on advancements in conservation practices and exhibition design. Such a discourse would consequently evolve into a transformative force for innovations in the field of book and paper conservation.

The author expresses gratitude to the *Art Institute of Chicago*, exhibition curators Dr. Victoria Lobis, Christopher Monkhouse, Dr. Leslie Fitzpatrick, Diane Miliotes, and conservators Deborah Howe and Lesa Dowd for their continued support during exhibition preparation and the conservation treatment of unique books and objects for the museum's beautifully designed exhibitions.

Permissions

Cuauhtemoc, portfolio cover for *450 años de lucha: Homenaje al pueblo mexicano (450 Years of Struggle: Tribute to the Mexican People)*, linocut gravure by Adolfo Quinteros, album of 146 graphic artworks published by *Taller de Gráfica Popular*, Mexico, 1960; *Fifty-two Plates Engraved from Portraits by Van Dyck and Others, 16th–17th Century; The Psalms of David. The Victoria Psalter*. Illumination and relieve binding by Owen Jones, London, 1861, collection of the *Ryerson and Burnham Libraries* of the *Art Institute of Chicago*; conservation and photography by Dr. Malina Belcheva.

References

- Adapted from NEDCC. (2012). *Preservation Leaflet 2.4 Protection from Light Damage*. <https://www.nedcc.org/free-resources/preservation-leaflets/2.-the-environment/2.4-protection-from-light-damage>
- American Institute for Conservation. *Exhibit Fabrication: 1.1.2 Wood, Plywood and Wood Composite Boards*. https://www.conservation-wiki.com/wiki/Category:Exhibit_Fabrication
- American Institute for Conservation. *Oddly Tests: Materials Databases*. https://www.conservation-wiki.com/wiki/Oddly_Tests:_Materials_Databases

- American Institute for Conservation. *Exhibition Standards and Guidelines*. https://www.conservation-wiki.com/wiki/Exhibition_Standards_%26_Guidelines
- American Museum of Natural History: *Light, Ultraviolet and Infrared*. <http://www.amnh.org/our-research/natural-science-collections-conservation/generalconservation/, preventive-conservation/light-ultraviolet-and-infrared/>
- Art Preservation Services. *Silica Gel Quantity Recommendation*. <https://www.apsnyc.com/demistifying-silica-gel>
- Association of College & Research Libraries. (2012). *ACRL/RBMS Guidelines For Interlibrary And Exhibition Loan Of Special Collections Materials*. <http://www.ala.org/acrl/standards/specialcollections>
- Avila, M. T. (2013). *Chronicles of Revolution and Nation: El Taller de Gráfica Populares 'Estampas de la Revolución Mexicana'* (Doctoral dissertation). Submitted in Partial Fulfillment of the Requirements for the Degree of Doctorate of Philosophy, Art History, The University of New Mexico, Albuquerque, New Mexico. Retrieved from https://digitalrepository.unm.edu/arthritis_etds/7
- Ballofet, N., & Hille, J. (2004). *Small Exhibitions*. In - *Preservation and Conservation for Libraries and Archives*. Chicago: American Library Association.
- Belcheva, M. (2018). *A Gold Leaf Installation*. ICON News. The Magazine of the Institute of Conservation, Issue 77, Institute of Conservation, Taylor & Francis Group, London, UK, August, 32–33.
- Belcheva, M. (2017). *A Novel Conservation Treatment Developed for the Restoration of The Psalms of David Relievo Papier-mâché Binding Designed by Owen Jones*. Annual Conference - Treatment: Innovation in Conservation and Collection Care, American Institute of Conservation of Historic and Artistic Works National Conference, Presentation and poster for the conservation of the book *The Psalms of David*, American Institute for Conservation of Historic and Artistic Works, Chicago IL, USA, May 2017. DOI: 10.13140/RG.2.2.35437.59361
- Belcheva, M. (2012). *Beauty and the Book: 19th and Early 20th Century Folios on the Decorative Arts*. The Art Institute of Chicago, Ryerson & Burnham Library, Chicago, IL, USA. [DOI: 10.13140/rg.2.2.36158.48966], < <https://archive.artic.edu/ryerson/beauty-book/> >
- Belcheva, M. (2021). *Conservation Consideration and Sequence of Treatment for Fifty-two Plates Engraved from Portraits by Van Dyck and Others, 16th - 17th Century*. In the book: *Book Conservation. One Philosophy - Many Interpretations*, Editors: Georgios Boudalis, Patricia Engel, Elissaveta Mousakova, Flavia Pinzari, Joseph Schiro and Jedert Vodopivec Tomazic, Verlag Berger Horn, Wien, Austria, 257–273.
- Belcheva, M. (2022). *Innovative Design and Experimental Structures in Victorian Design Binding (1800-1900) – Technology and Conservation of Relievo Papier-mâché Binding by Owen Jones for The Psalms of David. The Victoria Psalter*. (In Bulgarian: *Иновативен дизайн и експериментални структури във викторианската книга (1800–1900) – технология и реставрация на релефен дизайн подвързия на Оуен Джоунс за "Псалмите на Давид. Псалтир на Виктория"*), "St. Kliment Ohridski" University Press, Sofia, Bulgaria, (464 pp.).
- Belcheva, M. (2020). *On the Study and Conservation of Fifty-two Plates Engraved from Portraits by Van Dyck and Others*. Guild of Book Workers Newsletter, no. 253, December, New York, NY, 14-18.
- Belcheva, M. (2021). *Remboitage of a Binding: Authenticity and Conservation of Fifty-two Plates Engraved from Portraits by Van Dyck and Others, 16th - 17th Century*. *Conservation, Exposition et Restauration d'Objets d'Art Journal*, no. 12, Association CeROArt, Liège, Belgium. Retrieved from <http://journals.openedition.org/ceroart/7138>
- Belcheva, M. (2022). *Unveiling Secrets of the Trade: Owen Jones and the Relievo Art of The Psalms of David*. In the book: *Suave Mechanicals: Essays on the History of Bookbinding*. Editor: Julia Miler, Vol. 7, The Legacy Press, Ann Arbor, MI, USA, 78-108
- Bell, N., & C. Clarkson. (2001). *Personal and professional reflections: A conversation with Christopher Clarkson*. *The Paper Conservator*, 25, 71-84

- Blaser, L. (1996). *Construction of Plexiglas Cradles*. The Book and Paper Group Annual. Washington, DC: American Institute for Conservation of Historic and Artistic Works, p. 3–23.
- Shahani, C.J. (1995). Aging of Paper Sealed within Polyester Film. In - *Accelerated Aging of Paper: Can it Really Foretell the Permanence of Paper*. Preservation Research and Testing Series No.9503. Washington, D.C.: Library of Congress, November. <https://www.loc.gov/preservation/resources/rt/AcceleratedAging.pdf>
- Campagnolo, A. (2015). *Transforming Structured Descriptions to Visual Representations. An Automated Visualization of Historical Bookbinding Structures*. Doctoral Thesis, University of the Arts London, London, UK.
- Canadian Conservation Institute. *Low Cost Plastic/Aluminum Barrier Foil*. CCI Notes 1/9 (2010). <https://www.canada.ca/content/dam/cci-icc/documents/services/conservation-preservation-publications/canadian-conservation-institute-notes/1-9-eng.pdf?WT.contentAuthority=4.4.10>
- Canadian Conservation Institute. Display Methods for Books. (1994). CCI Notes 11/8 . <https://www.canada.ca/content/dam/cci-icc/documents/services/conservation-preservation-publications/canadian-conservation-institute-notes/11-8-eng.pdf?WT.contentAuthority=4.4.10>
- Carter, J. (1972). *A B C for book collectors*. 5th ed., Hart Davis, London, UK.;
- Carter, J. (2004). ABC for Book Collectors, 8th ed. ed., Oak Knoll Press, British Library, New Castle, London, UK.
- Connecting to Collections Care: *Webinars and Forums*. www.connectingtocollections.org
- Craddock, Anne Brooke. (1992). *Construction Materials for Storage and Exhibition*. In - Conservation Concerns: A Guide for Collectors and Curators. K. Bachmann, ed. Washington: Smithsonian Institution, pp. 23–28
- Emery, J. A. (1861). *Technical Report: Structural Wood Panels and Formaldehyde*. Tacoma, WA: American Plywood Association, 2002. https://www.roseburg.com/UserFiles/Library/APA_Tech_Bulletin_on_Formaldehyde.pdf
- Jones, Owen. *The Psalms of David. The Victoria Psalter*. Illuminations and relieve binding by Owen Jones, Day and Son, London, UK.
- Etherington, D., & Roberts, M. (1982). *Bookbinding and the Conservation of Books. A Dictionary of Descriptive Terminology*. Library of Congress, Washington, DC, US. Exhibitions at the *Art Institute of Chicago*:
- Van Dyck, Rembrandt, and the Portrait Print*, Curator Dr. Victoria Lobis, <https://www.artic.edu/exhibitions/2281/van-dyck-rembrandt-and-the-portrait-print>
- Ireland: Crossroads of Art and Design, 1690–1840*, Curator Christopher Monkhouse, <https://www.artic.edu/exhibitions/1768/ireland-crossroads-of-art-and-design-1690-1840>
- What May Come: The Taller de Gráfica Popular and the Mexican Political Print*, Curator Diane Miliotes, <https://www.artic.edu/exhibitions/1906/what-may-come-the-taller-de-grafica-popular-and-the-mexican-political-print>
- Beauty and the Book: 19th and Early 20th Century Folios on the Decorative Arts*, Curator Dr. Malina Belcheva, <https://archive.artic.edu/ryerson/beauty-book/>
- Exquisite & Rare*. Exhibition curated by Philip Maddock with Jason McElligott, Keeper and Julia Cummins, Librarian at Farmleigh, Marsh’s Library, Dublin, Ireland. <http://www.marshlibrary.ie/digi/collections/show/175>; <http://www.marshlibrary.ie/digi/>
- Fifty-two plates engraved from portraits by Van Dyck and others, 16th – 17th century. Album of fifty-two portrait prints, The Art Institute of Chicago, Chicago, IL, US.
- For more information about packing, see NEDCC. (2020). “Preservation Leaflet 4.5 Packing and Shipping Paper Artifacts,”. <https://www.nedcc.org/free-resources/preservation-leaflets/4.-storage-and-handling/4.5-packing-and-shipping-paper-artifacts>
- Goodman Family Papers, 1795–2003, Bulk, 1880–1995, Midwest.MS.Goodman Family, The Newberry Library–Modern Manuscripts, Newberry Library, Chicago, IL, US.

- Grattan, D., & Michalski, S. (2020). "Environmental guidelines for museums." Ottawa: Canadian Conservation Institute, modified 2017-09-21. Accessed December 23, 2020. <https://www.canada.ca/en/conservation-institute/services/preventive-conservation/environmental-guidelines-museums.html>
- Hatchfield, P., & Carpenter, J. (1987). *Formaldehyde: How Great is the Danger to Museum Collections?* Cambridge, MA: Center for Conservation and Technical Studies, Harvard University Art Museums, pp. 44.
- Hatchfield, P. (1994). *Choosing Materials for Museum Storage*. In - *Storage of Natural History Collections: Basic Concepts*, Carolyn L. Rose and Catherine A. Hawks, eds. Pittsburgh, PA: Society for the Preservation of Natural History Collections.
- Herskovitz, R. Minnesota Historical Society. Personal communication. P. Hatchfield.
- Hind, A. (1915). *Van Dyck his Original Etchings and His Iconography*. Houghton Mifflin Company, Museum of Fine Arts, Boston, US, 12.
- Horton, R. (1994). *Photo Album Structures, 1850-1960*. Guild of Book Workers Journal XXXII, No. 1, Spring 1994, N: 32, 1994, New York, NY, USA, 33 – 43.
- Holland, J., & Mcfarlane, C. The exhibition life of a book, Challenges of space and material.
- Jean Tétrault. *Products Used in Preventive Conservation – Technical Bulletin 32*, Ottawa: Canadian Conservation Institute. <https://www.canada.ca/en/conservation-institute/services/conservation-preservation-publications/technical-bulletins/products-used-preventive-conservation.html#a3a>
- Ludwig, K. *National Archives and Records Administration. Personal communication*.
- Library of Congress Collections Care: *Limiting Light Damage from Display and Exhibition* <https://www.loc.gov/preservation/care/light.html>
- Ligatus Project, *The Language of Bindings Thesaurus (LoB)*, University of the Arts London, London, UK.
- Lobis, V. (2016). *Van Dyck's Legacy. The Artists as subject and the vitality of the portrait print*. In: Lobis, Victoria with an essay by Maureen Watten. *Van Dyck, Rembrandt, and the Portrait Print*, The Art Institute of Chicago, Yale University Press, New Haven and London, NH, US.
- Lull, W. P., & Merk, L. (1980). *Preservation Aspects of Display Lighting*. Electrical Consultant (November-December): 8, 9, 12, 14, 20, 39.
- Lull, W. P., with the assistance of Paul N. Banks. *Conservation Environmental Guidelines for Libraries and Archives*. Albany, NY: New York State Library Division of Library Development, 1990, 87.
- Maddock, P. *Irish Bookbinding*. - In: *Ireland: Crossroads of Art and Design, 1690–1840*, Edited by William Laffan and Christopher Monkhouse with the assistance of Leslie Fitzpatrick, The Art Institute of Chicago, p. 200-205.
- Maddock, P. *Irish Bookbinding: a Timeline of Design and Materials*. <https://www.youtube.com/watch?v=JV-CAYbkuti8>
- Maxon, J. (1983). *The Art Institute of Chicago*. Thames and Hudson, London, UK.
- Mechanical Production. *Gold Leaf Restoration and Gilding with Gold Leaf by Giusto Manetti Battiloro*. Florence, Italy; <http://www.manetti.com/>
- Miliotes, D. (2014) *What May Come. The Taller the Grafica Popular and the Mexican Political Print*, The Art Institute of Chicago, Yale University Press, Canada.
- Minnesota Historical Society: *Getting a Handle on the Museum Environment* <http://www2.mnhs.org/about/publications/techtalk/TechTalkMarch1999.pdf>
- Murphy, J. (2014). *Collective Brilliance*. Review of "What May Come: The Taller de Gráfica Popular and the Mexican Political Print"; What May Come: the Taller de Gráfica Popular and the Mexican Political Print, by D. Miliotes. *Art in Print*, 4(4), 50–51. Retrieved from <http://www.jstor.org/stable/43045715>.
- National Park Service. *Choosing UV Filtering Window Films. Conserv O Gram 3/10* (September 2001, updated August 2004), 6pp. <https://www.nps.gov/museum/publications/conservoogram/03-10.pdf>

- National Park Service. *Safe Plastics and Fabrics for Exhibit Storage*. Conserv O Gram 18/2 (August 2004), 7, <https://www.nps.gov/museum/publications/consveogram/18-02.pdf>
- National Park Service. *Using Silica Gel in Microenvironments*. Conserv O Gram 1/8 (1999). <https://www.nps.gov/museum/publications/consveogram/01-08.pdf>
- National Park Service: Museum Handbook Chapter 4 (Museum Collections Environment) <https://www.nps.gov/museum/publications/MHI/chap4.pdf>
- NEDCC. Leaflet 2.5: Protecting Paper and Book Collections During Exhibition. www.nedcc.org MUSEUM EXHIBITIONS: INNOVATIONS 108 FOR THE CONSERVATION OF BOOKS AND OBJECTS FOR...
- NEDCC. *Preservation Leaflet 2.2 Monitoring Temperature and Relative Humidity*. 2012. <https://www.nedcc.org/free-resources/preservation-leaflets/2.-the-environment/2.2-monitoring-temperature-and-relative-humidity>
- NEDCC. *Preservation Leaflet 4.10 Matting and Framing for Works on Paper and Photographs*. 2019. <https://www.nedcc.org/free-resources/preservation-leaflets/4.-storage-and-handling/4.10-matting-and-framing-for-works-on-paper-and-photographs>
- NEDCC. *Preservation Leaflet 2.2 Monitoring Temperature and Relative Humidity* 2012. <https://www.nedcc.org/free-resources/preservation-leaflets/2.-the-environment/2.2-monitoring-temperature-and-relative-humidity>
- NEDCC. *Preservation Leaflet 4.10 Matting and Framing for Works on Paper and Photographs*. 2019. <https://www.nedcc.org/free-resources/preservation-leaflets/4.-storage-and-handling/4.10-matting-and-framing-for-works-on-paper-and-photographs>
- NEDCC: Preservation 101 Section 2 – The Building and Environment. <https://www.nedcc.org/preservation101/session-2>
- NEDCC: Preservation Leaflets Section 2 (Environment). <https://www.nedcc.org/free-resources/preservation-leaflets/overview>
- Nicholson, C. (1993). *What Exhibits Can Do to Your Collection*. Restaurator 13(3), 95–113.
- Peachey, S. J. (2013). *Beating, Rolling, and Pressing: The Compression of Signatures in Bookbinding Prior to Sewing*. Suave Mechanicals: Essays on the History of Bookbinding. Editor: Julia Miler, Vol. 1, The Legacy Press, MA, USA.
- Posada, J. (2012). *Posada's Popular Mexican Prints*. Dover Pictorial Archive. Dover.
- Registrars Committee of the American Association of Museums, *Standard Facility Report – United States*, 1988. <https://static1.squarespace.com/static/58a5dc6cb3db2b9edd19c676/t/590e3923414fb521f0402aba/1494104356487/1998StandardFac.pdf>. Summary available from ACRL/RBMS, ACRL/RBMS Guidelines For Interlibrary And Exhibition Loan Of Special Collections Materials, Appendix II: AAM General Facility Report. 2012. <http://www.ala.org/acrl/standards/specialcollections#standard>
- Rhodes, B. (1990). *Hold Everything!: a storage and housing information sourcebook for libraries and archives*. New York, NY: Metropolitan Reference and Research Library Agency, pp. 63.
- Rutherston, J. (1999). *Victorian Album Structures*. The Paper Conservator, Taylor & Frances, 23(1), London, UK, 13 – 25.
- Shenton, H. (1997). Developments in the display books at the Victoria and Albert Museum. The Paper Conservator 21, 63-79.
- Smith, M. (1981). *Matting and Hinging Works of Art on Paper*. Washington, DC: Library of Congress, pp. 32. <https://www.loc.gov/preservation/care/SmithBrown.PDF>
- South East Museum Development Programme: Environmental Monitoring <http://southeastmuseums.org/conservation-advice-environmental-monitoring>
- Spicer, G. (2019). *Magnetic Mounting Systems for Museums & Cultural Institutions*. Spicer Art Books, Delaware, USA.

- Taller de Gráfica Popular. (1960). 450 años de lucha: Homenaje al pueblo mexicano (450 Years of Struggle: Tribute to the Mexican People), Taller de Gráfica Popular, Mexico City, Mexico.
- Thomson, G. (1978). *The Museum Environment*. Boston, MA: Butterworth, rev. 1986, pp. 293.
- Watteeuw, L. (2013). *Books in Exhibitions: History and Adventures in Display*. Graphic Paper Conservation: Decisions & Compromises. ICOM-CC Graphic Documents Working Group Interim Meeting, Vienna, Austria.
- Weintraub, S. (2002). *Demystifying Silica Gel*. Objects Specialty Group Postprints, Volume Nine, 169-194. <http://resources.culturalheritage.org/osg-postprints/wp-content/uploads/sites/8/2015/02/osg009-12.pdf>
- William P. L. (1992). Selecting Fluorescent Lamps for UV Output. *Abbey Newsletter*; 16(4), pp. 54.

CHAPTER 5

FROM THE CAVE TO THE CANVAS “KEEPING THE ANCIENT ART OF ROGAN SILK PAINTING ALIVE”

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Abstract

The Bamiyan Valley's cultural landscape and archaeological sites are a testament to Buddhism's artistic and religious evolution. The Bamiyan valley marked the most westerly point of Buddhist expansion and was once a crucial hub for travellers and trade. Its caves are home to the earliest known oil paintings dating to 650 CE, where scientists also documented traces of resins and numerous ochres, just as one would find in any modern-day artist's studio. While the Monks of these art studios applied their oil paints to the walls, this period was also the peak of the Silk Road trade and no doubt there was significant artistic experimentation with oils on textiles such as silk. Evidence of the expansion of oil painting can be found nearby within the Afridi tribal arts. The Afridi are the oldest Pashtun tribe in the region, and they have occupied the mountainous areas straddling Afghanistan and Khyber Pakhtunkhwa, Pakistan, long before the arrival of Islam. Their oil painting technique is referred to as “Rogan Silk Painting” (‘Rogan’ is the Persian word for ‘Oil’). They were once well known in the marketplace for their artistic oil-based block-printed Afridi Lac Cloth. While the Afridi no longer practice this tribal art, the technique remains in the region with one local family of Rajput descent from the old Silk Roads city of Peshawar. The Ahmad family has a long history of working as Rogan Silk Painters. As artists of old, they travelled widely, painting only the best textiles across this region of South Asia. Rogan painting spread as far east as Gujarat, India, where the Khatri family today continue to produce handmade and printed Rogan Islamic-style art. The Khatri family trace their Rogan heritage back around four hundred years. Today, Rogan art has been revived in India. Yet, in Pakistan, Fayyaz Ahmad is finding it much more challenging to keep this fading art alive. Although his art has gained some international interest, the Rogan painting technique is yet to be fully recognised and preserved in Pakistan. Rogan painting offers a new chapter in the history of oil painting through the journey from the cave to the canvas.

Keywords: Intangible Cultural Heritage, Buddhist Heritage, Rogan Silk Painting, Silk Road Arts, Bamiyan, Peshawar, Gandhāra

1. Introduction

Oil painting is undoubtedly at the apex of the art world in terms of artistic value in the modern day, yet little is known about its true origins. The emergence of oil painting has been widely misunderstood and misattributed throughout history. While it is often identified as an art form of the European renaissance period, its true origin is rarely well-communicated with Asia being the birthplace of oil painting long before Europe. Oil paintings originated in Afghanistan as far back as the 7th century, with the first evidence being documented in Buddhist Bamiyan. The Buddhist cave paintings, murals and sculptures featured natural pigments bound in plant-based oil, gums and saps. Techniques of thinning and blending oils to create varied hues characteristic of oil painting were mastered through the hybridisation of Asian and Persian styles over time. Throughout the centuries, the art form has evolved into what we know today as oil painting, gradually spreading to Europe through the myriad of trade routes. The lessons that local Asian artists drew from their surroundings including the forest, mountains, nature and spiritual world views set oil painting in Asia and Europe on different trajectories. What is central to knowledge is that the arts of Asia and Europe have developed with differing centres of attention. European art focuses on real life, the object, the sense of the artist and time, and detailed and individual expression of moods and emotions. Whereas the focus of Asian art is on a transcendent spirit and movement without constraint and ego. Shade and shadow was not the central concept. Asian arts offers a different space in the painting that provides depth and complexity; it is the emptiness of the real world. It is not designed to be seen through the artist's eyes at a specific time.

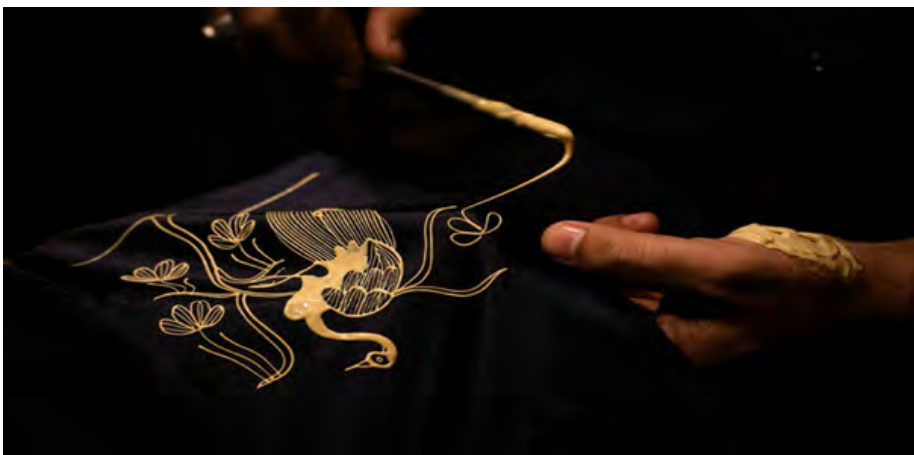


Figure 1. In Roghan Silk Painting, the peacock is one of the most traditional designs

Over 700 years of oil-based art in Asia remains untold, and much more remains to be uncovered. This chapter takes us on a journey through time, revealing part of the story of oil painting through the ancient plant-based oil painting techniques of “*Rogan Silk Painting*.” “*Rogan*” being the Persian word for oil. We begin in the Buddhist Monastic Sanctuaries of Bamiyan, Afghanistan, where the first known plant-based oil paintings were discovered as recent as 2008. These paintings dated to approximately 650 CE, but even more significant is the site itself which is not simply caves but art studios. The 600 CE period was the peak of the Silk Roads trade and the emergence of globalisation through a network of trade routes. Until more recent times, a return journey from China to Europe could take as long as nine years.¹

Peshawar and its ancient history is central to Buddhism, in the Gandara Civilisation, Sikh and Hindu communities while also being a centre of Pashtu Muslim Society. Plant-based oil paints remained in this region of South Asia, along the Silk Roads from Peshawar to Bamiyan, and can be seen in two distinct textile painting techniques that we explore in this Chapter. One, an oil-based block printing using thickly heated oils on cloth printed in geometric patterns and was the art of the Afridi tribal communities referred to as “*Afridi Lac Cloth*.” The other oil painting on silk uses a traditional freehand technique and is centred on paintings depicting nature, spirituality, plants, dragons, birds, religious deities, Sufi symbols and calligraphy. This was a practice of only a few Peshawari families who created and traded the Rogan artworks in the markets of Peshawar and some who were known to travel, plying their art across Northern India. Unlike Buddhist Bamiyan, which faded as a centre of arts and textiles, Peshawar continued to be a centre of trade and a melting pot of religions, languages and arts, crafts and artisanal practices, that remain today.

Within this chapter, we journey through the link between the Buddhist Bamiyan and the Afridi tribal freehand artists of Peshawar, the Afridi tribal communities. The heritage story of the Afridi tribes also dates back to the pre-Islamic times and the peak of the Silk Roads. The Afridi are the keepers of the Khyber Pass,² the main travel route linking Afghanistan with India through modern-day Pakistan. It is said that no trade has ventured through the Khyber Pass without their knowledge and approval. The tribes were and, until recently, remained the suppliers of plant-based oils for Rogan artists such as the Ahmad family. The Afridi were intimate with the alchemy of extraction and creation of the thickened oil base for Rogan silk painting and there one cannot consider Rogan painting without considering the Afridi tribe.

1 Frankopan, P. (2015). *The Silk Roads: A New History of the World*. PPN237185245. Published by Bloomsbury.

2 Starr, L. A. (1920). *Frontier folk of the Afghan border and beyond*.

Similarly, the freehand artistic technique of Rogan Silk Painting remains but the skill is retained only by one last artist, Fayyaz Ahmad. The home and workshop of Fayyaz is situated in one of the oldest corners of Peshawar City, inside the Lahori Gate. The Ahmad family's practice of traditional freehand silk painting has been kept alive by a small but steady demand from foreigners in Pakistan. Despite its heritage, this demand has only allowed Fayyaz Ahmad to continue but not to expand his practice. However, the history of Rogan Silk Painting is well worth exploring. What opportunities are there for Rogan Silk Painting to re-emerge? While Rogan Silk Painting is not the luminous monumental wall paintings of the European renaissance, it has a lot to offer the art world in filling a gap in the knowledge of arts. Still, as a practice, it is an intricate, skilful, and meditative art that can add a delicate, elegant feel to the world of modern art.

2. Rogan, the oils and ochres

As numerous artists and scholars have pointed out over the years,³ as a way of telling stories or depicting objects, oil painting is almost outlandishly inefficient. In reality it is a very slow way to perceive and present a figure. Yet, that is what makes it art, it opens up the mind to a story and when we view an art work there are no doubt as many interpretations, ideas and imaginings as there are people who view it. The value of oil painting can be in the story of the art and where it emerged. Beyond this we also note the mesmerising technique use in Rogan Silk Painting.

Along with the oil-based paints identified in the Buddhist Monastic settlements of Bamiyan, there were also traces of resins, plant oils and ochres, and no doubt the same would be found in any modern-day artist studio. From this, we can determine that the Buddhist Monks of this era experimented widely and acquired skills, knowledge and techniques from passing crafts-folk, wayfarers, and traders that ventured through the Monastic settlement along the Silk Roads. While the plant oils of the day were local plant seeds, such as poppyseed, walnuts and perilla oils, the plant-based oils used in Rogan arts today are drawn from the flax seed, which produces linseed oil. For some specific work, such as a block print, castor oil is also used because it is a much easier process to produce painting oil and is more viscous when using a stamping technique. In the past, the resin was also used by traditional shoemakers for shoe repair. Today, Sadat Shah is the only artisan manufacturing oil-based resins from flax seed in Pakistan, and Fayyaz Ahmad, the last Rogan artist is his only customer.

To make the oils in a consistency suitable for Rogan painting, the linseed oil (flax seed extract) is treated at a temperature above 107 degrees Celsius (225° F) in a process that can take

3 Elkins (2004)

from six to eight hours, depending on the attentiveness and skills of the maker. The linseed oil transposes into a resin as it is carefully heated and cooled until the consistency is formed. The process is done by hand and by eye, as Sadat Shah adjusts the heat in an unscientific fashion although producing the oil to the correct consistency is both challenging, laborious, and dangerous. Once the oil reaches a temperature above 150 degrees F (65C), the linseed oil begins to thicken. Once it reaches 225 degrees F (107C), it begins to polymerise. The linseed oil can combust at 548 degrees F (286C), so the resin producer must monitor the oil as it continually transforms throughout the process. It is not difficult to see a more effective mechanised, safe, and efficient method developed to make the Rogan paints. Making the oils is dangerous, and the toxins released require heating in open areas. Fayyaz Ahmad explains that this is why the oil was never produced in Peshawar; his family only bought the oils from the remote tribal areas where they were freely made in quantities.

Once the resin is prepared, colours can either be mixed with ochre before painting, creating a pallet of colours or the painting is mixed with the natural oil and the ochres infused with the oil in the hours before the oil is completely dry and hard. The colours used in Rogan art in previous times would have been vast, through a range stemming from various hand-ground earthy coloured ochres. Fayyaz remembers that some of the colours he used in the early times of his apprenticeship came from Afghan travellers. The yellow, red, sienna (a reddish-brown natural clay containing iron, manganese and clay), black ochre (a natural black clay containing iron oxide) to Persian green. Today, Fayyaz Ahmad has passed through phases of popular modern paint colourings in powder form that are imported from China before returning to hunt for hand-ground local ochres. His Rogan work also includes stone sediments from the Jeweller's Bazar in Peshawar (*Namak mandi*), allowing him to experiment with the past traditions of using semi-precious and precious ground stones to colour the oils including Lapis Lazuli, jade, emerald and ruby.

The oil used in Rogan Silk Painting is heated and thickened to prevent the oil from running in the cloth. The oil paint dries by oxidation, which occurs once oil meets oxygen and produces a chemical reaction. Still, when the oil is polymerised, the artist has a greater opportunity to work with colours. The oil has already transformed from liquid to gel in the heating process and can be worked with as it continues to harden completely. Oil paint has a much slower drying process, allowing the painter to spend more time on detail and colour. How the technique of thickening the oil developed was likely an evolution stemming from making plant-based resins for myriad other uses beyond painting. As oil paint reacts when brushed onto silk, the only technique imaginable without a primer or resist is polymerising the oil and

applying it as is seen in Rogan. The alternative is the printing method, as seen in the Afridi style of Lac Cloth production. If the oil is not polymerised, then painting the silk with a brush with any detail would require a type of resist or Gutta to form a barrier on the outline of the oil paint, preventing it from bleeding. Fayyaz and the Afridi traditionally use a brush, but this is to colour the oil after the neutral paint design is applied. The use of brushes and resists are a modern addition to the process of oil painting and one that arrived much later through the introduction of the Gutta plant from Indonesia around 1400 CE.



Figure 2. Two Afghan Roghan Artists working in Peshawar, 1930.

There is likely much that has been lost from Rogan Silk Painting over the years, but we can also see that the limits of Rogan Silk Painting are yet to be fully realised in a modern artistic context. For example, we see some changes occur as the art of Rogan migrated to Gujarat, India. Due to its availability in Gujarat, the Khatri family use castor oil instead of linseed oils. In contrast to Ahmad and the Afridi, the Rogan artists of Gujarat mostly colour their oils before application. Their style is centred on geometric patterns with a basis in their Islamic heritage, and they use a mixture of handwork and pressed prints. Although it is possible, across all the Rogan painters in South Asia, Rogan painting lends itself best to thin lines and not broad strokes or highly textured patterns. While the oil is thickened, it can easily be loosened or thinned by adding a touch of lime powder; it can be heated and returned to liquid, coloured, and applied with various tools.

3. The journey of rogan, the painting oils

In 1935 Walter Benjamin criticised mechanical reproduction for devaluing “*the aura of an object d’art.*” He proposed that the unique value of the “*authentic*” work of art has its basis in ritual and the location of its original use. Despite their authenticity, many artisanal practices have failed to find an enthusiastic space in the modern day with rapidly changing globalised markets. Yet, a few authentic ancient skills miraculously remain in rare pockets across the globe. In many parts of the world, traditional crafts are being revived from what we presume are their most authentic selves. When we start putting ourselves in the paduka sandals of the people of the past, we find that “*authentic*”, as Walter Benjamin proposed, is, in fact, a challenging term in the context of intangible cultural heritage. What is authentic when we consider the historical context of arts such as oil paints that are developed and displayed in various, times, places and ways.

Artistic practices have many variables, and even the simplest of traditional skills can be littered with new technologies that change and develop a craft from an artisanal technique to the arts either incrementally or through great leaps of change. We see inputs vary as an artistic practice moves across new cultural or environmental boundaries and is used for spiritual practice, leisure or work. Materials such as ochres, pigments and dyes often change with the natural geological landscape and biology. Likewise, textile patterns and colours change with cultural and economic factors. Demand and exposure to other cultures result in different styles and fashions as unique designs influence creators of arts and new patterns emerge. As change occurs, new technologies are introduced, old practices fade out, and cultural links to the past disappear. Much like languages, numerous arts, crafts, and artisanal traditions fade with little trace of their existence. This was almost the case for Rogan Silk Painting. From what is known and understood, this mesmerising oil painting “*technique*” had remained relatively close to its original state over the centuries. This is primarily due to its cultural use and isolation within Pathan, Muslim, and tribal societies.



Figure 3. Remaining Buddhist Art, cave walls of Bamiyan Afghanistan (Tom Corcoran 2017)

Despite its long history in South Asia, Rogan Silk Painting as an oil-based art is not well known or understood outside of the western areas of South Asia, encompassing Peshawar, Pakistan and the region of Gujerat in India. Recently in India, Rogan Silk Art returned to favour with the attention of President Modi of India. President Modi offered a gift of Rogan Art to the American President, Barak Obama, during his trip to India in 2015 thus raising the local profile of this fading art. Despite this recognition, Rogan Silk Painting has been perceived less as a form of ‘oil painting’ and more as a textile art with its geometric patterns and motifs that are largely representative of its Persian heritage. A heritage representative of the early times of oil painting styles but differing significantly from that of the Ahmad arts of Pakistan that reveal many Buddhist, Hindu and Peshawari elements.

Until recently, art history linked the origins of oil paints to the artist Jan Van Eyck in the early Renaissance period of Europe 1410. Until recently, Van Eyck was considered the inventor of oil-based paints, but now we more correctly refer to him as; *the artist that developed modern oil painting techniques within Europe*.⁴ In the “*Lives of the Artists*”, Giorgio Vasari originally credited Jan Van Eyck as the inventor of oil painting. Vasari also invented the term “*Renaissance*,” as he outlined the progression of the arts in Europe through Giotto, Brunelleschi, to Michelangelo, Raphael and Leonardo Da Vinci. However, Vasari gave too much credit to Europe and his Renaissance period. In fact, oil-based paints were well documented before Van Eyck by the Theophilus Presbyter (1070–1125) in the “*Theory and Practice of Medieval Arts*.” Theophilus Presbyter compiled detailed descriptions of various medieval arts in the «*Schedula diversarum atrium*» (*the List of various arts: likely collected between 1100 to 1120*).

Theophilus Presbyter was a 12th-century German monk who referred to linseed oil as the basis of Monastic arts. He primarily documented its use for painting as a tough waterproof cover for exposed woodwork, especially for protecting wood exposed to the outdoors. In all he highlights this the longevity of oil paints, lasting centuries without corrosion. Oil painting and other artistic techniques were well known to the early Christian Monks, and a great deal of art was practised within Christian Monastic settlements. While Theophilus documents the modes and parameters of making “Art” from learning various techniques to the creation of form, he had little to offer on the origins of such arts; thus, our knowledge of oil painting production remained limited. For Monks, these arts were clearly a spiritual activity, and not simply static elements or exercises to be employed thoughtlessly.⁵ The link from the Monastic

4 Abraham, 2019

5 Gearhart, Heidi C P.129.. Theophilus and the Theory and Practice of Medieval Art, Pennsylvania State University Press, 2017. ProQuest Ebook Central, <http://ebookcentral.proquest.com/lib/bham/detail.action?docID=6224465>.

spiritual practice of oil painting may have been passed from Buddhism to Christian Monks, but this remains to be explored.

The writing of Theophilus on arts and oil paints was largely unknown until the author and poet Gotthold Lessing highlighted his work in the 1800s. This led to a string of additional writers linking the origins of oil painting to the 12th Century. Numerous researchers have highlighted how oil was used to detail tempera paintings, for example, Cennino Cennini, described the painting technique of *tempera*, where light layers of oil were used as early as the 13th Century. He too underlines how the slow-drying properties of organic oils were known by early artists, but they were not the preferred medium, as oil paints were difficult to master, which meant a scarcity of supply for those wishing to pursue the arts in oil. Before the 12th century CE, we needed to look further East than Europe; to the complex interactions and dialogues that flowed from east to west along the Silk Roads. We now know that this is where much of the credit for the arts, culture, and philosophy we directly associate with the European Monastic knowledge originated. The eastern contribution and artistic perspective are primarily absent when documenting the roots of cultural heritage of Europe. When we do so, we fail to acknowledge much of the story of humanity and the arts. In “*Re-Writing the Renaissance*”, Brotton (2016) argued that much of what we admire in the renaissance is owed to Islamic cultures of the east and beyond. In fact, all of Europe once looked to the east to define itself, both artistically and culturally. This is evident in the proliferation of Islamic artefacts in the interiors (*sculpted, crafted and painted*) of European churches and grand European homes and estates. Elaborate Afghan rugs containing Persian motifs are seen in Renaissance paintings and elude to a constant stream of material goods and technical skills that were imported via the ancient Silk Roads and into Europe, which underpinned the Achievements of the age.⁶

Through modern dating technologies, we now understand that oil-based painting was alive and well as early as the 7th Century CE. In 2008, scientists from ‘The National Research Institute for Cultural Properties of Tokyo (NRICT)’ working with UNESCO, sampled some of the paint that remains on the walls of Bamiyan’s labyrinth of caves and corridors. The results were highly significant to our knowledge of art history, Buddhist cultural heritage and this region of South Asia. Far from simply being cave art, they identified traces of resin, plant oils and ochres which lead us to envisage similar rooms to any modern-day artist’s studio; rather than primitive cave art. This discovery took our knowledge of the birth of plant-based oil painting back in time from the previously proposed 12th Century Europe to about 650CE at a time of the Gandhāra Civilisation and the peak of the Silk Roads.

6 Baltsavias, et al., 2006

The Gandhāra Civilisation was a relatively small area, being a geographic triangle west of the Indus River and bounded in the north by the Hindukush. However, its influence extended beyond its boundaries to Bamiyan, the most westward reaches of Buddhism some 450km west of Peshawar. The ancient city of Peshawar is Central to Gandhāra and no doubt central to the Silk Roads trade as the gated rest stop before the journey through the Khyber pass. The earliest written accounts of Bamiyan were documented in the pilgrimage of Xuanzang,⁷ the Buddhist Monk, although he explained that the Gandhāra of the 7th Century CE was mainly in decline, he also gave an impressive description of life, and Buddhism at the time. The dominant influence in Gandhāra was Mahayana Buddhism, which focused on a healthy life, a balance of spiritual and social aspects of living, promoting a balance of spiritual and earthly living. The Sangharama were the centre of delivering this healthy life, which included the arts of sculpting and colouring as they created places of prayer, spiritual practice, and great beauty and tranquillity.⁸ Xuanzang, wrote about Peshawar in several travel logs, where he highlighted the peacefulness, it's the Great Bazaar and Caravanserais. He also underscored Peshawar as a centre for manufacturing cloth although he gave little detail on the arts beyond shrines, sculptures and temples throughout his journey.

The artworks and materials discovered inside the Monastic settlements of Bamiyan provide evidence that point to monks being very dedicated to the colour and vibrance of painting; using ochres and oil paints, amongst other artistic pursuits, as a medium to express their religious devotion. For example, we know that the Bamiyan Buddha statues were rich with mural paintings representing Buddha-like figures, bright-coloured persons, ornaments, flowers behind hanging curtains.⁹ The Giant Buddhas are undoubtedly the most visible artworks of the 6th to 7th century Buddhist Era. The larger male, referred to as Salsal (*light shines through the universe*) and the female Shamana (*The Queen Mother*), featured brightly painted faces and hands as well as robes, that revealed innovative colour experimentation. It has emerged that from the results of these early Buddhist artists and their arts, it is easy to imagine how early plant-based oils developed within textiles, which in turn facilitated easy transportation beyond Bamiyan on woods, bark, and fabrics which were plentiful at the time. In the case of Bamiyan, the plants used for oil extraction are believed to have been derived from walnut or poppy seed; however, oils extracted from other seeds, such as the flax plant, replaced them over time.

7 Xuanzang is written as Hsüan-Tsang or Yuan Chwang in the old script (602- 664 CE). He undertook a 16-year pilgrimage to learn Buddhism in India from the source. Wriggins, S. (2020). Xuanzang: A Buddhist Pilgrim on the Silk Road. Routledge.

8 Gall, Carlotta (2006) 6th of December. From the Ruins of Afghan Buddhas a History Grows.

9 Baltsavias, et al., 2006

From the technique of extracting plant oils to decorate textiles in Bamiyan the process made its way through Afghanistan to Peshawar via the Khyber Pass. Here we see oils being adopted by the earliest tribal communities of the area, who used Rogan to make elaborate patterns on clothes, including wedding dresses and dowry gifts that were presented to brides. Court historians and Generals of Alexander the Great passed on accounts of the Afridi tribes that inhabited the mountainous regions of the Khyber Pass as far back as the 3rd Century BCE. We can only speculate how the use of oil painting came to be central to the Afridi tribes, perhaps in encounters with Buddhist arts, a technique learnt as guardians of the Khyber Pass, moreover, we cannot rule out the possibility that the tribes of the Khyber region first developed plant based oils themselves. As with Buddhist arts, Afridi's utilised the brightest colours and developed decoratively designed patterns and motifs. Today, the patterns and bright colours traditional to the Afridi heritage remain but the Rogan painting on the Afridi Lac Cloth has been replaced with embroidery. In Peshawar, Mastan Shah Afridi recently retired from his work in Rogan Lac Cloth decorative painting in 2022. He explained that the demand had all but died in the last two decades. He occasionally returns to his small Rogan arts shop when he receives a rare wedding gift request to produce a decorative shawl or traditional textile. Still, in general, his artisanal work is at an end. His retirement also ends the connection to the supply of Rogan paints although the technique is well known to the Ahmad family. The retirement of Mastan Shah Afridi, also leaves the knowledge of traditional "Rogan Silk Painting techniques, myths and design knowledge in the hands of one remaining artist, Fayyaz Ahmad. Like the Afridi, the Ahmad family have a centuries old heritage of Rogan Masters that persists through the family line of Rajput. Rajput is derived from the Sanskrit "raja-putra," which means the 'son of a king.' Rajput is a member of one of the clans of western, north and central, India and which prior to 1948 included Pakistan. The Rajput are often posited as the descendants of the Hindu warrior who became prominent during the time of the development of oil paints and the Silk Road trade around the 6th BC onward.

4. The last artists of rogan silk painting

Having established the heritage of Rogan Painting from the Bamiyan to the Afridi Tribes and the Ahmad family of Peshawar (*the early Rajputs*) to the Khatri family of Gujarat, India, we must now consider the future of this form of South Asian art. Over the years, many artists and artisans have moved away, transitioned, or retired from Rogan work, and although a niche market for this kind of art has been created, it has remained limited. It is believed that the decline began in the Peshawar region in the 1980s with the introduction of new techniques in embroidery and modernised production equipment. There is no doubt that this is why many

Afridi people moved away from the Rogan painting process at a large scale. Accounts suggest that the demand for traditional Afridi Lac cloth producers declined to so few and only a request for one-off pieces for customers from Peshawar to Kabul and occasionally to areas of Kashmir that this form of livelihood could not continue in the current region's economic climate.

Both retired, Wazir-e-saqafat (Master) Riaz Ahmad and Mastan Shah Afridi of Peshawar point to the old Rogan painters as the most sought-after and highest-paid artists and artisans of their time. In the 1950s, when Riaz was an apprentice, there was a high demand for hand-painted silks and the Afridi tribal Lac Cloth. However, with the influx of modern prints and machine-made embroidery from the East and the ever-changing fashion styles, the demand for Rogan art rapidly declined. Master Riaz emphasises that the value of Rogan art lies as much in its heritage as it does in the production of the art itself. Riaz Ahmad also explains various contributing factors, including the conflict in Afghanistan, which restricted the movement of people and goods across the region. It contributed to their traditional work becoming increasingly endangered. Yet, Pakistan's cultural departments have given Rogan little attention in favour of European painting styles and relegating it to handicrafts. The Ahmad family began marketing their paintings to foreign visitors to ensure the craft remained alive. They centred their work on traditional designs such as the Peacock, the tree of life, and the dragon and traditional Islamic styles from geometric patterns to spiritual scripts and Sufis.

Master Riaz Ahmad, now 76, fondly reminisces when his younger self made the equivalent of USD6 per day as an artist in the 1960s. He is proud that his craft kept his family housed and clothed and remained in the house they inherited from their forefathers. Master Riaz recalls his grandfather's account of 8-10 generations in their family's lineage, although many names now elude him. Miran Mohammad Ahmad, Sher Mohammad Ahmad and Mian Mohammad Ahmad's names persist as part of Ahmad's oral history. Still, he also knows this line through the Rajput, the name printed on the identification documents from colonial times.

Today, Fayyaz Mohammad Ahmad is the last in his family line. He inherited the tradition of Rogan Silk Painting from his father, Master Riaz, and grandfather, Miran, as a child. In 1996, with the ever-declining demand for art in Peshawar and a flood of mass-produced textiles from other parts of Asia, Master Riaz and Fayyaz sought outlets to sell their art. They embarked on a journey to Islamabad in search of opportunities. They were offered a chance to showcase their works at the government-created exhibition space for the arts of Pakistan called "Threadline Gallery." Operated under the Ministry of Industry, beyond art, the gallery was established to preserve and promote Pakistan's history of handicrafts and textiles. Despite

its effort, Threadline Gallery, in 2003, terminated its activities after a brief and intermittently successful period. Following this, Master Riaz, with hands not as steady as they once were, returned to Peshawar to re-establish his home studio.

Fayyaz Ahmad explains how his father's small niche in his hometown of Peshawar did not provide enough income to sustain the two artists and Fayyaz's expanding family. Thus he was forced to continue to exist with the small but steady demand from foreigners for his Rogan Silk Paintings in Islamabad. Fayyaz rented a small room and worked as a shop assistant in craft stores during the day while carefully crafting his pieces at night. Although Fayyaz encountered challenges in building a client base for his unique Rogan Art locally, he found that foreigners had a special appreciation for his works. Despite the work turnover, he failed to advance and struggled with creativity while beginning to feel a painful sense of loss for his family heritage. At this time, and with several children of his own, he decided he would be the last in his family to preserve Rogan Silk Painting by declaring that none of his children would bear the burden of his family's heritage as he had.

For Fayyaz, keeping Rogan Silk Painting alive was not exactly intentional. A profoundly religious man, he often posits that it is the will of Allah to both gift him and burden him with Rogan at the same time. Upon reflection, he also knows that he has been involved in Rogan Silk Painting since childhood and knows nothing else. During moments, he also emphasises that he was gifted in art and skill through his family but not a business. In the early 2000s, many Pakistani artists rose in popularity, but Fayyaz went in a slightly different direction rather than joining this society. He began experimenting with cheaper synthetic colours to replace the natural ochres. He moved from quality silk and mixed silk materials to lower quality fabrics and reduced the price, even dabbling in "Truck Art" and painting small works as souvenirs. His focus narrowed, and he moved away from traditional Asian designs to painting anything foreigners in Islamabad requested or found interesting.

However, in 2011, Fayyaz's persistence and growing networks in Islamabad began to come to fruition. He and his artwork were taken in by a Pakistani businessman with a high-end furniture store. The support was not purely altruistic; the businessman admired Fayyaz's art but was equally interested in his grasp of the English language and growing connections with the Islamabad expatriate community. Fayyaz was given ten square feet (1 m²) of floor space to create and display his craft. He used this space to sell his unique Rogan Silk Paintings, but much of his time was spent attending to foreign customers who visited the store. With time, Fayyaz made several connections within the Islamabad diplomatic community. In 2019, this culminated in the wife of a Japanese Diplomat in Islamabad purchasing various works. Impressed by the art's

Buddhist elements, cultural comparability with Japanese crafts, and meditative nature of the art itself, the diplomat sponsored Fayyaz to undertake an official visit to Japan. This allowed Fayyaz to share his skill and technique with numerous Japanese artists under “Arts of the Silk Roads.”

Unfortunately, the journey to Japan was not to be a door opening to expose Rogan Art to the world as he had imagined. In February 2020, Fayyaz Ahmad travelled to Tokyo, but within days of his arrival, the exhibition was cancelled as he faced COVID-19 and the strict Japanese lockdowns. During the lockdowns, he saw the departure of many foreigners from Pakistan, and Fayyaz lost many of his connections. Within days the last Pakistani Rogan Silk Painter was back in Peshawar, Pakistan, where he was again faced with lockdowns, and the chance to return to Japan was doubtful. However, upon his return from Japan to Pakistan, the “*Fading Cultures Project*” focused on keeping the art of Rogan Silk Painting alive. The team have since been working with Fayyaz Ahmad supporting his work and researching and documenting the journey of arts and the Silk Roads while he has returned to the traditional techniques of Rogan Silk Painting. In 2023, Fayyaz Ahmad is commissioned to complete a series of traditional works representing the story of oil painting, Rogan Silk Painting, Peshawar, and the Silk Roads. While there is still much to do, Fayyaz can now experience the satisfaction of slowly seeing his art recognised and recorded beyond the gates of Peshawar. Through the Fading Cultures Project, Fayyaz runs workshops, sells artworks and has time to prepare for local and international exhibitions where he can share his cultural heritage. While no one can guarantee the success of an individual artist or assume what success really means in the eyes of an artist, Fading Cultures ensures that gaps in the knowledge of the history and heritage of plant-based oil painting are being stitched together. Further, it provides that the knowledge of ancient artistic techniques is available to other artists to take authentically or in new directions.

In conclusion, the ancient art of Rogan Silk Painting has remained alive and vibrant throughout centuries of cultural transitions, the creation of borders, and cultural and economic changes in this ancient corner of the world. There are still many arts, artisanal traditions, and crafts to be rediscovered in the many hidden cultural pockets. By advocating and promoting Rogan Silk Painting through exhibitions, sales and workshops, and passing the skill and knowledge onto others, the culture and the beautiful art form may be preserved and continue influencing artists. Still, we must remember where it came from and the families and craftsfolk who the art represents. The art represents and blends together cultures that have walked the Silk Roads, prayed and dedicated works to Buddhism, Hinduism, and Islam, ranging from Persian, Afghan and Pakistani to Indian and South Asian. There is a responsibility to preserve, continue and expand the beauty and history of this unique art form for generations to come.

5. At the centre of Rogan Silk Painting

The traditional works highlighted by the artists in this chapter include the “*Tree of Life*” which is a concept commonly found in many spiritual and religious belief systems, art, and literature. In his study as an apprentice Rogan Silk Painters were taught that it represented the interconnectedness of all life and the cyclical nature of existence. As an important symbol in ancient cultures, the Tree of Life often represented the link between the visible mortal realm and the invisible supernatural realm, connecting all living things within the space between heaven and earth. The symbolism of the Tree of Life is common to their Rogan artistic culture and folklore where the roots and branches representing different aspects of life. The canopy of the Tree of Life can represent protection, food, and shelter; the trunk is seen as a pillar of strength, while the tree’s roots symbolize stability. Some stories even tell of a magical “Tree of Life” that can heal all wounds and answer all questions.

“*The Peacock*” is a popular motif in Islamic art and has become an iconic symbol of the Islamic faith. The Peacock is perceived as a symbol of beauty and royalty, and is commonly used to represent celebration and joy. The Peacock is also associated with immortality and spiritual power, which are important themes in Islamic artwork. Additionally, the Peacock is believed to be a symbol of paradise in Islamic culture. The “*Dragon*” is a sacred creature, often seen as a symbol of power, strength, and protection in Eastern religious and cultural lore. In Buddhism, the Dragon is particularly important. It is an esoteric, otherworldly being and is believed to be the manifestation of the enlightenment being whose nature surpasses the understanding of humans and possesses miraculous power. In Buddhism, the Dragon is believed to be a manifestation of Dharma, which is the path of spiritual wisdom and enlightenment. The Dragon is seen as a powerful symbol of protection and guidance and well known to Rogan Silk Painting where the Dragon are often depicted in their artwork is a Buddhist symbols of enlightenment, like the lotus flower or a dharma wheel.

“*Geometric shapes*” and patterns are used in Islamic arts because they represent the unity of God, the belief in one god and the infinite possibilities of existence. They can also symbolize harmony, balance, and beauty. Geometric patterns often occur in nature and this suggests divine creation as well. Additionally, these patterns can illustrate complex geometric theorems and mathematical concepts without the use of words; an alternate way to understand and appreciate science. The geometric shapes on Afridi lac cloth are symbols of fertility and prosperity. They are believed to bring luck and abundance to whoever wears them. They also represent the four classical elements (earth, water, air and fire). The traditional dress of the Afridi people hails from an ancient culture that is found in the mountainous areas of Northern

Pakistan. The Afridi wedding dress features brightly coloured and intricate designs, which includes an assortment of symbols and motifs with strong cultural significance. Red is the most prominent colour, symbolising love and joy, while purple, green and yellow are used to express a desire for a warm and prosperous union. Blue is said to be associated with good health, while white and black represent power and protection from bad luck, respectively. The designs also have deep religious meaning, featuring the crescent and star, which represent the Islamic faith, and floral motifs which are associated with the beauty of nature. These symbols, along with vibrant colours and ornate embroidery, create a unique look that is representative of the unique culture and heritage of the Afridi people. The traditional dress is a source of pride for those who wear it and a reminder of the centuries of heritage.

References

- Aafreedi, N. J. Claimants of Israelite Descent in South Asia. *The Journal of Indo-Judaic Studies*, 97.
- Ahmad Fayyaz (2019). Rogan Silk Painting, artisan interview, Peshawar city Pakistan. Corcoran, Tom Ethnographic PhD research Birmingham University United Kingdom.
- Ahmad Riaz (2019). Rogan Silk Painting artisan interview Peshawar city Pakistan. Corcoran, Tom. Ethnographic PhD research Birmingham University United Kingdom.
- Ahmad Riaz (2022). Rogan Silk Painting artisan interview Peshawar city Pakistan. Corcoran, Tom. Ethnographic PhD research Birmingham University United Kingdom.
- Anderson JA. (2009). China's Southwestern Silk Road in World History By: James A. Anderson, "China's Southwestern Silk Road in World History," *World History Connected* <http://worldhistoryconnected.press.illinois.edu/6.1/anderson.html>
- Baltsavias, Emmanuel P; Gruen, Armin; Gool, Luc Van; Baltsavias, Manos ; Pateraki, Maria., (2006). Recording, Modeling and Visualization of Cultural Heritage: Proceedings of the International Workshop, Centro Stefano Francini, Monte Verita, Ascona, Switzerland, May 22-27, 2005. Netherlands, Taylor & Francis, 2006.
- Bijan Omrani (2013) *The Buddhas of Bamiyan*, *Asian Affairs*, 44:1, 120-121.
- Brotton, J. (2002)., *The Renaissance bazaar: from the Silk Road to Michelangelo*, Oxford University Press, Oxford.
- Brotton, Jerry, (2006) 'Rewriting the Renaissance' *The Renaissance: A Very Short Introduction*
- Caroe Sir Olaf (2003) *The Pathans – 550 BC – AD 1957, 1958*, Macmillan Company, Reprinted Oxford University Press
- Dukpa, (2002). Presentation made at the course on Preservation and Restoration of wooden structures in Nara.
- Elisseff, V. (2000). *The Silk Roads: highways of culture and commerce*, Berghahn Books, New York, Paris.
- Elkins, J. (2004). *What painting is*. Routledge.
- Encyclopaedia Britannica: Gandara, (2022) Available online at: <https://web.archive.org/web/20070929225502/http://concise.britannica.com/ebc/article-9035986/Gandhara>
- Frankopan, P. (2015). *The Silk Roads: A New History of the World*. PPN237185245. Published by Bloomsbury.
- Hashmi, S. Q., Sarfraz, S., & Naeem, S. (2022). Hand Block Printing: The Ancient Craft of South Asia. *Journal of Development and Social Sciences*, 3(2), 38-47.

- HCAS (2012). Remembering the Bamiyan Buddhas. *Himalayan and Central Asian Studies*, 16(2), 102-107.
- Higuchi, T., & Barnes, G. (1995). Bamiyan: Buddhist Cave Temples in Afghanistan. *World Archaeology*, 27(2), 282–302. <http://www.jstor.org/stable/125086>
- Holdich, T. H. (1899). “Swatis and Afridis.” *The Journal of the Anthropological Institute of Great Britain and Ireland*, vol. 29, no. 1/2, 1899, pp. 2–9. JSTOR.
- Holdich, T. H. (1899). Swatis and Afridis. *The Journal of the Anthropological Institute of Great Britain and Ireland*, 29(1/2), 2–9.
- ICCROM, (2021). Rethinking Textile Conservation. International Centre for the Study of the Preservation and Restoration of Cultural Property, available at: <https://www.iccrom.org/events/rethinking-textile-conservation>
- Kaur, J. Kutch: (2021). Creative Journey-A Case Study. S. Sobha Singh Department of Fine Arts, Punjabi University Patiala.
- Kuczkiewicz-Fras, A. (2016). Over the Khyber: Afghans and South Asia - History of Contacts. *Politeja*, 13(40), 47-65.
- Kulke (2004), A History of India. Professor of Asian History Hermann; Kulke, Hermann; Rothermund, Dietmar. Psychology Press. ISBN 978-0-415-32919-4
- Lliveras-Tenorio, A., Vinciguerra, R., Galano, E., Blaensdorf, C., Emmerling, E., Maria, P. C., Bonaduce, I. (2017). GC/MS and proteomics to unravel the painting history of the lost giant buddhas of bāmiyān (afghanistan). *PLoS One*, 12(4).
- Maas Rupert (2009). The History of Oils, Jan van Eyck discovers the secret of oils. *The Artist Explorer was generously funded by Foyle Foundation*. Available at: <https://www.mallgalleries.org.uk/learning/resources/history-oils>
- Miles, L. W. (1994). Traditional methods. *Textile Printing*, 1.
- Morgan Llewelyn (2012). *The Buddhas of Bamiyan*. Profile Books, London, 2012.
- NWFP (2016) In Search of a Name: pakhtunkhwa.com. Archived from original on the 31 January 2016.
- Riazuddin, A. (1988). *History of Handicrafts: Pakistan India*. Islamabad: National Hijra Council.
- Shah Mastan (2022). Rogan oil traditional block printer; Interview Peshawar city, Pakistan, February 2022; December 2022.
- Starr, L. A. (1920). Frontier folk of the Afghan border and beyond.
- Taniguchi, Y. Cultural Identity and the Revival of Values after the Demolishment of Bamiyan’s Buddhist Wall Paintings. In *The Future of the Bamiyan Buddha Statues: Heritage Reconstruction in Theory and Practice*; Nagaoka, M., Ed.; Springer: Cham, Switzerland, 2020; pp. 51–70.
- Taniguchi, Y. Issues of Conservation for the Bamiyan Buddhist Mural Paintings. In *Mural Paintings along the Silk Road: Cultural Exchanges between East and West*, Proceedings of the 29th Annual International Symposium on the Conservation and Restoration of Cultural Property, National Research Institute for Cultural Properties, Tokyo, January 2006; Yamauchi, K., Taniguchi, Y., Uno, T., Eds.; Archetype Publications: London, UK, 2007; pp. 144–151.
- Wijesuriya (2013). Introduction, *Asian Buddhist Heritage*. Conserving the Sacred -CHA International Forum on Conservation of Asian Buddhist Heritage: Conserving the Sacred Seoul, Republic of Korea
- Wriggins, S. (2020). *Xuanzang: A Buddhist Pilgrim on the Silk Road*. Routledge.
- Wylly, H.C.,(1912) *From the Black Mountain to Wazirista*, Sang-e-Meel Publications, Lahore, Pakistan 1912.
- Yacopino, F. (1977). *Threadlines Pakistan*. Ministry of Industries, Government of Pakistan.
- Yusuf, Imtiyaz. (2017). Tracing the exculsion of the Rohingya Director of the Center for Buddhist-Muslim Understanding College of Religious Studies Mahidol University Salaya, Thailand Ta’seel Commons

CHAPTER 6

A CLASSIFICATION-BASED ASSESSMENT OF THE UNESCO TENTATIVE LIST OF TURKIYE*

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Abstract

On the 50th anniversary of the adoption of the Convention Concerning the Protection of the World Cultural and Natural Heritage, the UNESCO World Heritage List currently contains a high number of heritage sites that have begun pushing controllable limits. The UNESCO World Heritage Committee has undertaken the responsibility for selecting the heritage sites to be inscribed on the list and has had to develop various restrictions and strategies regarding the list. After the Convention, the 2005 Operational Guidelines for the Implementation of the World Heritage Convention took the first step toward changing the types of classifications of heritage sites on the list and defined four new specific types of heritages. Some revisions were made in the 2008 Operational Guidelines, and minor revisions have been made to the Operational Guidelines up to 2021. This study conducts an analysis based on the heritage classifications found in the Operational Guidelines up to the 2021 revision. The analysis accepts the cultural and mixed heritage sites that have been inscribed on the list since 2009, uses those that have been included in the UNESCO Tentative List of Türkiye (UTLoT) as observations, and examines the distributions for the observations based on classification type. An agglomeration has been observed to be present in the monuments classification, with the number of heritage sites in the Groups of Buildings and Cultural Landscapes classifications remaining proportionally low. In addition, the four heritage sites in UTLoT were seen to not have been included under any classification following the Operational Guidelines instructions. In this context, suggestions have been developed for UTLoT to show a more homogeneous distribution in terms of classification.

Keywords: History of art, Conservation and restoration of cultural heritage, World Heritage List, World heritage site classification

* This study was developed from the doctoral dissertation titled “Model Proposal for the Application Process to UNESCO World Heritage List - Sample of Cultural and Mixed Heritage of Türkiye”.

1. Introduction

Connecting the Red Sea to the Mediterranean, the Suez Canal became ready for use in 1869 after much effort. This development increased Europe's interaction with Egypt and led to the recognition of Egypt as a historical treasure. As a result, the Europeans, who thought Egypt's rich cultural heritage that blended the ruins of ancient Egyptian civilization with Arab Islamic artifacts were not given enough attention, tried to raise Egyptians' awareness of conservation (Reid, 1992, pp. 57–58), thus developing awareness of cultural heritage in the region. In 1959, the governments of Egypt and Sudan applied to United Nations Educational, Scientific and Cultural Organization [UNESCO] for the protection of many historical monuments, especially the Abu Simbel Temple, which was to be covered by a lake with the construction of the Aswan Dam that was being designed on the Nile River in the second half of the 20th century. After this development, archaeological excavations in the region accelerated and the Abu Simbel and Philae Temples were dismantled piece by piece, moved to a safe area, and reassembled (Ürün, 2016, p. 4). This event has shown that an international campaign can be successful for the preservation of a cultural heritage. In the following period, similar international campaigns were started and concluded successfully for Venice, Italy in 1966 and Borobudur, Indonesia in 1970 (Labadi, 2013, p. 26).

Simultaneous with these developments and alongside the increase in global awareness of cultural heritage, UNESCO adopted the Recommendation on the Means of Prohibiting and Preventing the Illicit Import, Export and Transfer of Ownership of Cultural Property in 1964 and the Convention on the Means of Prohibiting and Preventing the Illicit Import, Export and Transfer of Ownership of Cultural Property in 1970. As a result of all these efforts (Merryman, 1986, pp. 832–833), the Convention Concerning the Protection of the World Cultural and Natural Heritage (henceforth the Convention) was adopted on November 16, 1972 at the 17th General Conference of UNESCO held in Paris between October 17–November 21, 1972. Afterward, the UNESCO World Heritage List (WHL) was created as the most important implementation tool of the convention. The UNESCO World Heritage Centre was established to organize and coordinate applications for the WHL, and the UNESCO World Heritage Committee (henceforth the Committee) was established as the decision mechanism for the applications of candidate heritage sites for the WHL. Since the signing of the Convention, the WHL has been one of the most successful international mechanisms for protecting the common heritage of humanity (International Council on Monuments and Sites [ICOMOS], 2004, p. 52).

Eight heritage sites were included in the WHL for the first time in September 1978. The ordinary annual session of the Committee discussed and decided upon the candidate heritage sites to be accepted for the WHL that year. The number of heritage sites on the WHL increases cumulatively each year and has reached a total of 1,154 as of 2022, of which 897 are cultural, 218 are natural, and 39 are mixed categories. This reveals the number of heritages to be approaching the limits of controllability and to require classification regarding nomination and listing processes.

A state party to the Convention that decides to inscribe a heritage on the WHL must first have its own heritage sites inscribed on a UNESCO tentative list for that state. In this way, understanding the plans state parties have for the list becomes possible. This study examines the heritage classifications for the UNESCO Tentative List of Türkiye (UTLoT), which has the highest number of heritage sites inscribed (see Figure 1) among 194 UNESCO tentative lists.

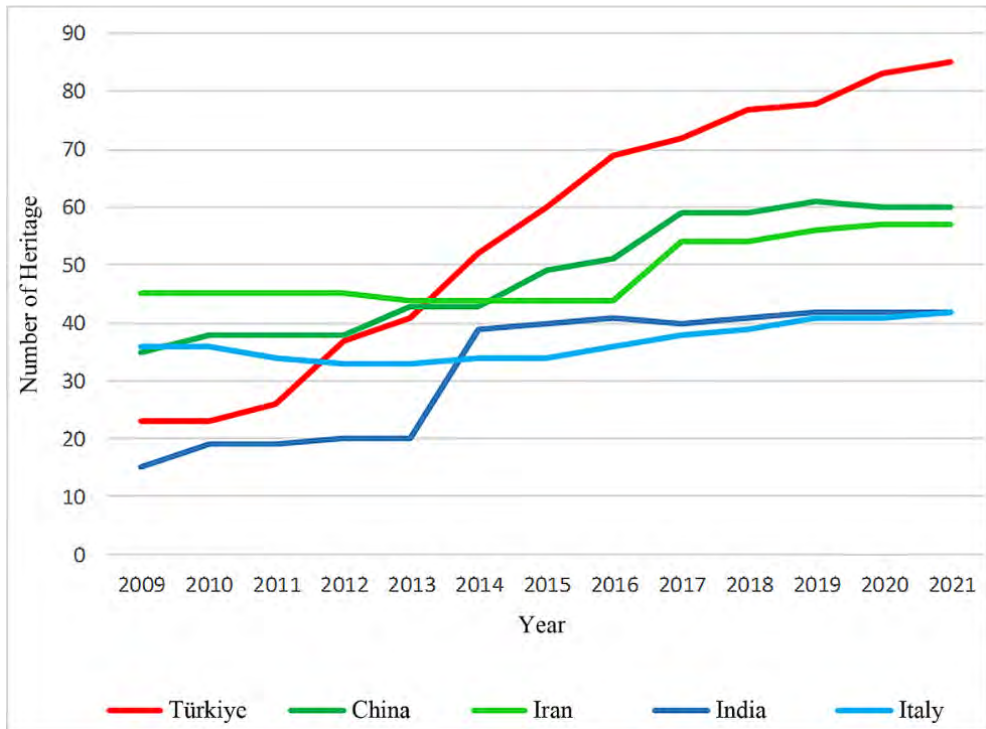


Figure 1. Number of heritage sites listed annually since 2009 in the top five tentative lists with the highest number of sites.

The classification study follows a path according to which of the world heritage sites from the tentative lists are most likely to be identified by following the heritage classification instructions in the Operational Guidelines for the Implementation of the World Heritage Convention (2019) (henceforth the Operational Guidelines).

2. Method

Cultural world heritage sites are divided into three classes in Article I of the Convention. As the number of heritage sites on the WHL increased in the following period, different heritage classifications were added to the Operational Guidelines (UNESCO World Heritage Centre, 2005) under the title of “specific types of properties” (Annex 3). Accordingly, seven different types of heritage sites can be mentioned as having been defined up to the 2021 revision of the Operational Guidelines. The study has determined within its scope that four observations in the UTLoT could not be included in just one of the classifications based on the Operational Guidelines (UNESCO World Heritage Centre, 2019), and thus this study has created an “Incompatible” classification for these observations. As a result, the study separates all classifications for the observations in UTLoT as follows:

- Monuments (M),
- Groups of Buildings (GoB),
- Sites (S),
- Cultural Landscapes (CL),
- Historic Towns and Town Centres (HTaTC),
- Heritage Routes (HR),
- Heritage Canals (HC),
- Incompatible (I).

2.1. Observation set

The study has formed its observations based on the cultural and mixed heritage sites in the UTLoT and the cultural and mixed heritage sites that have been accepted for the WHL since 2009 by taking into account the developments in the statements of outstanding universal value. In this context, 233 observations in the WHL and 81 observations in the UTLoT have been classified based on three general and four specific types of cultural and mixed heritage sites as defined in the Operational Guidelines.

2.2. Classification of observations

The study followed the heritage classification instructions in the Operational Guidelines when classifying the observations and examined the property area definitions of world heritage sites and statements of outstanding universal value when classifying the WHL heritage sites. The class in which each world heritage site should be located has been determined according to the instructions. When classifying the UTLot heritage sites, the study examined the property areas for which definitions have not yet been made and the definitions of heritage sites included in the statements of the outstanding universal value of heritage sites and decided which classification an area was mostly likely to be defined as according to the property area definitions.

2.3. Ambiguities about classification

Contrary to the general approach, some WHL observations were nominated for different heritage classifications or evaluated by advisory bodies as falling under a class different from the heritage classification it should have been placed under according to the guidelines. Within the scope of the study, such heritage sites have been classified based on the Operational Guidelines.

2.4. Enumeration of observations

Each observation classification was assigned an observation number. To avoid confusion, different numbering formats were applied to the WHL and UTLot observations. The observation numbers for the WHL observations were formed by the year the heritage site had been accepted onto the WHL, followed by a hyphen and the WHL dossier number for that heritage site. The UNESCO World Heritage Committee did not convene in 2020 to discuss the acceptance of heritage sites to the WHL due to the COVID-19 pandemic, so the status of the 2020 candidates was also discussed in 2021. For this reason, unlike the observations accepted onto the list in other years, 2020-21 has been written in the year section for the reference numbers of heritage sites accepted onto the list in 2021.

The observation numbers for the UTLot observations are formed by the letters “GL” followed by a hyphen, the tens and ones digits of the year in which the inheritance was inscribed onto the UTLot, another hyphen, and finally the UTLot reference number of the heritage site (Figure 2).

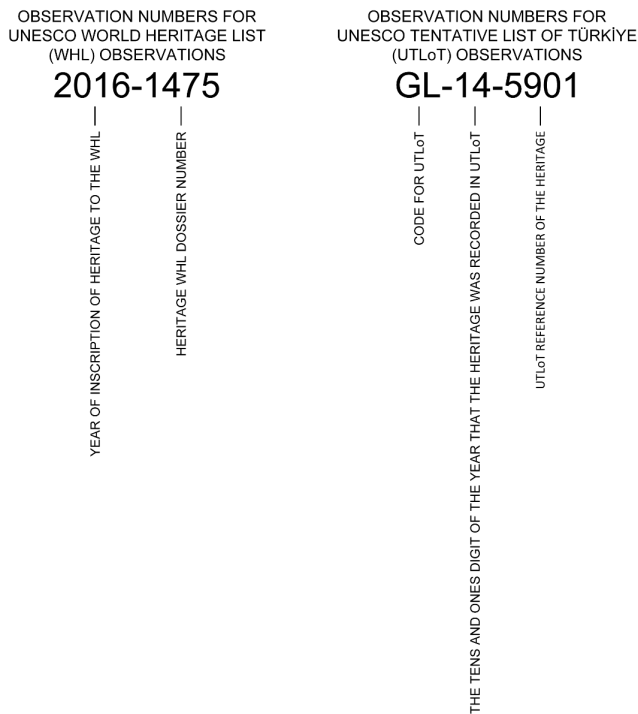


Figure 2. Creation of the observation numbers.

3. Results

As a result of the research over a total of 314 observations that were divided into eight classes, 54 fall under the Monuments (M) classification, 25 under the Groups of Buildings (GoB) classification, 31 under the Sites (S) classification, 95 under the Cultural Landscapes (CL) classification, 94 under the Historic Towns and Town Centres (HTaTC) classification, five under the Heritage Routes (HR) classification, seven under the Heritage Canals (HC) classification, and four under the Incompatible (I) classification. The classification study of the observations has been visualized in the radial diagram in Figure 3. Each observation is represented in the diagram by the observation number described in Figure 2. To the left of the diagram, the observations are lined up counterclockwise in the order in which they are listed. WHL observations are grouped by the year they are listed. To the right of the diagram, the observations are listed clockwise separately by heritage classification. The transition relation of each observation from left to right side is indicated by lines with the heritage classification color. The outermost ring of the diagram has an indicator describing the number of observations in each group and classification.



Figure 3. Diagram of the classification of observations.

3.1. Incompatible heritages in the UTLot

Within the scope of cultural heritage sites, the Tombstones of Ahlat the Urartian and Ottoman citadel is a settlement area belonging to the Urartian and Ottoman periods with cemeteries predominantly from the Seljuk period, this settlement area has been defined as having different world heritage site components. Both the differences between the civilizations that produced the heritage and the differences in use and function between the components prevent the heritage from being included under just one classification. While the heritage component that defines the settlement area has similar characteristics with the heritages in the HTaTC classification, the heritage components that define the cemeteries in different locations, including the tombs, show similar characteristics with heritage sites in the M, S, and CL classifications.

The definition for the Mardin Cultural Landscape heritage site was made through the components of the historical city of Mardin and the Dayrulzafaran Monastery. While the historical Mardin city component of the heritage site shows characteristics specific to the HTaTC classification, the Deyrulzafaran Monastery component shows characteristics of the M classification.

The definition for the heritage site of St. Paul’s Church, St. Paul’s Well, and the surrounding historic quarters emphasizes many monuments and thus gives the impression of an M classification, while the name of the heritage reflects an HTaTC classification. However, determining exactly what the term “surrounding historic quarters” qualifies is difficult, as no definition of a property area has been made for the heritage site yet.

Another incompatible UTLot observation involves the Sardes Ancient City and Bintepele Lydian Tumulus heritage site. While the Sardes Ancient City component of the heritage site falls under the HTaTC classification, the Bintepele Lydian Tumulus component can be considered under the CL or the S classification.

4. Discussion

Upon examining the distribution of classifications by list (Table 1), 27 of the 53 observations falling under the “Monuments” classification are from the UTLot. This rate corresponds to a high rate of 51%, which reflects the importance the Republic of Türkiye as a state party shows to defining “Monuments”-classification heritage sites to the WHL. This percentage is quite different for the observations falling under the “Groups of Buildings” classification, which has a total of 25 observations and of which only one is on the UTLot. This corresponds to 4%, which is quite low.

Table 1. Percentage Distributions for the Observation Classifications by List					
Class of Heritage	Observations		Total	WHL %	UTLoT %
	WHL	UTLoT			
Monuments	26	27	53	49%	51%
Groups of Buildings	24	1	25	96%	4%
Sites	24	7	31	77%	23%
Cultural Landscapes	88	7	95	93%	7%
Historic Towns and Town Centres	61	33	94	65%	35%
Heritage Routes	5	0	5	100%	0%
Heritage Canals	5	2	7	71%	29%
Incompatible	0	4	4	0%	100%
Total	233	81	314	74%	26%

Among the 31 observations under the Sites classification, seven (23%) are on the UTLot. Regarding the Cultural Landscapes classification, the UTLot contains seven (7%) of the 95 total observations. This rate is also quite low. Another important heritage classification finding is that 33 of the 94 observations occur in the UTLot under the Historic Towns and Town Centres classification. This corresponds to a high rate of 35% of the same

number of sites on the WHL with this classification. The UTLoT has no observed sites under the Heritage Routes classification and two observations under the Heritage Canals classification. The WHL has 7 observed sites under the Heritage Canals classification, thus the UTLoT's observation rate is 29%, which is close to the proportional distribution of the total number of observations.

As can be seen from Table 1, the most defined heritage classifications among the UTLoT observations are Monuments and Historic Towns and Town Centres. Compared to the WHL observations, the low number of observed sites under the Groups of Buildings and Cultural Landscapes classifications draws attention. In particular, the Cultural Landscapes classification was the most preferred heritage site classification among the WHL observations, occurring 88 times; the fact that UTLoT only had 7 sites observed under this classification suggests that cultural landscapes should be considered more in the UTLoT strategies. In terms of heritage site definitions, no heritage site was detected among the UTLoT observations that could fall under the Heritage Routes classification. However, due to property area definitions regarding the UTLoT observations not having yet been made, saying anything definitive about this is not possible.

Classifying four observations on the UTLoT is quite difficult, as heritage site definitions show more than one class feature, thus prohibiting these observations from falling under only one heritage site classification. This shows various difficulties will occur in the candidacy process regarding the likelihood of these four heritage sites making the WHL.

Another important issue regarding the classification distributions of the observations according to the lists is a comparison of the percentage distributions of the classifications of the observed sites within each list (Table 2). Comparing the percentage distribution for both lists will provide insight into the extent to which UTLoT heritage sites are pertinent regarding the classification trends for identifying heritage sites on the WHL.

As can be seen in Table 2, two heritage site classifications can be argued to be prominent regarding the preferred classifications for both lists, with the Historic Towns and Town Centres classification being among the first two most-preferred classifications in both lists. Meanwhile the WHL also preferred the Cultural Landscapes classification as one of the top two, and the UTLoT preferred the Monuments classification. The Sites and Heritage Routes classifications were preferred in both lists at similar rate. Due to their rarity, very low numbers were found on both lists for heritage sites falling under the Heritage Routes and Heritage Canals classifications, which have a linear structure.

Table 2. Distribution of Observations by Heritage Classification Type for Each List				
<i>Class of Heritage</i>	<i>Observations</i>			
	<i>WHL</i>		<i>UTLoT</i>	
Monuments	26	11.2%	27	33.3%
Groups of Buildings	24	10.3%	1	1.2%
Sites	24	10.3%	7	8.7%
Cultural Landscapes	88	37.8%	7	8.7%
Historic Towns and Town Centres	61	26.2%	33	40.7%
Heritage Routes	5	2.1%	0	0.0%
Heritage Canals	5	2.1%	2	2.5%
Incompatible	0	0/0%	4	4.9%
Total	233	100.0%	81	100.0%

Among the heritage sites on the UTLoT, four could not be included under just one heritage classification when following the heritage classification instructions in the Operational Guidelines. The main reason for these heritage sites, which have been classified as Incompatible within the scope of the study, is that the heritage definitions made cannot be considered as serial nominations of components belonging to only one heritage site classification or as components formed by a common civilization or a community belonging to different classifications.

5. Conclusion

This study has conducted research based on comparing the classification distributions regarding cultural and mixed heritage sites as defined on the UTLoT with the classification distributions for current and similar examples on the WHL. The results from this study show the Monuments and Historic Towns and Town Centres classifications for heritage sites to be favored more highly in the UTLoT than in the WHL, while the Cultural Landscapes and Groups of Buildings heritage site classifications were significantly less preferred on the UTLoT. In addition, UTLoT heritage sites that could not be included under just one heritage classification have been classified on the UTLoT as Incompatible, and this should be reconsidered within the scope of the study. Another important discourse of the study is that efforts should be made to capture the heritage site listing trends under the Cultural Landscapes classification on the WHL when defining heritage sites to be inscribed to the UTLoT and heritage sites to be nominated from the UTLoT for the WHL.

This study has proposed a method for the practical applicability of the Operational Guidelines regarding the classification of world heritage sites. The study has used within its scope the types of cultural heritage that are defined in the Operational Guidelines, has proposed

recommendations regarding the nomination conditions used in the classification of world heritage sites in accordance to their similarities, and proposed a classification method in this direction. In this context, the study has observed ambiguities to be present regarding the type of heritage instructions that are made according to heritage classifications in the Operational Guidelines. From which scale certain heritage site classifications diverge has yet to be clearly revealed. In this context, if a demand is found in the future for the practical use of the instructions in the Operational Guidelines for the classification of heritage sites, then how heritage sites are classified will need to be more clearly stated.

References

- ICOMOS (2004). *The World Heritage List: Filling the Gaps - an Action Plan for the Future (An Analysis by ICOMOS)*. Paris: International Council on Monuments and Sites.
- Labadi, S. (2013). *UNESCO, Cultural Heritage, and Outstanding Universal Value*. Plymouth: AltaMira Press.
- Merryman, J. H. (1986). Two ways of thinking about cultural property. *The American Journal of International Law*, 80(4), 831-853.
- Reid, D. M. (1992). Cultural imperialism and nationalism: The struggle to define and control the heritage of Arab art in Egypt. *International Journal of Middle East Studies*, 24(1), 57-76.
- UNESCO World Heritage Centre, 2005. *Operational Guidelines for the Implementation of the World Heritage Convention*. Paris: UNESCO World Heritage Centre.
- UNESCO World Heritage Centre, 2019. *Operational Guidelines for the Implementation of the World Heritage Convention*. Paris: UNESCO World Heritage Centre.
- Ürün, Ş. (2016). *Dünya Kültürel ve Doğal Mirasın Korunmasına Dair Sözleşme: Doğal Miras Alanları Başvuru, Adaylık ve Değerlendirme Süreçleri*. Ankara: UNESCO Türkiye Milli Komisyonu.

CHAPTER 7

HISTORIC CENTERS AND OVERTOURISM: OPPORTUNITIES AND THREATS FOR THREE HISTORIC EUROPEAN CITIES

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Abstract

The past and present co-exist in constant dialogue in historic centers. Such locations do not merely denote a unity of architectural monuments; they also represent a complex layering of meanings connected to their natural environments, geological structures, and metropolitan hinterlands, which combine the familiarity of the old and the notion of progress attached to the new. Tourism could become an important contributor to the economic realization of historic areas because their conservation is contingent on the availability of funds and their cultural heritage must thus first be identified. A delicate balance currently exists between tourism functioning as a support for conservation or becoming the reason for conservation. Today, the facts underlying the conservation-related approaches of historic towns and factors that make tourism a subject of conservation efforts must be readdressed. Historic centers have now become tourism development domains that are often extended beyond their capacities. Overtourism, also defined as excessive advances in tourism damages the long-term conservation of cultural heritage sites. Hence, the social, environmental, and economic consequences of overtourism have become keenly contended issues in recent years. The current chapter focuses on the effects of overtourism on historic areas. It analyzes the historic centers of Barcelona, Venice, and Athens as case studies, examining issues related to overtourism in these areas. Each case study evaluates how overtourism occurred in the relevant site, the factors promoting such excessive development of the tourism industry in these locations, and the new conditions that have reshaped the circumstances of both inhabitants and visitors. The chapter investigates strategies to control overtourism and assesses their effectiveness in achieving historic urban conservation. It analyzes the effects of overtourism on the physical and social structures of historic centers. It further examines the effectiveness of legislative tools to conserve historic areas. Finally, based on the three conducted case studies, the chapter formulates proposals to control overtourism and achieve a balance between conservation and tourism.

Keywords: Overtourism, historic centers, urban conservation, Barcelona, Venice, Athens

1. Introduction

The first attempts to define the negative effects of tourism began in the 1960s when the first signs of the downgrading of local environments appeared. Such declining conditions caused residents to harbor negative attitudes against visitors to their surroundings (Koens, et al., 2018). In the decades that followed, the adverse impact of intense tourism development resulted in debates about defining the limits of consequences caused by the progression of mass tourism. The Spanish term *tourismofobia* was initially used to describe the unfavorable attitudes of residents to the harmful characteristics of tourism development (Vascuez & Davila, 2020). Today the term “overtourism” is utilized to denote the negative impact of the travel industry (European Parliament, 2018).

The World Tourism Organization defines overtourism as the impact of tourism on a destination, or parts thereof that excessively influences the perceived quality of life of citizens and/or adversely affects the quality of the experiences of visitors (World Tourism Organization, 2018). The Responsible Tourism Partnership describes overtourism in terms of destinations that hosts or guests, residents or visitors believe house too many people, intolerably diminishing the region’s quality of life or the quality of experiences visitors can attain in the area (Goodwin, 2017). Thus, responsible tourism purposes to use the industry to improve areas in which people live and to which people travel. The downgrading of a location often affects both guests and visitors (Fig.1).



Figure 1. Crowds at the Trevi Fountain in Rome

Monuments and historical sites attract visitors. Historic city centers become important to the tourism industry as places that enable people to admire cultural inheritances. Heritage tourism originated in the Renaissance idea that only people who had traveled extensively to experience art and culture could be considered educated. The Grand Tour was the first organized tourist journey to areas of historic value. This traditional journey through Europe continued from the 17th to the early 19th centuries. The tour lasted months or years and included varied areas of cultural interest. It began in northern Europe and ended in the cities of Italy, with Venice as a prominent destination (Verhoeven, 2019). The subsequent development of railroads made historic areas more easily accessible to people with lower incomes. Later, the advent of the 20th century made culture accessible to everyone.

Historic centers were recognized as heritage locations in the second half of the 20th century. Policies for place-based conservation emerged in the latter part of the 20th century when the importance of cultural heritage as a link between urban life and development processes was acknowledged thanks to the work of international organizations like the United Nations Educational, Scientific and Cultural Organization (UNESCO), the International Council on Monuments and Sites, and the Council of Europe. The concept of conservation has expanded in the last few decades to include the architectural, social, and economic dimensions. The connections between the past, present, and future are maintained through culture, which forms an integral component of urban and human existence.

2. Tourism in historic centers

Diachronically, cultural tourism has evolved concurrently with urban conservation in historic towns. The travel and tourism industries are expanding globally. Historic cities function substantially and sometimes powerfully to facilitate preservation efforts and augment economic regrowth (European Association of Historic Towns and Regions, 2006). Historic cities benefit from tourism but increased demand also results in decreased quality of life and tourism appeal, leading to increased housing costs and environmental pollution. These effects negatively impact the daily lives of residents, overcrowd public spaces, congest infrastructure as well as services, and amplify traffic. Thus, while tourism causes urban legacies to be preserved, it also often contributes to their downgrading.

The facadist approach to conservation and the museumification of legacies are increasingly becoming typical features of historic centers. Many historic areas are shifting their conservation goals toward more aesthetically pleasing exterior attributes that influence visitor impressions. Historic cities are shaped by varied factors such as their historic, eco-

conomic, environmental, social, or legislative attributes. Tourism plays a significant economic role as cultural capital and has evolved into a product that can be advertised, bought, and recreated. The current examination comprises three case studies of historic cities that attract many visitors. It investigates the consequences of their tourism appeal on their historic areas, adopting the lens of sustainable cultural conservation to scrutinize the effects exerted on these three historic locations by tourism and by policies encouraging the development of the tourism industry.

2.1. The case of Barcelona

Barcelona is traditionally renowned for its innovative design from the time Cerda devised and executed its urban plan in 1859 to the redesigning of the city for the 1992 Olympic Games (Barcelona City Council, 2012). Barcelona's tourist industry has grown since the 1960s. The city's picturesque architecture attracted global attention in 1992 when it hosted the Olympic Games.

In economic terms, the construction industry and the real estate sectors in Spain attracted much of the flow of global capital because of the Maastricht Agreement in 1992. The inclusion of Spain in the European Union led to the city's de-industrialization and the abandonment of secondary sectors (Martins, 2018). In subsequent years, a significant urban rehabilitation initiative converted the provincial, industrial, port city of Barcelona into a cosmopolitan metropolis with Mediterranean beaches (Fig.2) and an open harbor. Barcelona became a leading



Figure 2. Barcelona's beaches

tourist destination in Europe and the city's economy became primarily grounded in cultural tourism in the years that followed. Barcelona's Catalan-focused cultural infrastructure expanded as public banks financed numerous urban projects to promote the regional culture (Datzira-Masip, 2006). Ancient docks were demolished, and tons of sand were hauled in to build kilometers of sandy beaches that now span from Barceloneta to Port Olympic. The city's Mediterranean beaches attract multitudes of tourists, day visitors, and locals.

Barcelona's success as a tourist attraction may be attributed in large part to the city's openness to the sea and its multiculturalism. Tourism is a principal objective for the City Council because of its economic value, the jobs it creates, and its contribution to Barcelona's enhanced reputation abroad.

Hotels in Barcelona increased by 90.3% from 1993 to 2007, adding 27,805 rooms (Tourism and Events Department, 2014). The data obtained from the Hotel Occupation Survey of 2019 revealed that Barcelona achieved 8.520.417 million hotel bookings in 2019 (World Cities Culture Forum, 2019). The geographically central location of Barcelona and its connections with other European countries and international areas was also a decisive factor for the increase of tourist arrivals. EL-PART Airport and Port serve millions of tourists per year as reference points in the Mediterranean area. Railway connections, bus routes, and tram facilities also enhance access to the city.

The policies governing the tourism industry promote business and conference tourism, also augmenting the number of visitors to the city. Typically, visitors stay less than two nights on average in Barcelona (Goodwin, 2019).

The first negative comments on tourism and its sustainability for the city were recorded during the Conference of Cultures in Barcelona in 2004. By 2008, mainstream and social media began recording strong criticism regarding violence and delinquency caused by tourism. The frequency of negative remarks concerning tourist experiences in Barcelona as well as adverse tourism-related encounters confronting the city's residents rose throughout 2009 (Nastase, 2016).

Barcelona aggressively adopted environmental and social sustainability measures in the next few years, lowering noise and water consumption, and increasing access to public transportation. The city aims to achieve high levels of social cohesion and quality of life. The coexistence of locals and tourists often becomes imbalanced because overtourism imposes visible changes on the urban space and affects the daily lives of locals. By extension, tourists and residents compete for space, and permanent residents are often forced to move to cheaper areas because tourism increases living and housing costs (Petrova & Hristov, 2016).

The tourism industry in Barcelona is constantly expanding. Its demands exceed the city's holding capacities, particularly in the congested central historic neighborhoods. The phenomenon of overtourism is thus observed.

The historic La Rambla Street (Fig.3) typifies this problem. One of the largest projects launched in 1995 in Barcelona as part of the development of the city's road network, this street no longer reflects Barcelona's local identity. An estimated 80–100 million pedestrians walk through La Rambla every year (Barcelonayellow.com, 2013) and land on either side of the street is used mostly for tourism-related activities.



Figure 3. La Rambla Street

Parc Güell, planned by Gaudi, attracts 25,000 visitors daily (Anon., 2023) and denotes another popular tourist destination in Barcelona. The park was regenerated for the Olympic Games and now represents an important city landmark. The city authorities decided to set restrictions in the monumental area by imposing an entry ticket in 2012. Many citizens opposed the measure because they lost their civic rights to the hitherto public park because of intense tourist traffic.

Tourist demands for services and spaces have caused the privatization of public space and have prompted local businesses to change, mostly to tourism-related ventures. Tourism has resulted in rental increases, land changes, and increased construction activity. It has instigated the displacement of businesses that serve local needs and heightened the prices of certain

products. Apartments are legally or illegally becoming tourist accommodation infrastructures, causing citizens to be expelled from their rental houses (Sánchez-Aguilera & González-Pérez, 2021).

Only a few areas of Barcelona were affected by gentrification between 2001 and 2006, primarily around the Old Quarter, la Barceloneta, Sarrià-Sant Gervasi, and Sant Andreu. Between 2006 and 2011, the district of Gràcia, the neighboring areas of Eixample and Horta-Guinardó, and Sants-Montjuïc also experienced rapid increases in gentrification, and by 2016, vast areas of Barcelona were affected by the urban renewal (Vollmer & Bisjak, 2022).

In 2007, the Catalonia region regulated economic activity in housing development through legislation, defining a municipal license for every new use and deeming the absence of the appropriate license a serious infringement. Therefore, short-term leases without due permission were considered illegal when Airbnb first appeared in Barcelona in 2009. In 2010, a decree allowing short-term leases for tourist accommodation was finally passed, but with specific rules and restrictions. In 2012, the Catalonia region imposed a tourist tax on every visitor through accommodation facilities. In 2014, the Municipality of Barcelona limited the number of short-term leasing licenses in Central Barcelona. This moratorium supplemented the previous restrictions on short-term leasing licenses established for Ciutat Vella (Goodwin, 2019).

In 2015, the municipal government of Barcelona halted the processing of new permits for the establishment of tourist accommodations, student residences, and youth hostels to assess the impact of all aspects of activities related to tourist accommodation and to draft a special urban development plan to regulate such undertakings. Ciutat Vella, the historic core of Barcelona, established a Land Use Plan to limit the expansion of tourist accommodations, whether hotels or flats (Rabassa & Ibarra, 2020). A Tourist Accommodation Working Group was formed to supplement municipal efforts to minimize the number of unregistered units. Also in 2015, the Neighborhood Union for Sustainable Tourism expressed the social discontent of local citizens and encouraged measures such as tourism reduction, the redistribution of benefits accruing from tourism, and the promotion of economic alternatives (Espiga, 2015). In this manner, Barcelona residents attempted to review the neoliberal tourism model, protect their public spaces from overtourism, and claim affordable rents (Goodwin, 2019).

In 2016, the Catalan government announced the implementation of a tax on hikers as well as visitors arriving on cruise ships, tourist buses, or by car, for contributing to the city's traffic congestion. Barcelona also suspended licensing new hotels in popular tourist areas. Barcelona Tourism Destination Management Organization played a decisive role in undertaking such

measures as it attempted to balance the negative effects of tourism on the city and its inhabitants. An aggregate of 6000 cases of illegal short-term leasing was recorded in 2016 (Lomas, 2016). The Special Regulation Plan for Tourism of 2017 interrupted the existing moratorium imposed to control tourist infrastructure by dividing the city into four areas and proposing specialized strategies for every area. These customized strategies were adopted in consultation with the area's residents and were based on the area's population and existing tourism facilities. This new position caused massive changes and tourism intensified. According to Goodwin, the number of residents in historic centers decreased by 11% between 2009 and 2017 (von Briel & Dolnicar, 2020). Tourism became the city's principal economic sector as well as a fundamental problem as short-term leasing for tourism increased continuously (Goodwin, 2019) (Fig. 4).

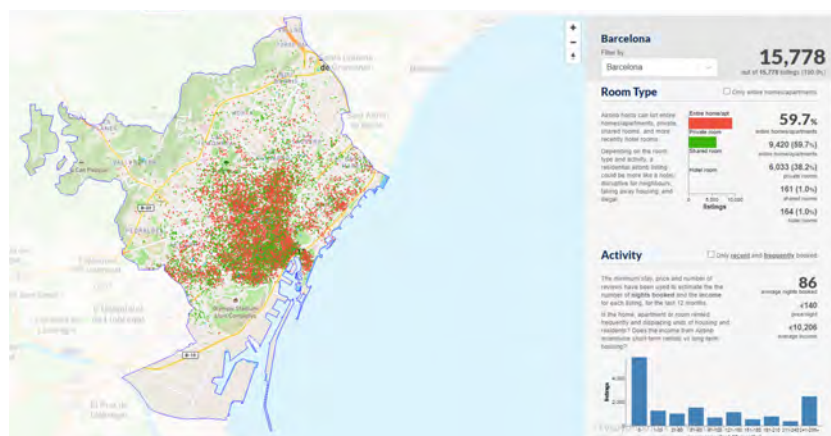


Figure 4. Airbnb listings in Barcelona (2022)

The Catalan authorities tried to control rents in 2018, creating a platform to record rent status. The “30% law” was enacted, obliging anyone restoring a building to attribute 30% of the reconstruction to affordable housing. Additionally, authorities promoted a program to build new social houses: downgraded buildings were bought and renovated with public funds to be turned into social residences. Finally, the municipality developed partnerships with the private sector to jointly manage the costs of renovating old apartments. In return, the private sector partners were allowed to lease the restored accommodations at affordable rates for five years.

Tourism activity decreased in Barcelona due to restrictions imposed during the novel coronavirus (COVID-19) pandemic. However, tourist footfall increased at the usual pre-COVID-19 rates in 2022. Figure 5 displays the diachronic increase in tourists and overnight visits to Barcelona's center and its wider regions from 1999 to 2022 (Observatori del turisme a Barcelona, 2022).



Figure 5. Evolution of tourists in hotels in Barcelona (1990–2022)

2.2. The case of Venice

Venice was constructed as a complex of 118 small islands (Fig. 6) in the Mediterranean Sea in 500A.C. Venice became a center of commercial and cultural activities during the Renaissance. The first excursions to Venice were organized in the mid-19th century, and houses began turning into tourist accommodations. The development of infrastructure connecting Venice with its surrounding cities improved access and promoted tourism. Lido, an abandoned island, transformed gradually into a tourism destination based on the 3S (sea, sand, and sun) model. Additionally, the Biennales of architecture, art, theater, and cinema accorded the city of Venice a new identity and enhanced its cultural capital.



Figure 6. Venice islands

According to Zannini (2014), Venice experienced two major periods of tourist expansion in the 20th century: during the first phase which spanned the postwar period to the 1980s, an elite market transformed into true mass tourism, the second phase stretching from the 1980s to the present is characterized by the constant growth of visitors from 1,669,000 in 1952 to 4,389,000 in 1992 (Zannini, 2014).

As the city's population increased rapidly, the historic center of Venice faced serious housing problems until the first half of the 20th century. The popularity of the city as a tourist destination increased continuously from the 1950s and its permanent population began to decrease. During this time, many non-Venetians settled in the city permanently or acquired a second home in Venice. The development plan of 1962 proposed to expand the industrial zone and construct new housing units for 60,000 people. In 1987, the city of Venice was included in UNESCO's cultural heritage list, and urban conservation was prioritized in the area over the next few years.

The period spanning from the 1990s to the present is distinguished by the emergence of postmodern tourist trends worldwide, national and local relaxation of municipal rules, and the concurrent collapse of the area's industrial strength. Research from 2000 reveals that by the beginning of the new millennium, three foreigners moved to the city for every two Venetians who left (Davis & Marvin, 2004). These new residents were either workers in tourism businesses or people who bought and renovated properties for use on vacations. This process caused rental rates and living costs in Venice's historic center to increase rapidly. Therefore, many residents were forced to relocate, primarily to surrounding areas such as the city of Mestre.

It was estimated that 28 million people visited Venice in 2011 and that the majority of them were day visitors. According to Fabbri, Venice records 500 visitors per year for each resident of the 750 hectares of the historical urban fabric (Fabbri, et al., 2020). Meanwhile, the permanent population of Venice reduced from 74000 in 2006 to 60050 in 2009 and 50000 in 2010.

Legislation was introduced in 2013 to control cruise ships, which were deemed to cause environmental downgrading. This law prohibited ships weighing more than 96,000 tons from passing through the Giudecca Canal. Also, the number of smaller boats that could cross the canal was limited to five per day. However, this law was overturned in late 2015. Venice is gradually becoming a hyper-tourist city because residents are forced to use services designed for tourists (D'Eramo, 2017). After an initial period of platform implementation (2010–2015), tourism increased briskly in tandem with the rise in short-term leasing.

The first attempt to control tourism control occurred in 2017 when gates were installed at the entry points to Piazza San Marco (Fig. 7) and Rialto Bridge (Fig.8) to control access during peak periods.

The gates would close when a large number of visitors had entered these sites, and only people with hotel reservations or Venezia Unica cards were allowed to enter. The Venezia Unica card is utilized predominantly by residents but can be bought for €40 by anyone using the water bus. At the same time, the municipal authorities prohibited the construction of new tourist accommodation facilities in the historic center of Venice to avoid increases in overnight visitors to the city. Also in 2017, more than 18,000 Venetians voted in an unofficial referendum to ban the docking of large cruise ships that downgraded the existing historic and natural environment (Vianello, 2017).



Figure 7. Piazza San Marco



Figure 8. The Rialto bridge

The city of Venice proceeded in 2017 to define measures in accordance with the Plan for the Territorial Governance of Tourism devised with its residents, tourism industry, and tourists. The final plan was the product of a participatory process initiated in 2016 that included citizens, tourism associations, and economic and cultural groups.

Further, in 2017 the Italian government defined a maximum booking limit of 30 rental days per year for short-term leasing and announced special tax measures. Still, the city has not effectively curbed short-term rental accommodations (Fig. 9) or ensured lower rents for

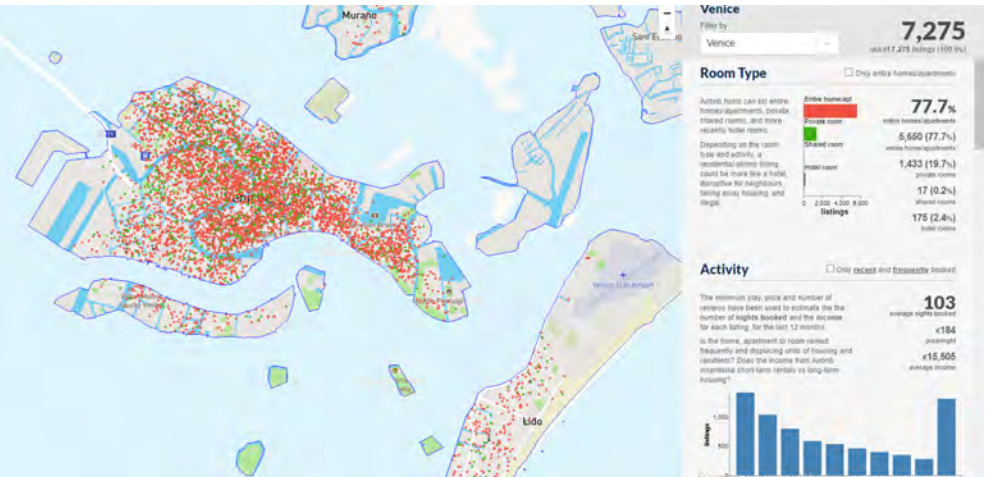


Figure 9. Airbnb listings in Venice (2022)

its permanent residents. Venice's inhabitants have organized groups such as the *Assemblea Sociale per la Casa* to defend their interests. These groups primarily act to prevent evictions or rehabilitate abandoned buildings.

The Plan for the Territorial Governance of Tourism in Venice established objectives and activities to attain sustainable tourism. According to this plan, Venice could innovate to enhance its urban component via sustainable tourism while preserving its originality and individuality as a World Heritage Site. The plan incorporates four macro-objectives: managing resources, safeguarding inhabitants, balancing expenses better to increase value, and developing new marketing and communication strategies to inform people about ethical and sustainable tourism.

In 2019, the Italian government introduced a tax for visitors. This tax to control the entry of too many visitors ranged from €2.50 to €10 per person depending on the season. Revenues from this tax would be used to cover the costs of maintaining and cleaning the city.

The installation of closed-circuit surveillance cameras in the historic center was another measure announced in 2019 to record tourists and residents through a mobile phone tracking system (Bubola, 2022). Every 15 minutes, police officers collected data pertaining to gondolas and boats, visitors in monuments and public squares, visitor congestion, destinations, and arrivals. Locals and tourists were distinguished to use the data to devise an effective plan to control overtourism. These surveillance measures were strongly criticized for violating privacy and breaching protected personal data.

2.3. The case of Athens

Athens, the capital of Greece (Fig. 10), boasts a history that dates to 3,200 BC but has recently experienced several shocks. Athens is a popular destination for tourists and the city attracts visitors from every part of the world. The historical monuments and museums of Athens represent the most visited sites in Greece. The city is located in the Attica basin and has faced numerous earthquakes, fires, heat waves, and other natural disasters. As of 2011, the municipality of Athens housed 665,000 people within its surface area of 2,929 km², along with a population of 3.75 million residents in its surrounding areas. The city's population increased significantly between 1951 and 1981. Athens built new public infrastructure prompted by the 2004 Olympic Games. Housing construction and infrastructure development in Athens were also influenced by Greece's admission into the European Union in 1981 (City of Athens, 2017).



Figure 10. Athens historic center

The economic crisis of 2009 and its consequences exposed the city's hidden vulnerabilities, including rising homelessness and poverty, population decline, inadequate defenses against climate change for its aging infrastructure, increasing energy poverty, massive influx of refugees, and disjointed spatial planning. The unemployment rate was rising, and public spaces were few and of poor quality. The human geography of the city has changed dramatically in recent years because a portion of the population has relocated to the suburbs. The inflow of refugees has contributed to the growth of the city's diminishing population. Social efforts and social solidarity organizations are essential resilience-development factors. However, the city has not been able to effectively address the mounting issues of poverty, homelessness, and unemployment in the absence of coordinated policies and activities undertaken by competent authorities.

Athens has immense cultural capital, which provides the city with ample opportunities for tourist growth (Fig.11). Athens is rapidly rising as a city break destination: 5.5 million people visited the city in 2018, a 600% increase from 2013. These new conditions have made Athens a profitable urban territory for short-term leasing companies. Airbnb began renting properties in Athens in 2010 and the company's business accelerated in the years that followed. In 2015, Airbnb conducted research on the advantages of the company's functions in Greece. The information provided by the firm regarding its operations in Greece affirmed advantageous opportunities for tourists as well as property owners who sought profitable methods to monetize their assets during the economic crisis (Airbnb, 2015). Yet, Airbnb failed to address the effects of its operations on long-term lease rentals, the real estate market, and the lifestyles of citizens.

The Hellenic Hotel Chamber also published an official report in 2015 on the operation and consequences of the sharing economy in the Greek hotel business. The report underlined that

The growth of Airbnb and other online platforms market in Greece is the result of a combination of global and domestic factors. In Greece, high property taxation and maintenance costs have pushed owners of holiday villas and homes to join the villa rental market as it is a very good way to produce income from the property. The outcome is that Airbnb and other house and villa rental platforms have gained a large market share in hospitality. The passing of Law 4179/2013 boosted the market's reputation by giving it an institutional framework that secures its sustainability. Based on the new legislation, Greek villa rental owners are obliged to register their villas with the Ministry of Tourism. As of 31/12/2014, approximately 6,500 villas were registered with the Ministry of Tourism (Hellenic Hotel Chamber, 2015).



Figure 11. Visitors to Acropolis archaeological site

According to this report, the combination of hotel rooms and short-term tourism leasing deprived the hotel sector of profits. Losses were also recorded at the level of public revenues because there was no institutional structure for the declaration and hence taxation of this activity.

The report also asserted that short-term leasing facilities have created a group of professionals who do not contribute proportionately to public finances but could further burden them. The physiognomy of the historic areas is also simultaneously downgraded because of the ongoing conversion of residences into tourist accommodation facilities and the development of uses entirely dependent on tourism. The report stated that the sharing economy replaced official tourist lodgings by 70%, while the hotel business suffered monetary losses of €523 million in 2014 because of the operation of short-term rental websites.

Rental rates increased due to lower offers for housing, causing financial losses to the state because of the absence of an institutional framework allowing the declaration and subsequent taxation of this activity. Hence, losses were recorded in public revenue. In particular, a noteworthy drop was observed in available long-term lease housing, long-term lease rents increased, and senior tenants were evicted, either directly through contract non-renewal or indirectly through unexpected rent hikes.

Finding long-term rental housing in Athens' center was extremely difficult over the next few years. The supply of rental units fell by 30.9% in two years, from 21.4% in 2015 to 14.8% in 2017. Property values in the city center rose, and hikes of 15%–20% were noted in apartment prices because of the increased demand.

Airbnb's widening operations (Fig. 12) changed the management status of the built environment in Greece. On the one hand, property owners turned their properties into tourist accommodations foreseeing an increase in their incomes. On the other hand, the extent of the phenomenon triggered chain reactions in the real estate market, leading to profiteering in the absence of any institutional framework or state control.

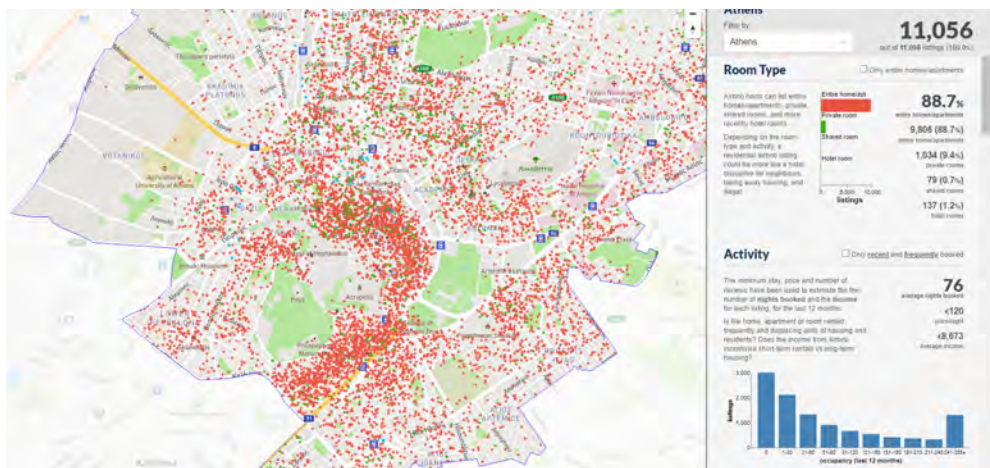


Figure 12. Airbnb listings in Athens historic center (2022)

Greece enacted a law in 2017, mandating the reporting of income from short-term leases by owners as well as rent from long-term leases. However, this legislation did not define timelines and geographical restrictions. These measures were oriented primarily toward the financial benefit of state agencies from short-term leasing without considering the effects of this development on urban conservation.

The increase in tourist interest because of the widespread increase in short-term leases instigated a growth in the commercial value of real estate in specific areas. The difference in commercial and objective values touched 30% in some areas. The differentials between the two values also allowed lower taxation of specific properties.

Recently, the Greek Ministry of Tourism has enacted Law 4875/2021 in 2021 to control overtourism. This law has instituted the Management and Promotion Destination Organization following Barcelona's standards. It aims to create, support, and implement tourism policy development and study, monitor, and upgrade tourism-related infrastructure and public services. It will also devise a strategic plan to develop and manage sustainable tourism at popular destinations, execute contracts with private sector agencies to promote destinations, and develop research projects on important tourism issues.

A survey conducted by the Hellenic Hotel Chamber in 2022 disclosed that the state lost profits above 300 million euros in that year because of the operations of 129,000 short-term rental accommodations. Also, short-term leasing deprived hotels of an additional 39,000 jobs a year (Grant Thornton Company, 2022). The survey report proposed setting temporal and spatial restrictions at a maximum rental limit of 90 days per year and recommended the establishment of minimum technical and functional specifications (e.g., minimum room area of 10 sq.m., natural lighting, maximum number of rooms, hygiene and fire safety certification, etc.). Conversely, owners' organizations note that the promoted measures would result in the complete financial strangulation of property owners, their managers, employees, and families as well as suppliers, businessmen, shopkeepers, and the local communities of Greece instead of regulating tourism. Such suggestions would cause an immense loss of public revenue, which would require the imposition of additional taxes at the expense of the citizens. Tourism remains Greece's heavy industry in the post-COVID-19 period, and no certain restrictions are yet defined for short-term leasing in the historic areas.

3. Strategies to manage overtourism in historic centers

Historic centers represent elements of culture and inherited values. They act as repositories of the collective memories of communities and their tangible as well as intangible assets should be conserved. Historic cities are dynamic and constantly evolving locations that must be modified to suit the requirements of modern societies. They must simultaneously preserve their historic elements to serve the needs of their residents as well as visitors.

Overtourism is a common phenomenon in historic centers. It accrues economic benefits but threatens the social structures, environmental protection, and cultural conservation of such

heritage sites. The increase in tourist accommodation facilities, the changing usage of housing stock, and rising local housing costs represent major challenges for the examined historic centers.

Policies have been instituted to attempt to control the above phenomena. However, the established policies appear to focus mainly on taxation, which represents a fragmental means of resolving a problem based on diverse elements. This examination of three historic centers presenting the effects of overtourism revealed the importance of defining the extent of acceptable changes and defining the holding capacities of the locations to ensure their cultural protection, social cohesion, environmental protection, and economic development. A tourist destination's key indicators and developing difficulties must crucially be identified. The increase in unlicensed tourist accommodations, modifications in the use of housing stock, changing shop offers, and rising local housing costs denote some common challenges and difficulties.

The present examination of the three cities divulged that numerous policies presenting both similarities and differences were applied in all instances. A common policy of taxation was observed: this course of action is divisive because the taxes are too inexpensive in some cases to dissuade visitors, but it allows local governments to generate funds to subsidize tourism management. Interestingly, the prevailing economic circumstances and political forces also shape distinct policies in all the studied cases, along with the degree of overtourism. Barcelona has attempted in many ways to control overtourism but has still not achieved the desired results. Interestingly, nevertheless, recent policies apropos specialized restrictions based on the particularities of certain areas in Barcelona and the monitoring and assessment of the effects of tourism-related activities on the city's historic, social, and economic capital have been instituted via participatory processes undertaken by all stakeholders. Venice is extremely dependent on tourism and simultaneously very vulnerable to climate change. This heritage city has focused on taxation, which has not yet proved an effective tool to control overtourism. Athens has confronted the effects of overtourism in the last decade but at slower rates compared to Barcelona or Venice. Profit is a stronger motivator than conservation for a country facing an economic crisis. Some general restrictions are defined but these measures have not achieved the desired control on changes to the city's land use and social structure.

Therefore, historic cities must develop specialized urban plans through participatory processes to protect their local communities from the effects of overtourism.

Tourism is an important sector for the economic development of historical centers. However, tourism should be managed to achieve a balance between permanent residents and

visitors. Finally, historic areas must not be downgraded by overtourism. Rather, historic cities could transform the very nature of tourism activities and transfigure the tourist experience by attracting travelers as temporary residents. In so doing, they could alter the dynamics of tourism and modify the conventional host-guest relationship.

References

- Airbnb, (2015). *AIRBNB'S Positive impact in Athens*, s.l.: s.n.
- Anon. (2023). *All You Need to Know About Park Guell in Barcelona*. [Online] Available at: <https://www.park-guell-tickets.com/park-guell-barcelona/> [Accessed 02 01].
- Barcelona City Council (2012). *The design sector in Barcelona*, Barcelona: Barcelona City Council.
- Barcelonayellow.com (2013). *Barcelona's most famous street is La Rambla*, s.l.: s.n.
- Bubola, E. (2022). *Venice, Overwhelmed by Tourists, Tries Tracking Them*, s.l.: NY Times.
- City of Athens. (2017). *Redefining the city: Athens resilience strategy towards 2030*, Athens: City of Athens.
- D'Eramo, M., 2017. *Il Selfie del Mondo. Indagine Sull'età del Turismo*. Milano: Feltrinelli.
- Datzira-Masip, J. (2006). Cultural heritage tourism — opportunities for product development: The Barcelona-Case. *Tourism Review*, Vol. 61 No. 1, pp. 13-20.
- Davis, R. & Marvin, G. (2004). *Venice, the tourist maze: a cultural critique of the world's most touristed city*. California: University of California Press.
- Espiga, F. (2015). *Barcelona licence freeze*, s.l.: s.n.
- European Association of Historic Towns and Regions. (2006). *Sustainable Cultural Tourism in Historic Towns and Cities*, Dublin: European Association of Historic Towns and Regions. European Parliament. (2018). *Overtourism: impact and possible policy responses*, s.l.: TRAN Committee, Policy Department for Structural and Cohesion Policies.
- Fabbri, G., Migliorini, F. & Tattara, G. (2020). *Venezia, il dossier UNESCO e una città allo sbando 2nd ed.* s.l.: Libreria Editrice Cafoscarina..
- Goodwin, H. (2019). *Managing Tourism in Barcelona, Working Paper 1. 3rd Edition*, s.l.: Responsible Tourism Partnership.
- Goodwin, H. (2017). *The Challenge of Overtourism*, s.l.: Responsible Tourism Partnership Working Paper.
- Goodwin, H. (2019). *Responsible Tourism Partnership Working Paper 1 (3rd edition)*, s.l.: Responsible Tourism Partnership.
- Grant Thornton Company (2022). *Special Report for Sharing Economy*, Athens: s.n.
- Hellenic Hotel Chamber (2015). *Greek hospitality report*, s.l.: s.n.
- Koens, K., Postma, A. & Papp, B. (2018). Is Overtourism Overused? Understanding the Impact of Tourism in a City Context. *Sustainability* 2018.
- Lomas, N. (2016). *Airbnb faces fresh crackdown in Barcelona.*, s.l.: s.n.
- Martins, M. (2018). Tourism planning and tourismphobia: An analysis of the strategic tourism plan of Barcelona 2010–2015. *Journal of Tourism, Heritage & Services Marketing (JTHSM)*, 4(1), pp. 3-7.
- Nastase, M. (2016). *The Impact of Tourism on Barcelona, Spain*, s.l.: s.n.
- Observatori del turisme a Barcelona (2022). *Barcelona 2022- Tourism activity Report*. [Online] Available at: https://www.observatorituristicbarcelona.com/sites/default/files/2022_Informe_Activitat_Tur%C3%ADstica_BCN_C%C3%A0psula_1.pdf

- Petrova, P. & Hristov, D. (2016). Collaborative management and planning of urban heritage tourism: public sector perspective.. *International Journal of Tourism Research* 18(1)., pp. 1-19.
- Rabassa, J. & Ibarra, S. (2020). The Land Use Plan for Ciutat Vella: Protecting community life. *The city after the pandemic*, 05, pp. 62-73.
- Sánchez-Aguilera, D. & González-Pérez, . J. (2021). International Residential Mobilities. Geographies of Tourism and Global Change.. In: J. Dominguez-Mujica, J. McGarrigle & J. Parreño-Castellano, eds. *Geographies of Gentrification in Barcelona. Tourism as a Driver of Social Change*.. s.l.:Springer, Cham..
- Tourism and Events Department (2014). *Barcelona's tourism activity: development and management*, Girona: INSETUR Higher Institute for Tourism Research.
- Vascuez, E. & Davila, J. (2020). Turismofobia: un análisis social desde los medios de comunicación.. *Boletín Científico INVESTIGIUM*, 5(10). pp. 33-37.
- Verhoeven, G. (2019). Young Cosmopolitans: Flemish and Dutch Youths and Their Travel Behaviour (From the Late Sixteenth to the Eighteenth Century). In: P. Sweet, G. Verhoven & S. Goldsmith, eds. *Beyond the Grand Tour: Northern Metropolises and Early Modern Travel Behaviour*. s.l.:Routledge.
- Vianello, M. (2017). The no Grandi Navi campaign: protests against cruise tourism in Venice. In: C. Colomb & J. Novy, eds. *Protest and Resistance in the Tourist City*. London: Routledge, pp. 185-204.
- Vollmer, A., & Bisjak, H. (2022). *Mapping Gentrification in Barcelona*, s.l.: s.n.
- von Briel, D., & Dolnicar, S. (2020). The evolution of Airbnb regulation - An international longitudinal investigation 2008-2020.. *Annals of Tourism Research*.
- World Cities Culture Forum (2019). *Number of international tourists per year*, s.l.: s.n.
- World Tourism Organization (UNWTO) (2018). 'Overtourism'? – *Understanding and Managing Urban Tourism Growth beyond Perceptions*, Madrid: World Tourism Organization (UNWTO); Centre of Expertise Leisure, Tourism & Hospitality; NHTV Breda University of Applied Sciences; and NHL Stenden University of Applied Sciences.
- Zannini, A. (2014). *Il turismo a Venezia dal secondo dopoguerra ad oggi*, s.l.: Laboratoire italien.

CHAPTER 8

INDUSTRIAL HERITAGE: NEW PARADIGMS FOR NEW CONSERVATION CHALLENGES

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Abstract

Industrial heritage (IH) is a relatively new field of study compared to other cultural heritage disciplines, such as painting and sculpture. IH objects are material testimonies of technical and industrial practices (e.g., a steam machine from a factory allows us to understand how the energy for the factory running was produced and what were the human and material resources involved). Their safeguarding depends on preserving material evidence of the technical and industrial practices, along with material stabilization. Although the importance of IH heritage is recognized, there is still a gap between conservation guidelines and their practices. The methodologies used are primarily adapted from other disciplines, with their responses conditioned by the unique characteristics of IH objects, such as objects composed of a wide range of materials with distinct dimensions and the possibility of conservation under different operational conditions (e.g., static or running). Recently, this situation has been reversed, and conservation of IH objects based on multidisciplinary approaches has emerged. Although these studies are still inadequate, they approach new science-based techniques to assess the conservation state of IH objects, new conservation techniques, and decision-making models addressing conservation challenges and facilitating the definition of new paradigms for the IH heritage. This chapter describes the main challenges of IH heritage conservation and the research developed in recent years to define the paradigms for this unique heritage preservation.

Keywords: Industrial heritage, conservation, science-based techniques, coatings, lubricants, management tools

1. Conservation of Industrial Heritage

The preservation of industrial heritage (IH) has been discussed since the 1970s. However, its conservation practice, encompassing the definition and implementation of methodologies, is relatively new compared to other cultural heritage disciplines (Licardi 2013). Therefore, conservation assessment, intervention, and maintenance methodologies for IH objects are still open questions. The current procedures are largely adapted from other disciplines, thereby limiting their effectiveness toward the specific features of IH objects. To overcome this limitation, new methods need to be defined. Hence, it is necessary to identify the most pressing IH conservation issues and associated challenges.

IH covers a broad range of distinct objects. This research focuses on industrial machinery, which depends on its industrial context and usage. The close relationship between machinery and its function enhances the importance of valuing and preserving the physical evidence that provides information about industrial activities.

The significance of preserving industrial material evidence has been emphasized for decades (Lindsley and Smith 1975). However, the methods available at the time and a lack of IH-impaired conservators hampered its implementation, contributing to the vulnerability of IH. In the following years, the importance of developing intervention methods for IH machinery, involving interdisciplinary collaborations and the implementation of procedures for the conservation and display of machinery in operational conditions, was extensively studied (e.g., Bos 1981; Buchananm 1978; Cossons 1978; Vanderhulst G. 1992; Hills 1981). However, although these requirements were enunciated decades ago (Kühn 1989), the methodologies for IH conservation have yet to be implemented.

This situation results from several factors, including the diversity and dispersion of objects and the institutional contexts of preservation of industrial sites (Mirambet-Paris and Mirambet 2011); the same is true for scientific heritage (Lourenço and Wilson 2013).

Multiple components made of a remarkable variety of materials, which includes metal, wood, glass, leather, organic and inorganic coatings, and lubricants, with different sizes and the possibility of preservation in distinct operational conditions, comprise the machinery manufactured and used in the industrial settings. As a result of the absence of conservation methodologies and programs, engineers and other non-specialized conservation personnel often intervene based on induction-specialized procedures (without the supervision of conservators-restorers (Knapp 2004). Their primary objective is the visual and operational recovery of the machinery, disregarding the preservation of physical evidence and its historical

values. There are occasional contextualized intervention works with the objective of valorizing the objects' material evidence despite the prevalence of intervention techniques founded on industrial practices (e.g., Bruggerhoff 2007; Casey 2007; Dempwolf 2006; Jeanneret and Bargholz 2013; Tissot et al. 2021; Witt 2019).

Recently, a community interested in developing conservation methodologies focused on conservation management plans (e.g., Barr 2006; Brueggerhoff, Goetz, and Tempel 2010; Karsten et al. 2013; Romanos and Russell 2010; Wain 2004a, 2004b, 2017) emerged. This interest is partly a consequence of the engagement with issues of the operability of machinery in operational conditions (Hallam 2007). The prevalence of management plans emphasizes the need to establish methodologies for conservation evaluation and intervention. However, guidelines for IH conservation have been published (Ball, Andrew, and Winsor 2009; Bryan 2018; Paine 1994). Except for specific cases (Dungworth and Paynter 2006), these guidelines lack in diagnosing methods, in the potentiality of the state of conservation assessment as a source of information for preservation, and in a working basis for the definition of conservation and restoration interventions.

In this work, we discuss the current challenges of IH conservation and the work and research that has been undertaken to address these challenges, and we point out possible future research lines.

2. Toward new paradigms for IH conservation

The current challenges and direction of research for IH conservation are established based on the state of the art, which include:

- increasing knowledge about materials and degradation mechanisms;
- developing treatments adapted to the characteristics of IH objects; and
- establishing decision-making and management tools.

By addressing these features, it will be possible to increase knowledge about materials, achieve more detailed and informed conservation assessments, decrease the vulnerability of IH machinery, and contribute to preserving it.

New treatments will reduce the cost and duration of intervention, factors that often dissuade and justify the option for maintenance based on industrial methods. The decision and management tools enable the formulation and implementation of plans for sustainable maintenance.

2.1. State of conservation assessment

The state of conservation assessment is key to defining a conservation program for a given IH machinery. In most cases, the conservation assessment is based on visual inspection of the machinery with several advantages, including early detection of potential issues, enhanced safety, and cost savings. Despite these advantages, some potential disadvantages remain, such as human error and the limited scope for accurate identification of materials and their degradation products and the inability to detect failures in the internal structure and mechanisms.

In some cases, science-based techniques are a way to supplement the accuracy and effectiveness of IH machinery visual inspection. These include techniques to characterize machinery materials that are currently applied to other cultural heritage areas and others that are used in modern industrial inspection to study machinery's physical, chemical, and mechanical properties.

The material characterization includes the analysis of the composition, structure, and properties of materials used in machinery. By understanding the materials' properties, conservators can foresee the machinery's behavior when exposed to external environmental parameters, such as temperature, humidity, and pollutants. Some techniques can be applied in situ using portable equipment (e.g., X-ray fluorescence spectroscopy). Others involve using laboratory-based instruments, requiring a sample collection (scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDS), micro-Raman spectroscopy).

Industrial inspection methods, such as nondestructive testing (NDT) comprise various imaging and sensing techniques, to evaluate the structural integrity of machinery without causing damage or the need to dismantle the mechanical parts completely. These can help to identify by, as cracks, internal corrosion, and deformation, that can lead to failure or malfunction of the equipment.

In this context, the application of science-based techniques in IH machinery has challenges that include machinery complexity (e.g., excellent dimensions with multiple components of different sizes made of a wide range of materials), the existence of materials resulting from maintenance actions (e.g., new coatings, over-lubrication), and the need to use nondestructive and noninvasive techniques.

Although the advantages of science-based techniques for evaluating the state of conservation of IH machinery are well known, their application is still limited. In 2006, the English Heritage published guidelines for the investigation of 17th- to 19th-century industries describing the use of visual inspection, low-power microscopy, high-power microscopy,

elemental analysis, analysis of compounds, and physical testing for IH objects (Dungworth and Paynter 2006). The application of these techniques is illustrated with case studies on five common industries, including iron, glass, pottery, tanning, and textiles. However, these guidelines do not approach the state of conservation issues.

Integrated scientific works considering science-based techniques for the IH conservation assessment have become more common since 2006. Nevertheless, they are primarily committed to the corrosion of metals and degradation of coatings, excluding the conservation assessment of the dynamical behavior of machinery.

Metal corrosion investigation was conducted on historic military vehicles (Boesenberg 2006, Saeed et al. 2011, Saeed and Khan 2013), on metallic fire extinguishers collection (Diaz Cortés et al. 2020) as well on several IH structures (Kreislóva, Knotková, and Geiplová 2013) preserved under different environmental conditions. By investigating cross-section samples from the metallic substrate of military vehicles using XRF, ultrasonic scanning, and SEM–EDS, the authors collected data on the elemental composition, the material loss due to corrosion, the metallic microstructure, inclusions, pits, and sub-surface cracks. The results provided knowledge of the materials used in historical machinery. They highlighted the importance of the influence of environmental parameters on corrosion processes, as Kreislóva et al. (2013) emphasized for IH structures. Notably, the authors considered it essential to proceed with a further investigation related to empirical models to predict the life span of the military vehicles based on the remaining thickness of the collected samples.

The investigation of metal corrosion mechanisms of a collection of metallic fire extinguishers by XRF and X-ray diffraction (XRD) revealed the elemental composition and the crystalline phases of corrosion products. The results indicated that the corrosion of some fire extinguishers was related to their respective fire extinguishing agents (foam and water), with the removal of the water or foam from their interiors deemed necessary for their future preservation. These material studies are essential contributions to conservators. IH objects are composed of distinct materials (e.g., foam from fire extinguishers), many of which have unknown behavior in the long term. The more detailed the information on materials is, the more accurate the conservation procedures can be.

Regarding coatings, there are studies published on their degradation mechanisms from diesel and steam engines (Dempwolf 2006, Manso and Tissot 2021, Tissot et al. 2021), footbridge (Costantini et al. 2022), and other IH structures (Kreislóva et al. 2013). These studies considered microscopic observations of cross-sectioned samples of the paint systems supplemented with SEM–EDS, micro-XRF, and micro-Raman spectroscopy analyses. SEM

images showed the morphology of the paint systems; EDS and micro-XRF spectroscopies describe their elemental content; and Raman spectroscopy reveals the structural information of the chemical compounds. In addition to the composition of the coatings, it was possible to interpret modifications of the coatings resulting from their use, such as alteration due to high temperatures during the engine functioning.

With a few exceptions (e.g., Manso et Tissot 2021), these studies primarily concentrate on collected samples for laboratory analyses, excluding portable equipment (e.g., portable XRF). This situation can be justified by two reasons: the stratigraphic study of coating is fundamental to the paint system knowledge (e.g., the number of layers, alteration in-depth, etc.), and the presence of high amounts of lubricant, dirt, corrosion, etc. on the IH machinery hampers the correct material characterization. Although sampling large objects may have a low impact on the machine structure, it is necessary to ensure that the samples taken are representative of the paint systems and their possible changes depending on the conditions of machine use (e.g., the existence of temperature gradients during use, maintenance actions, etc.).

Research using nondestructive testing methods to infer the mechanisms' dynamical behavior is extremely limited. Brambilla et al. (2021) assessed the moving mechanism of three historic vehicle engines with acoustic emission testing. Although the potential of this tool was recognized, the need to apply it in other historical engines to verify the repeatability of the methodology was highlighted. Manso and Tissot (2021) reported the mechanisms' state of conservation of an early 20th-century steam machine in operating conditions for demonstrative purposes. Gamma radiography, magnetoscopy, and thermography were used to inspect the engine's structural components for identification of cracks, fractures, and vapor leaks, and vibration analysis to provide a way for monitoring the mechanisms. Despite the obtained information, experimental methodologies using these techniques, conceived for current industrial equipment, must be applied to IH machinery, which has different assumptions, thereby requiring the equation of experimental conditions. However, in a museum, the different materials and wear profiles of historic equipment operate under reduced load and frequency unlike modern machinery and will require the identification of appropriate condition indicators, the determination of reference lines representative of their condition, and the investigation of profiles representing both regular and advanced wear.

Recent interdisciplinary and international projects (e.g., ACUME_HV, Switzerland; COMPACT, Spain; IH4Future, Portugal) (Brambilla 2018; Cano 2018; Manso 2018) may be contributing to an increase in the number of published studies on the use of science-based techniques to investigate IH objects. Nonetheless, there is a need for further research on the

topic, particularly concerning the applications of contemporary industrial inspection techniques. Increasing research on using science-based techniques on IH machinery will improve knowledge and attain the critical mass required for analytical protocol developments, hence providing science-based conservation assessments.

2.2. Conservation practices

In our opinion, the relative dimensions of some machinery and the existence of dynamic systems are the two main features that necessitate reevaluating conservation methods. The coating cleaning and lubrication processes are the most challenging tasks because, currently, the used methods disregard, in most cases, the preservation of the original surface in addition to being costly and not environmentally sustainable.

The methodologies to be developed and applied ought to guarantee the preservation of the original surface and marks of use, promote optimization of time and costs, and use environmentally sustainable processes.

2.2.1. Paint coatings

Many IH machinery have paint coatings applied with the dual function of decoration and protection of the metallic substrate. The substrate and coating alteration encompasses the formation of corrosion products that develop under the coating and promote its detachment with the deposition of corrosion products on the top of the coating (Jouet et al. 2021).

In these cases, the cleaning procedure aims at improving the surface reading by removing the corrosion products formed on the coating (with other materials deposited on the surface) and preserving the original coating if possible.

Typically, the methods used for these cleanings, if done by conservator-restorers, involve using chemicals (e.g., Ball et al. 2009; Grima 2020) with disadvantages for the health and environment owing to the usage of hazardous compounds. Moreover, it is difficult to guarantee chemical waste elimination, making the operation more hazardous and expensive. Alternatively, one can use mechanical cleaning by projecting abrasives, such as sand or water (Casey 2007; Witt and Stahn 2011). However, this technique also has the disadvantage of removing the abrasives, although less dangerous for the environment. In both cases, if we consider the intervention to machinery where mechanisms cannot be disassembled, the disadvantage of leaving both abrasive and water residues inside them can induce corrosion.

Recently, other methods have been explored and examined to address these disadvantages. Among them is the projection of CO₂ particles, which is called green cleaning, developed for

industrial applications with solid CO₂ particle projection under pressure. The cleaning mechanism is based on the combined effects of kinetic energy, thermal shock triggered by CO₂, and sublimation energy (Spur, Uhlmann, and Elbing 1999). The advantages of this method are the low hardness of the particles (between 2 and 3 on the Mohs scale) and the absence of abrasive residues as the particles sublime after collision with the surface (Stratford 1999).

This technique has been applied to remove bitumen layers and paint coatings from small metallic objects of cultural interest (Cutulle and Kim 2015). In large objects in an industrial context, we mentioned the case of the cleaning of a three-cylinder engine of the Tomar powerplant in Portugal (Tissot, Lemos, and Filipe 2016). In this case, it was possible to recover marks of use made on the coating layer and covered by corrosion products (Figures 1 and 2). The operation time decreases considerably, although the equipment and dry ice costs are high. Nevertheless, the time/cost benefit is positive.



Figure 1. A) The 1927 diesel engine from the Société Suisse de construction de locomotives et de machines (SLM) (Winterthur, Switzerland) installed at the Levada de Tomar powerplant (Portugal). B) Diesel engine cleaning process using CO₂ technique (Photos: M. Tissot, Archeofactu).

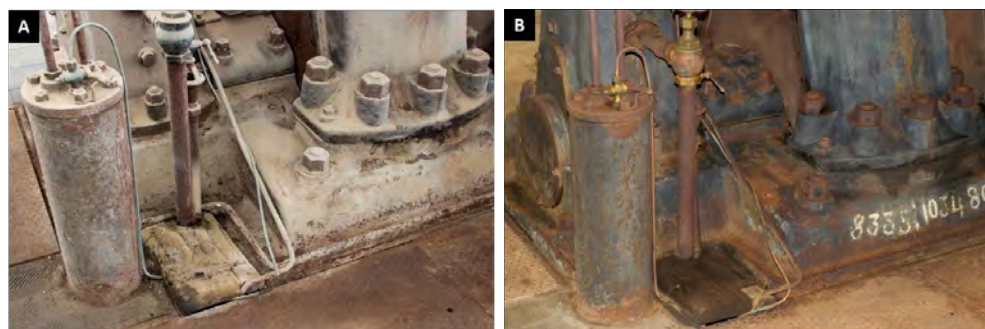


Figure 2. Detail of the 1927 diesel engine installed at the Levada de Tomar powerplant (Portugal) before (A) and after (B) cleaning using the CO₂ technique, revealing the original blue coating and marks of use made on the coating (Photos: M. Tissot, Archeofactu).

The scientific validation of the positive practical outcomes by conservator-restorers is still inadequate. Despite this, the research results indicate that CO₂ cleaning should be considered an alternative method. Researchers (Van der Molen et al. 2010; Schröter and Domjan 2016) investigated the effects of the CO₂ cleaning technique on the removal of organic layers on aluminium, brass, and Corten steel substrates. Three-dimensional confocal microscopy, SEM, and XRD analysis of the surfaces before and after cleaning revealed that the substrates were not considerably altered. Therefore, this method is a solution for cleaning large machinery. Although it has been practiced occasionally since the 2000s on cultural heritage objects, the community of conservators specialized in IH is still unaware of CO₂ cleaning as an effective alternative.

In some instances, it is impossible to preserve the original paint coatings. Replacement of coatings (partial or total) is reasonable when coatings are degraded with substantial detachment, loss of protective function, and a high risk of substrate corrosion. The evaluation and decision for coating removal should consider the loss of authenticity and the compatibility and stability of the materials, among others.

Some studies addressed this issue by considering the application of transparent protective layers (Bruggerhoff 2007; Mottner et al. 2004) and new coating systems (Casey 2007) applied to protect the substrate. Researchers (Mottner et al. 2004) tested transparent coatings and lacquers, such as polyurethane, polyester, ketonic resin, oil, and an inorganic–organic hybrid system (OMORCER®). These coatings were tested on steel specimens in aging chambers. Preliminary results indicated that the various compounds were stable and constituted a promising option for substrate protection. However, these studies did not anticipate long-term alteration or detail the complexity of applying these layers to large objects (e.g., ensuring the application of homogeneous layers). Casey (2007) reported applying a paint system on the Victorian steamship *Great Britain* consisting of epoxides and polyurethanes. The author did not specify why this system was chosen and whether it was tested before. This situation demonstrates the void still exists in studies on applying new paint systems to IH objects.

Another subject related to coatings is investigating solutions for crevice corrosion when overcoating, i.e., applying new layers without removing the previous ones (Wentland 2021). Wentland (2021) proposed using dewatering fluids to protect crevice areas. Although dewatering fluids have been used in conservation since 1990, few scientific studies support their application.

2.2.2. Lubricants

The conservation of machinery motion permits the demonstration of mechanical movements and operations. Lubrication is required to prevent corrosion and mechanical degradation. Applying a lubricant will, on the one hand, prevent contact between metal surfaces and avoid wear and tear phenomena and, on the other hand, prevent corrosion by acting as a barrier against moisture (Hallam, Asthon, and Ogilvie 2004). Furthermore, some lubricants have the advantage of having corrosion inhibitors as per their composition (CCI 2002).

In the early 2000s, the lubrication of the IH machinery issue was enunciated (CCI 2002; Hallam et al. 2004). The choice of a lubricant to use on IH objects should consider the maintenance and operating conditions of the machine (e.g., static, running for demonstration purposes, regular operation under original conditions). The Canadian Conservation Institute has indicated distinct lubrication methods for different exhibition conditions. They all involve using oils and greases, with more or less viscosity depending on whether the machine is operated occasionally or regularly (CCI 2002).

Although the need for regular maintenance is mentioned, the disadvantages of using oils and greases, such as the effects of over-lubrication, the influence of the lubricant modification on the corrosion of metal substrates, and the environmental sustainability of using oil-based lubricants are disregarded. Furthermore, replacing lubricants when the original supply runs out is not considered (Ball et al. 2009).

A few research has been developed seeking the use of dry lubricants, such as colloidal graphite, TiSiC and, depending on the type of machinery, even equating the use of moist steam lubrication (in the case of steam machines) (Rimmer 2021). However, unlike the cleaning methods, neither applications of these new lubricants on IH objects are representative, nor does scientific research support them. Considering the above, this is a research direction for which more questions can be answered.

2.3. Decision-making and maintenance plans

One major decision arises when considering preserving IH machinery: its conservation mode, whether static or functional (Ashton and Hallam 1990; Newey 2000; Pye 2023).

A machine preserved in operational condition and functioning provides a holistic understanding of the object, including its significance, how it functions, and intangible

characteristics, such as sound and scent (Casanelles and Douet 2013; Hallam and Thurrowgood 2004). Keeping the machinery safely running may require repairing and replacing parts and removing and applying new coatings and lubricants that may impact the machinery's authenticity (Ball et al., 2009). On the other hand, static mode conservation has the advantage of preserving the original components but the disadvantage of losing the perception of machinery functioning. This option can also pose a risk to the preservation of the mechanisms, as the lack of movement can result in the occurrence of cracks due to a constant static force in a given direction (Bryan 2018).

Several other questions can arise in connection with these options. For example, If a machine is kept operational, under what conditions is it viable to maintain it? What resources should be allocated to one or the other option? What is the limit of parts replacement to get a piece of machinery running without interfering with its authenticity?

The main question underlying all these is how to choose between options. Which parameters and inputs should be considered? This decision will be partly influenced by the conservation assessment condition and maintenance plan requirements (e.g., human and financial resources) (Ball et al. 2009; Romanos and Russell 2010). Recently, there has been an increased interest in proposing guidelines and defining conservation management plans for machinery kept in operational mode (Ball et al., 2009; Bryan, 2018). Although these guidelines discuss the authenticity of the object, with some exceptions (Oevermann 2019; Wain 2007), the discussion has focused on the material and primary resource aspects (human resources and funding required for conservation).

Preceding these plans, in our opinion, an integrated documentation of machinery and its exhibition context is missing. This documentation, in the form of a protocol, should consider the contributions of several experts and wider features related to the preservation of the IH (e.g., material and scientific culture, sustainability, and valorization of the IH).

Above all, this protocol should support the decision-making process and be a tool for conserving, managing, strategically planning, and promoting cultural heritage.

This approach is well known in built heritage (e.g., Bertolin and Loli 2018; Kioussi et al. 2013). The research process should involve defining a model adapted to IH machinery. To this end, based on the (Kioussi et al. 2013) structure of integrated documentation of built heritage, we proposed discussing a model for IH machinery integrated documentation (Figure 3).

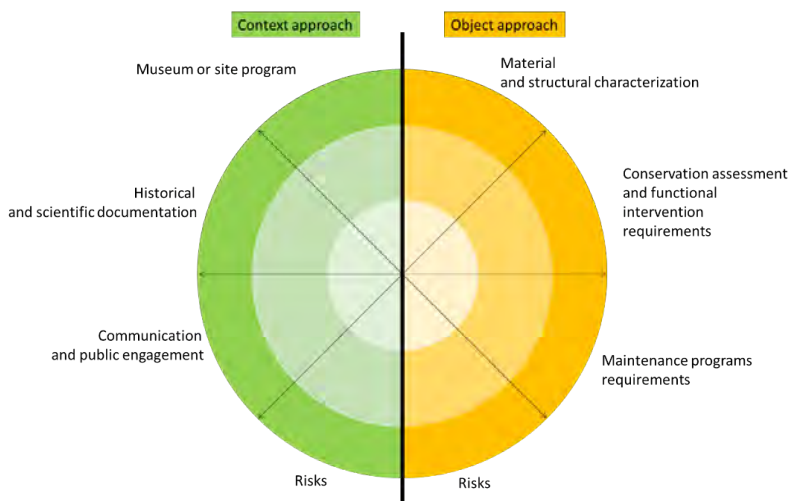


Figure 3. Proposed structure of integrated documentation protocols for industrial heritage machinery based on Kioussi et al. 2013.

As machinery conservation is strongly related to the location of use, the documentation protocol should consider two parts: the object and its context of preservation/use. The representation assumes a circular form that is divided into two halves (context and object approaches). Each half considers the key parameters that should be assessed. As one approaches the edge of the outer circle, the detail and complexity of the information increase in successive layers (Kioussi et al. 2013). The higher the quantity and quality of data, the better is the foundation for deciding on a particular mode of conservation and maintenance.

This structure also suggests inter and transdisciplinary approach, providing a more comprehensive evaluation. Considering the parameters for the context approach, we believe that information on the museum or industrial site programs, historical and scientific documentation, communication, and public engagement is necessary. The object approach assessment includes material and structural characterization, condition of conservation assessment, requirements for a dynamic intervention as opposed to a static one and management programs. The approaches involve the identification and assessment of risks.

The quantity of current data for each parameter will be shown visually to understand which ones require further development. The overall assessment will allow us to determine the reliability level of decision making.

Developing an integrated documentation protocol with this structure strongly depends on the research on industrial history, state of conservation assessment, and intervention methods for IH, which will contribute to accumulating data for each parameter.

3. Final remarks

The current challenges in IH conservation focus on developing methodologies for material characterization, state of conservation assessment, intervention and decision-making, and management tools. In this research, we discussed the main developments in IH conservation in recent years.

We demonstrated the potential application of science-based techniques to gather data on the materials used in industrial machinery, their importance to the history of the objects, and their conservation. Moreover, we highlighted the research on adapting industrial monitoring techniques (e.g., acoustic emission, vibrational analysis) for the mechanisms of IH machinery assessment. Although with a high potential of enhancing the knowledge of the history and conservation of IH machinery, practical applications of science-based methods are still inadequate.

The research for new intervention methods is one of the most advanced topics. Regarding cleaning methods, there are scientifically validated alternatives, such as CO₂ cleaning, suitable for the specificities of industrial heritage machinery (superlative dimensions and presence of mechanisms). With this cleaning, it is possible to remove corrosion products over paint coatings without interfering with the original surface, with the advantages of being faster and more environmentally sustainable. However, as it is necessary to invest in disseminating this method in the conservator-restorer community, its application is limited in practice. Conversely, we revealed the need for further research on lubricants for IH machinery. At this moment, although in a barely sustained way, new materials, such as solid graphite and TiSiC, have been tested in practice, their applications have yet to be investigated.

Finally, we discussed decision-making processes for the preservation of IH machine to contribute to the complex choice between conserving machinery in functional or static mode. The decision for the conservation of IH machinery requires the contribution of several experts (museumologists, historians, managers, and conservators). The need to establish integrated documentation protocols for developing a conservation tool was demonstrated, and a workflow structure was proposed for IH machinery. This tool previews data collection of distinct parameters (e.g., museum or industrial site policies, historical and scientific documentation, communication, and public engagement, assessment of the material and structural characterization, state of conservation assessment, requirements for a functional or static intervention, and management programs) related to the object and its context of preservation.

This research reflected the most recent research on IH conservation and drew attention to future research. The research on IH conservation helps value the IH and decreases its vulnerability.

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References

- Ashton, J., and D. Hallam. (1990). The Conservation of Functional Objects—an Ethical Dilemma. *AICCM Bulletin* 16(3), 19–26. doi: 10.1179/bac.1990.16.3.003.
- Ball, S., P. Andrew, and P. Winsor. (2009). *Larger & Working Objects: A Guide to Standards in Their Preservation and Care*. Collection Trust.
- Barr, J. (2006). The Conservation of ‘Working Objects’: Development of a Conservation Management Tool.
- Bertolin, C., & A. Loli. (2018). Sustainable Interventions in Historic Buildings: A Developing Decision-Making Tool. *Journal of Cultural Heritage*, 34, 291–302. doi: 10.1016/j.culher.2018.08.010.
- Boesenberg, J. S. (2006). Wrought Iron from the USS Monitor: Mineralogy, Petrology and Metallography. *Archaeometry*, 48(4), 613–31. doi: 10.1111/j.1475-4754.2006.00276.x.
- Bos, J. M. (1981). “Conservation and the Historical Alibi.” Pp. 109–16 in *Trans. 3rd Int. Congr. Conserv. Ind. Monum.*, edited by M. Nisser. Sweden: Nordiska museet.
- Brambilla, L. (2018). “ACUME_HV Acoustic Emission Monitoring of Historical Vehicles.” Retrieved February 23, 2023 (Acoustic Emission Monitoring of Historical Vehicles).
- Brambilla, L., B. Chalançon, A. Roda Buch, E. Cornet, G. Rapp, and S. Mischler. (2021). Acoustic Emission Techniques for the Detection of Simulated Failures in Historical Vehicles Engines. *European Physical Journal Plus*, 136(6). doi: 10.1140/epjp/s13360-021-01611-9.
- Brueggerhoff, S., Goetz, K., & Tempel, N. (2010). “Between Different Interests – Conservation Planning for Industrial Heritage Sites.” *Big Stuff 2010*. Retrieved February 23, 2023 (<https://bigstuffheritage.org/bigstuff-2010/>).
- Brueggerhoff, S. (2007). “Coatings for Industrial Heritage Surfaces – between the Poles of Aesthetics and Durability.” *Big Stuff 2010*. Retrieved February 20, 2023 (<https://bigstuffheritage.org/big-stuff-2007/>).
- Bryan, T. (2018). *Guidelines for the Care of Larger and Working Historic Objects*. Association of British Transport and Engineering Museums.
- Buchananm, R. A. (1978). “Industrial Monuments as the Subject of International Research.” Pp. 143–50 in *Trans. 2nd Int. Congr. Om Conserv. Ind. Monum.*, edited by W. Kroker. Bochum: Deutsches Bergbau-Museum.
- Cano, E. (2018). “La Conservacion De Los Metales En El Patrimonio Científico-Técnico.” Retrieved February 23, 2023 (<https://www.csic.es/es/investigacion/proyectos-de-investigacion/la-conservacion-de-los-metales-en-el-patrimonio-cientifico>).
- Casanelles, E., & J. Douet. (2013). “Conserving Industrial Artefacts Title.” P. 195 in *Industrial Heritage Re-tooled The TICCIIH Guide to Industrial Heritage Conservation*, edited by J. Douet. LEFT COAST PRESS INC.
- Casey, S. (2007). “Preventative Conservation of Large Scale Industrial Objects.” *Big Stuff 2007*. Retrieved February 22, 2023 (<https://bigstuffheritage.org/big-stuff-2007/>).
- CCI. (2002). “Lubrication for Industrial Collections.” *CCI Notes* 15/5.
- Cossons, N. (1978). “Regional Reports on Industrial Archaeology - Britain.” Pp. 115–24 in *Trans. 2nd Int. Congr. Conserv. Ind. Monum.*, edited by W. Kroker. Bochum: Deutschen Bergbau-Museum.
- Costantini, I., K. Castro, J. M. Madariaga, and G. Arana. (2022). Analytical Techniques Applied to the Study of Industrial Archaeology Heritage: The Case of Plaiko Zubixe Footbridge. *Molecules*, 27(11). doi: 10.3390/molecules27113609.

- Cutulle, C., & Kim, S. (2015). "Dry Ice Blasting in the Conservation of Metals: A Technical Assessment as a Conservation Technique and Practical Application in the Removal of Surface Coatings." Pp. 77–100 in AIC Objects Specialty Group Postprints, edited by E. Hamilton and K. Dodson.
- Dempwolf, T. (2006). Industrial Heritage Conservation: The Historic Diesel Power Station in Wustermark. *Studies in Conservation* 51(sup2), 76–81. doi: 10.1179/sic.2006.51.supplement-2.76.
- Díaz Cortés, A., Ramírez Barat, B., Perez-Chao, J.L., Llorente, I., Del Egido, M., & Cano, E. (2020). Diagnóstico Del Estado de Conservación de Colecciones Científico-Técnicas: Extintores Históricos Del MUNCYT. *Ge-Conservacion* 18(1), 7–19. doi: 10.37558/gec.v18i1.771.
- Dungworth, D., & S. Paynter. (2006). Science for Historic Industries. Guidelines for the Investigation of 17th- to 19th- Century Industries. Swindon: English Heritage.
- Grima, M. (2020). The Tod Head Lighthouse Lantern. The Conservation-Restoration of a Technical Object That Has Been Continuously Modified over the Years. *Architectus* 1(1(61)), 0–2. doi: 10.37190/arc200102.
- Hallam, D. (2007). "Ethical and Philosophical Issues of Operating Functional Objects." Big Stuff 2007. Retrieved February 23, 2023 (<https://bigstuffheritage.org/big-stuff-2007/>).
- Hallam, D., Asthon, D., & Ogilvie, C. (2004). "Corrosion, Wear and Corrosive Wear; the Story of Lubrification in Systems on Large Technology Object Store and Use." Big Stuff 2004. Retrieved February 20, 2023 (<https://bigstuffheritage.org/big-stuff-2004/>).
- Hallam, D., & Thurrowgood, D. (2004). "Preserving the Significance: Why the Journey Mattered More than the Car." Big Stuff 2004. Retrieved February 23, 2023 (<https://bigstuffheritage.org/wp-content/uploads/2020/10/Thurrowgood-and-Hallam-2004-Preserving-significance.pdf>).
- Hills, R. L. (1981). "Trans. 3rd Int. Congr. Conserv. Ind. Monum." Pp. 177–89 in Problems of displaying and working textile machinery in a museum, edited by M. Nisser. Sweden: Nordiska museet.
- Jeanneret, R., & Bargholz, W. M. Z. (2013). "Conservation restauration Du Générateur Nr. 10 de La Centrale Hydroélectrique de Rheinfelden (D)." Pp. 1–7 in E-FAITH 2013 - 7ème Rencontre Eur. Pour Le Patrim.Ind. Tech.
- Jouet, J., Chalançon, B., Genachte-Le Bail, A., Neuner, M., & Loeper-Attia, M. A. (2021). "Traitement Du Patrimoine Industriel En Metal Peint : Les Cas d'une Voiture à Pedales Euréka." in ICOM Métal 2021.
- Karsten, I., Lambert, S., Warren, S., & Michalski, S. (2013). "Managing Risks to Big Stuff: Risk Assessment and Reduction at the Canada Science and Technology Museum." Big Stuff 2013. Retrieved February 22, 2023 (<https://bigstuffheritage.org/big-stuff-2013/>).
- Kioussi, A., Karoglou, M., Labropoulos, K., Bakolas, A., & Moropoulou, A. (2013). Integrated Documentation Protocols Enabling Decision Making in Cultural Heritage Protection. *Journal of Cultural Heritage* 14(3 SUPPL), e141–46. doi: 10.1016/j.culher.2013.01.007.
- Knapp, C. (2004). "Professional Conservators in Practice: An Introduction to the Conservation of Air and Land Transport Collections." Big Stuff 2004. Retrieved February 23, 2023 (<https://bigstuffheritage.org/bigstuff-2004/>).
- Kreislova, K., Knotkova, D., & Geiplova, H. (2013). "Atmospheric Corrosion of Historical Industrial Structures." pp. 311–43 in Corrosion and Conservation of Cultural Heritage Metallic Artefacts. Elsevier.
- Kühn, H. (1989). The Restoration of Historic Technological Artefacts, Scientific Instruments and Tools. *Museum Management and Curatorship* 8(4), 389–405. doi: 10.1016/0260-4779(89)90005-8.
- Licardi, J. (2013). "The Conservator-Restorer Perspective." p. 45 in Approaches to industrial heritage what works?, edited by J. Cassar and R. Grima. Malta: The Farsons Foundation.
- Lindsley, S., Smith, S. B. (1975). "On Site Preservation of Industrial Monuments." pp. 55–68 in Trans. 1st Int. Congr. Conserv. Ind. Monum. Shropshire: The Ironbridge Gorge Museum Trust.
- Lourenço, M., Wilson, L. (2013). Scientific Heritage: Reflections on Its Nature and New Approaches to Preservation, Study and Access. *Studies in History and Philosophy of Science Part A* 44(4), 744–53. doi: 10.1016/j.shpsa.2013.07.011.

- Manso, M. (2018). "Material Culture, Scientific Culture: Industrial Heritage for the Future (IH4Future)." Retrieved February 23, 2023 (<https://sites.google.com/fct.unl.pt/ih4future/>).
- Manso, M., & Tissot, I. (2021). "Aplicação de Técnicas de Exame e de Análise No Estudo de Património Industrial." Pp. 43–56 in *Cultura Material, Cultura Científica: Património Industrial para o Futuro*, edited by G. Filipe, I. Tissot, and M. Manso. Lisboa: Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa.
- Mirambet-Paris, A., & Mirambet, F. (2011). La Conservation-Restauration Du Patrimoine Technique et Industriel Dans Le Cadre de La Loi Sur Les Musées de France, Une Mission Impossible ? *La Lettre del'OCIM* (135), 27–35. doi: 10.4000/ocim.874.
- Van der Molen, R., Joosten, I., Beentjes, T., & Megens, L. (2010). "Dry-Ice Blasting for the Conservation and Cleaning of Metals." Pp. 135–41 in *Metal 2010: Proceedings of the interim meeting of the ICOM-CC metal Working Group*, edited by P. Mardikian and E. Al. Charleston.
- Mottner, P., Roemich, H., Pilz, M., Brueggerhoff, S., & Kiesenberg, J. (2004). "Investigations of Transparent Coatings for the Conservation of Iron and Steel Outdoor Industrial Monuments." Pp. 279–88 in *Proceedings of the 2001 ICOM Metals*, edited by I. D. MacLeod, J. M. Theile, and C. Degriigny.
- Newey, H. (2000). Conservation and the Preservation of Scientific and Industrial Collections. *Studies in Conservation* 45(sup1), 137–39. doi: 10.1179/sic.2000.45.Supplement-1.137.
- Overmann, H. (2019). Good Practice for Industrial Heritage Sites: Systematization, Indicators, and Case. *Journal of Cultural Heritage Management and Sustainable Development* 10(2), 157–71. doi: 10.1108/JCHMSD-02-2018-0007.
- Paine, C. (1994). *Standards in the Museum Care of Larger & Working Objects*. London: Museums and Galleries Commission.
- Pye, E. (2023). Challenges of Conservation: Working Objects. *Science Museum Group Journal* 6(6). doi: 10.15180/160608.
- Rimmer, R. (2021). "The Pros and Cons of Wet Steam Lubrication." Webinar 2 Big Stuff Heritage. Retrieved February 23, 2023 (<http://bigstuffheritage.org/wp-content/uploads/2021/05/Big-Stuff-webinar-1-12-April-2021-corrosion-protection-coatings.pdf>).
- Rojas-Sola, J., & E. De la Morena-De la Fuente. (2018). Agustín de Betancourt's Double-Acting Steam Engine: Analysis through Computer-Aided Engineering. *Applied Sciences* 8(11), 2309. doi: 10.3390/app8112309.
- Romanos, J., & Russell, A. (2010). "A Conservation Management Tool for Functional Objects Conservation-Management Tool for Functional Objects." Big Stuff 2010. Retrieved February 23, 2023 (<https://bigstuff-heritage.org/big-stuff-2010/>).
- Saeed, A., Khan, Clark, M., Nel, N., & Smith, R. (2011). Non-Destructive Material Characterisation and Material Loss Evaluation in Large Historic Military Vehicles. *Insight: Non-Destructive Testing and Condition Monitoring*, 53(7), 382–86. doi: 10.1784/insi.2011.53.7.382.
- Saeed, A., & Khan, Z. A. (2013). "Corrosion Damage Analysis and Material Characterization of Sherman and Centaur — The Historic Military Tanks." (February). doi: 10.1520/MPC20120016.
- Schröter, J., & Domjan, A. (2016). Le Nettoyage Cryogénique Des Métaux : Évaluation Du Procédé Appliqué Au Patrimoine. *Conservation-Restauration Des Biens Culturels CRCB*, 34, 19–25.
- Spur, G., Uhlmann, E., & Elbing, F. (1999). Dry-Ice Blasting for Cleaning: Process, Optimization and Application. *Wear*, 233–235, 402–11. doi: 10.1016/S0043-1648(99)00204-5.
- Stratford, S. (1999). Dry Ice Blasting for Paint Stripping and Surface Preparation. *Metal Finishing*, 97(5), 481–87. doi: 10.1016/S0026-0576(99)80815-0.
- Tissot, I., Fonseca, J. F., Tissot, M., Lemos, M., Carvalho, M.L., & Manso, M. (2021). Discovering the Colours of Industrial Heritage Characterisation of Paint Coatings from the Powerplant at the Levada de Tomar. *Journal of Raman Spectroscopy*, 52(1), 208–16. doi: 10.1002/jrs.5924.

- Tissot, M., Lemos, M., & Filipe, G. (2016). "Power Plant in Levada de Tomar: The Conservation and Musealisation of Industrial and Technical Heritage." in ICOHTEC 43rd Annual Meeting. Porto.
- Vanderhulst, G. (1992). "L'industrie, l'homme et Le Paysage." Pp. 15–27 in *Ind. Man Landsc.*, edited by G. Vanderhulst. Brussels: The International Committee for the conservation of the Industrial Heritage.
- Wain, A. (2004a). "A Well-Planned Operation." in *Big Stuff 2004*.
- Wain, A. (2004b). "Organising an Effective Maintenance Plan for Big Stuff." *Big Stuff 2004*. Retrieved February 22, 2023 (<https://bigstuffheritage.org/big-stuff-2004/>).
- Wain, A. (2007). "Large Technology Projects – Success and Sustainability." *Big Stuff 2007*. Retrieved February 20, 2023 (<https://bigstuffheritage.org/big-stuff-2007/>).
- Wain, A. (2017). "The Importance of Movement and Operation as Preventive Conservation Strategies for Heritage Machinery." *Journal of the American Institute for Conservation* 56(2):81–95. doi: 10.1080/01971360.2017.1326238.
- Wentland, E. (2021). "Research for Protective Coatings for Industrial Heritage Aiming to "preserve an Authentic Feel and Look." Webinar Big Stuff Heritage Coatings. Retrieved February 20, 2023 (<http://bigstuffheritage.org/wp-content/uploads/2021/05/Big-Stuff-webinar-1-12-April-2021-corrosion-protection-coatings.pdf>).
- Witt, G. (2019). "Two Ways of Overcoating of World War II Free-Weathered Weapons (an Antiaircraft Gun and a Searchlight) for Outdoor Coastal Display." *Big Stuff 2019* 1–3. Retrieved February 22, 2023 (<https://bigstuffheritage.org/big-stuff-2019/>).
- Witt, G., & Stahn, U. (2011). "A Giant Moor Plough and an Encrusted Typewriter. The Conservator as the Objects' Advocate." pp. 1–5 in *International Council of Museums (ICOM), ICOM-CC 16th Triennial Conference*.

CHAPTER 9

A COMPREHENSIVE APPROACH TO OCCUPATIONAL HEALTH AND SAFETY PLANNING: CONSIDERING MATERIAL ANALYSES IN RESTORATION AND CONSERVATION STUDIES

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Abstract

Occupational health and safety in restoration and conservation works is considered only as repair or constructional works due to the action of these projects, but this approach will be incomplete especially for these projects where exposure to hazardous substances is a significant risk. In addition to organizing the methods to be used during the works, areas, materials, scaffolding and similar items according to current standards and international admissions, a work safety program is created during these repairs according to the qualities of the materials contained in the works, ensuring that the precautions to be taken are complete. It is very important to determine the hazards and risks correctly for each work and to plan the occupational safety measures according to these completely determined hazards as the hazards and risks may differ from project to project. Accurate analysis of the authentic or repair materials that constitute the architectural heritage, art objects, movable or immovable cultural assets and the comparative evaluations of the obtained results will both ensure that appropriate restoration and conservation practices to be carried out and that correct occupational health and safety measures to be taken during these implementations. Cultural assets contain construction technologies and materials from different periods and many materials whose damage was not known at the time of their manufacture appear as a danger in today's restoration-conservation works. Starting the restoration and conservation projects without determining these hazardous materials and including these determinations in occupational safety studies may expose dangers and risks that may even affect public health, depending on the scale of the project. In this study, the importance of material analysis for the complete planning and implementation of occupational health and safety in restoration and conservation projects is addressed with measures that can be taken according to the results of correct evaluation and material analysis.

Keywords: Restoration, conservation, material analysis, risk management, occupational health and safety

1. Introduction

The concept of conservation is the whole of scientific studies that include the practices that are carried out by taking into account the cultural assets, material properties, construction techniques, its deteriorations, factors that cause deterioration and without disturbing the physical and chemical structure of the cultural assets. Although the purpose of preventive and effective protection is to protect the work, each application may contain different types of studies, dangers and risks together. Restoration activities, on the other hand, consist of technical interventions when considered under the umbrella of the protection of cultural asset.

As each work is different from the other in conservation and restoration works, the structural problems, material properties and applications to be made vary. For this reason, there are many different elements that need to be reviewed in terms of occupational health and safety in a conservation and restoration project. While the risk factors that arise in architectural restoration works are difficult to overlook due to their large volume and amount, a painting restoration requires taking full precautions due to the possibility of containing toxic components such as arsenic and mercury, which are much more harmful although the risk factor is small. The nature of the conservation work is the basis for determining the measures to be taken according to the applications to be made, but a complete planning is possible with the data obtained from the material analyzes and researches.

In this study, hazards and risks are examined through material samples and the precautions that can be taken are presented together.

2. Mortars

Mortars and concretes employed in ancient structures concern composite materials which have exhibited excellent durability through time. They were used as lining materials in cisterns, wells, aqueducts, shafts and duct drains, as supporting materials for pavements and mosaics, as plasters on external and internal walls, as supporting materials for frescoes and as joint mortars on masonry structures. They were comprised of various binding materials (or mix of them) and natural or artificial aggregates, along with natural or artificial pozzolanic additions, primarily of volcanic origin, that improved their performance and prolonged their longevity (Moropoulou et al., 2005). Mortars, which are a mixture in principle, can be risky according to the types of materials they contain, especially when considering large architectural structures or works in archaeological sites. In this context, it would be healthier to make an evaluation according to the binders, aggregates and additives that make up the mortars.

2.1. Binding materials of mortars

2.1.1. Soil

Soil, as a binding material that has survived from ancient times to the present day, is a mixture of very small granules that arise from the crumbling of rocks in nature over time and the decay of organic materials under the influence of physical and chemical reactions. It consists of different fractions as clay, silt and sand according to the size of the particles. The size of the clay particles is less than 0.005 mm. The primary constituents of argillaceous soils are hydrated silicates and aluminas, but they can also contain iron oxide, calcium oxide, magnesium oxide, alkalis and sand. Silicate minerals constitute a significant part of the clay fractions of the soils (Sumner, 2001).

When considered in terms of content, silica dust is a risk that should be considered in addition to the key risks in studies with soil materials that are rich in silicon and silicon dioxide (SiO_2) content. When exposed to silica fume, these fumes accumulate in the lungs and cause an occupational disease called silicosis. Silicosis is a type of pneumoconiosis caused by breathing in free silica (silicon dioxide) crystals. Silicosis creates a continuous reaction against dust in the lung and as a result of this reaction, collagen fibers in the lung increase and lead to fibrosis (Öztürk et al., 2012). It is necessary to take precautions against silica fume, and the working conditions must be controlled in terms of silica fumes in cases where work will be carried out in a field where soil material is dense, especially in closed areas. for respirable quartz powder ($10\text{mg}/\text{m}^3$) / ($\%\text{SiO}_2+2$), this value for total silica-based powders ($30\text{ mg}/\text{m}^3$) / ($\%\text{SiO}_2+2$) and silicates containing less than 1% crystalline silica, mica, ($80\text{ mg}/\text{m}^3$) / ($\%\text{SiO}_2+2$) for talc and amorphous natural diatomaceous earth (Dust Removal Regulation, 2013). In addition to the safety measures taken in accordance with the whole study, respiratory system protection should be ensured in works containing silica fume. Thus, it will be appropriate to use at least FFP3 type dust masks or half face masks with dust protective filters throughout the work to protect the respiratory system in addition to the measures to be taken according to the scope of the work. The amount of silica fume in the environment should be checked regularly, if work is carried out in a closed area, continuous ventilation and protection should be provided with equipment that can collect the fumes in the environment. When the amount of fume reaches or exceeds the limit level, the work should be stopped and the health screening of the personnel in the working environment should be carried out within the program deemed appropriate by the occupational physicians.

2.1.2. Gypsum

The mineral called gypsum is the raw material which serves as the basis for the manufacture of plaster of Paris, “cement plaster” and the various related types of plasters (Edwin and Eckel, 1922). If the plaster obtained by baking the gypsum ($\text{gypsum-CaSO}_4 \cdot 2\text{H}_2\text{O}$) does not contain molecular water, in other words, if the baking temperature is below 190°C ; gypsum is processed in the form of CaSO_4 , at a baking temperature above 190°C and if it contains molecular water, gypsum is obtained in the form of $\text{CaSO}_4 \cdot 1/2\text{H}_2\text{O}$ (Erdoğan and Erdoğan, 2007). The mortar is obtained when gypsum, obtained in one of two different compositions and powdered, is combined with water and aggregate.

When inhaled, gypsum powders used as a binder or application material may accumulate in the lungs and cause pneumoconiosis, for this reason, it is in the harmful dust class and the total dust amount in the working environment is 15 mg/m^3 for gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and 10 mg/m^3 exposure threshold limit values (TWA) for calcium sulfate hemihydrate ($(\text{CaSO}_4)_2 \cdot \text{H}_2\text{O}$), known as plaster of Paris shall not be exceeded (Dust Removal Regulation, 2013). For this, in addition to the measures to be taken according to the scope of the work, it is necessary to use appropriate particle filter respiratory protection according to the concentration of gypsum in the air and to prevent dusting in order to protect the respiratory system (ILO-WHO International Chemical Safety Cards (ICSC):1217, 2004). If work is carried out in a confined space, protection should be provided with continuous ventilation and equipment that can collect dust in the environment. When the amount of dust reaches or exceeds the limit level, the work should be stopped and the health screening of the personnel in the working environment should be carried out within the program deemed appropriate by the occupational physicians.

2.1.3. Lime

As a result of baking the limestone (calcium carbonate- CaCO_3) at 900°C , the carbon dioxide (CO_2) in its structure is separated and calcium oxide (CaO) is obtained in the form of stone. If there is magnesium carbonate (MgCO_3) in the limestone, it becomes magnesium oxide (MgO) at 700°C . Lime obtained as a result of the heat treatment of limestone is called *quicklime* (CaO or $\text{CaO} \cdot \text{MgO}$) (Erdoğan and Erdoğan, 2007).

In order for hydrated lime to be used as a binder material, it must be reacted (hydrated) with water and turned into hydrated lime (hydraulic lime) ($\text{Ca}(\text{OH})_2$) or ($\text{Ca}(\text{OH})_2 \cdot \text{Mg}(\text{OH})_2$).

The material obtained as hydrated lime becomes a formable mixture when combined with water. This binder reacts with carbon dioxide (CO_2) in the air over time and turns into calcium carbonate (CaCO_3) ($\text{Ca}(\text{CO}_3) \cdot \text{Mg}(\text{CO}_3)$) and hardens. Lime, which has been used as a coupler since ancient times, is still used today and is frequently encountered in historical buildings (Erdoğan and Erdoğan, 2007). When considered chemically, quicklime is the solution in water is a medium strong base. Reacts with water. This generates sufficient heat to ignite combustible materials. Reacts violently with acids, halogens and metals. Appropriate particle filter respirator should be used according to the concentration of lime in the air and dusting should be prevented in order to protect the respiratory system in the presence of this dust (ILO-WHO International Chemical Safety Cards (ICSC):0409, 1997). When considered as a chemical substance, slaked lime decomposes when heated; its solution in water is a medium strong base. In order to protect the respiratory system in the presence of this dust, appropriate particle filter respirator should be used according to the concentration of slaked lime in the air and dusting should be prevented (ILO-WHO International Chemical Safety Cards (ICSC):0408, 1997). It should not be forgotten that working with a dangerous dust when working with materials containing lime (calcium carbonate), especially scraping, mechanical cleaning, etc. in working conditions where dust is present. The amount of dust to be exposed to is limited in works with calcium carbonate, magnesite (MgCO_3) originating from marble or limestone. For the aforementioned harmful dusts, the respirable dust amount (TWA/ZAOD) in the working environment is 5 mg/m^3 , while the total dust amount (TWA/ZAOD) is 15 mg/m^3 (Dust Removal Regulation, 2013). For this, in addition to the measures to be taken according to the scope of the work, considering that other dangerous dusts may also be present in the area where restoration and conservation work is carried out, it will be appropriate to use half-face masks with suitable particulate filters to protect the respiratory system during the work. If work is carried out in a confined space, protection should be provided with continuous ventilation and equipment that can collect dust in the environment. When the amount of dust reaches or exceeds the limit level, the work should be stopped and the health screening of the personnel in the working environment should be carried out within the program deemed appropriate by the occupational physician. Considering the chemical properties of these materials, contact with the skin and eyes should be avoided and protective clothing, gloves of appropriate properties, goggles and other protective equipment suitable for work should be used.

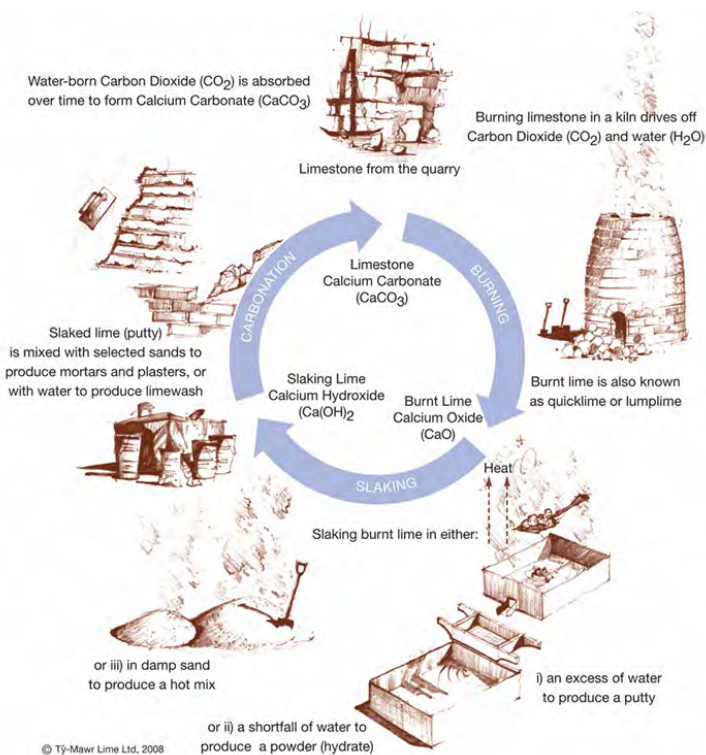


Figure 1. Cycle of obtaining building lime (Tŷ-Mawr, 2016).

2.1.4. Hydraulic lime

It is a product obtained by moderate burning ($900\text{--}1100\text{ }^{\circ}\text{C}$) of raw limestone which contains small proportion of clay (silica and alumina) 5-30 percent and iron oxide in chemical combination with the calcium content ($\text{CaO}+\text{MgO}$ 70-80% with MgO less than 5%). In slaking considerable care is required to provide just sufficient water and no excess, since an excess would cause the lime to harden. Depending on percentage of clay present these are classified further as, feebly, moderately and eminently hydraulic lime (Duggal, 2008). Since the work done with hydraulic lime binder contains dusts containing calcium carbonate and silica as components, it should be accepted that work is done with these harmful dusts and, in addition to the precautions to be taken according to the other risks involved in the work, other dangerous dusts may also be found in the area where the restoration and conservation work is carried out, and dust to protect the respiratory system. It will be appropriate to use half-face masks with suitable particulate filters during the work. If work is carried out in a confined space, protection should be provided with continuous ventilation and equipment that can collect dust in the environment. When the amount of dust reaches or exceeds the limit level, the

work should be stopped and the health screening of the personnel in the working environment should be carried out within the program deemed appropriate by the occupational physician. Considering the chemical properties of this material, contact with the skin and eyes should be avoided during the production of mortar, and it should be used together with protective clothing, gloves, glasses and other protective equipment suitable for wo.

2.1.5. Natural cement

Natural cements are produced by burning a natural clayey limestone containing 15 to 40 percent of silica, alumina and iron oxide without preliminary mixing and grinding. This burning takes place at a temperature that is usually little, if any, above that of an ordinary lime-kiln. During the burning the carbon dioxide of the limestone is almost entirely driven off and the lime combines with the silica, alumina, and iron oxide, forming a mass containing silicates, aluminates and ferrites of lime. In case the original limestone contained any magnesium carbonate the burned rock will contain a corresponding amount of magnesia compounds (Edwin and Eckel, 1922). The term “natural cement” is used for a large class of low-energy cementing products obtained by calcining naturally occurring single rock sources below the sintering point and then grinding the burnt material to a fine powder. The natural cements obtained can differ both in performance requirements and applications (Tišlová, 2008). When considered in terms of its content, it will be appropriate to use FFP3 type dust masks or half-face masks with dust-protective filters throughout the work to protect the respiratory system, considering that there may be other dangerous dusts in the area where restoration and conservation work is carried out. If work is carried out in a confined space, protection should be provided with continuous ventilation and equipment that can collect dust in the environment. When the amount of dust reaches or exceeds the limit level, the work should be stopped and the health screening of the personnel in the working environment should be carried out within the program deemed appropriate by the occupational physician. Considering the chemical properties of this material, contact with the skin and eyes should be avoided during the production of mortar, and it should be used together with protective clothing, gloves, glasses and other protective equipment suitable for work.

2.1.6. Portland cement

The crucial components of Portland cement are calcium silicates, which in the manufacturing process are formed by heating a mixture of calcium oxide (CaO) and silicon dioxide (or silica, SiO₂) to high temperatures. Both of these occur in the earth's crust in large quantities, the former in various forms of calcium carbonate (CaCO₃), e.g., chalk and limestone, and the latter in a variety of mineral forms in sand, clay or shale (Domone and Illston, 2010). Portland cement

dusts are in the harmful dust class, while the respirable dust amount (TWA/ZAOD) in the work environment for harmful dusts is 5 mg/m^3 , the total dust amount (TWA/ZAOD) is 15 mg/m^3 (Dust Removal Regulation, 2013). Care should be taken to prevent dusting as much as possible in the conservation and restoration works carried out in buildings where Portland cement is used as a binder, in cases where this cannot be fully achieved, it will be appropriate to use half-face masks with suitable particle filters to protect the respiratory system, considering that there may be other dangerous dusts in the area where restoration and conservation work is carried out in addition to the measures to be taken according to the other risks involved in the work. If work is carried out in a confined space, protection should be provided with continuous ventilation and equipment that can collect dust in the environment. When the amount of dust reaches or exceeds the limit level, the work should be stopped and the health screening of the personnel in the working environment should be carried out within the program deemed appropriate by the occupational physician. Considering the chemical properties of this material, contact with the skin and eyes should be avoided during the production of mortar, and it should be used together with protective clothing, gloves, glasses and other protective equipment suitable for work.

2.2. Additives of mortars

2.2.1. Pozzolan materials

Pozzolan materials are amorphous, silica and alumina materials that have little or no binding property on their own, but can act as hydraulic binders when they are small in size and combine with calcium hydroxide in an aqueous medium. In order for the material to show this feature, they must be fine-grained. Volcanic ashes, pumice stones, volcanic tuffs, some soil types and some terra-cotta are natural pozzolan materials, while fly ashes, high hearth cinders etc. materials are classified as artificial pozzolans (Erdoğan and Erdoğan, 2007). While working with materials that are found to contain pozzolana, respiratory protection should be planned, as in works containing silica dust, in addition to the safety measures taken in accordance with the whole of the work. For this, in addition to the measures to be taken according to the scope of the work, it will be appropriate to use FFP3 type dust masks or half-face masks with dust-protective filters throughout the work to protect the respiratory system, considering that there may be other dangerous dusts in the area where restoration and conservation work is carried out. If work is carried out in a confined space, protection should be provided with continuous ventilation and equipment that can collect dust in the environment. When the amount of dust reaches or exceeds the limit level, the work should be stopped and the health screening of the personnel in the working environment should be carried out within the program deemed appropriate by the occupational physician.

2.2.2. Asbestos

Although the use of asbestos fibers as a direct binder additive is limited, asbestos fibers are encountered in historical buildings, especially in early period cement buildings, as well as in various building elements such as roofs and floor slabs cause occupational diseases and special precautions shall be taken when working.

In case of exposure to carcinogenic asbestos dust, which is a filamentous, solid mineral, diseases such as asbestosis, mesothelioma and lung cancer occur. The most common types of asbestos;

Chrysotile (white asbestos, CAS No: 12001-29-5),

Amosite (brown asbestos, CAS No: 12172-73-5)

Krocidolite (blue asbestos, CAS No: 12001-28-4) asbestos.

The use of asbestos decreased rapidly and its use was banned in the whole European Union in January 2005 and in Türkiye with the regulation published in 2006 within the scope of the law no 4857 with the proof that exposure to asbestos and asbestos-containing materials causes various diseases (asbestosis). It was aimed to prevent exposure to asbestos and the limit value was determined with the “Regulation on Health and Safety Precautions in Working with Asbestos” published in the Official Gazette dated 25.01.2013 and numbered 28539 within the scope of the Occupational Health and Safety Law No. 6331 in Türkiye. Accordingly, the TWA value in studies with asbestos is 0,1 fiber / cm³ (Regulation on Health and Safety Precautions in Working with Asbestos, 2013). If it is necessary to work with structures that have been determined to have asbestos fibers by researches, it is important that an accurate work plan is put forward by experts first. Accordingly, in the works to be carried out, the works should be planned in a way to minimize the dust and the materials containing asbestos should be collected and destroyed in a way that meets the legal requirements. Ensuring respiratory protection, personal and environmental hygiene in areas where asbestos is suspected is important for both employees and public health. Disassembly operations in areas where asbestos is suspected can only be carried out by asbestos removal specialists and asbestos removal workers. Conservation and repair works should be carried out after it is documented that there is not any risk of exposure to asbestos fibers in the ambient measurements to be made after the asbestos removal operations are completed and continuous environmental control should be carried out in the area. Activities that will cause dust should be avoided until the situation is clarified in areas where asbestos is suspected and in addition to the precautions to be taken according to the scope of the work as a precaution during the work, it will be appropriate to use half-face masks with dust protective filters to protect the respiratory system throughout the work, and to provide environmental and personal hygiene measures.

2.3. Mud brick

It is obtained as a result of placing the plastic mixture formed by combining argillaceous soil and water into various molds and then drying the material removed from the mold in open air. Its strength and water resistance are not high, but materials such as straw, sand, lime, ash or cement are added to increase strength (Erdoğan and Erdoğan, 2007). It should not be forgotten that the predominant risk factor exposed to in studies with mud-brick is silica-containing dust. In addition to the safety measures taken in accordance with the work carried out, respiratory protection should be provided in accordance with the silica dust risk. For this, in addition to the measures to be taken according to the scope of the work, it will be appropriate to use FFP3 type dust masks or half-face masks with dust-protective filters throughout the work to protect the respiratory system, considering that there may be other dangerous dusts in the area where restoration and conservation work is carried out. If work is carried out in a confined space, protection should be provided with continuous ventilation and equipment that can collect dust in the environment. When the amount of dust reaches or exceeds the limit level, the work should be stopped and the health screening of the personnel in the working environment should be carried out within the program deemed appropriate by the occupational physician.

2.4. Khorasan mortar

This type of mortar, named after the Iranian city of Khorasan is obtained by mixing ground brick or terracotta materials with lime binder and water. Materials such as cracked, ground bricks, tiles and ceramics were called “khorasan” in the Seljuk era (Erdoğan and Erdoğan, 2007). Materials such as ground brick, tile, and ceramic are the materials with pozzolanic properties. It should not be forgotten that precautions should be taken against silica dust that may arise during conservation and restoration works involving Khorasan mortar. In addition to the safety measures taken in accordance with the whole work, respiratory protection should be provided in accordance with the silica dust risk. For this, in addition to the measures to be taken according to the scope of the work, it will be appropriate to use FFP3 type dust masks or half-face masks with dust-protective filters throughout the work to protect the respiratory system, considering that there may be other dangerous dusts in the area where restoration and conservation work is carried out. If work is carried out in a confined space, protection should be provided with continuous ventilation and equipment that can collect dust in the environment. When the amount of dust reaches or exceeds the limit level, the work should be stopped and the health screening of the personnel in the working environment should be carried out within the program deemed appropriate by the occupational physician. The skin and eye

contact of the binder should be prevented during the production of the mortar in repairs considering the chemical properties of the binder of this mortar and it should be used together with protective clothing, gloves, glasses and other protective equipment suitable for working.

3. Brick

One of the oldest building material brick continues to be a most popular and leading construction material because of being cheap, durable and easy to handle and work with. Clay bricks are used for building up exterior and interior walls, partitions, piers, footing and other load bearing structures (Duggal, 2008). It is the material obtained by first producing the formable mixture obtained by combining the grated argillaceous soil with some water in blocks of the desired dimensions and then passing through the drying and baking operation (Erdoğan and Erdoğan, 2007).

Terra-cotta products such as bricks and floor or roof tiles are made from natural clays of the illite-montmorillonite type, with the addition of fillers, inert materials that do not undergo transformations or shrinkage up to the firing temperature. The filler material may be siliceous and/or, quite frequently, grog (called chamotte in France and Italy), which is made by grinding baked terra-cotta from previous production. Ancient Roman bricks and tiles frequently contain pozzolana as filler (Torraca, 2009). It should not be forgotten that the predominant risk factor for brickwork is the soil contained in the brick and/or silica-containing dust in argillaceous structures. Respiratory protection should be provided in accordance with the silica dust risk in addition to the safety measures taken in accordance with the whole of the work. For this, in addition to the measures to be taken according to the scope of the work, it will be appropriate to use FFP3 type dust masks or half-face masks with dust-protective filters throughout the work to protect the respiratory system, considering that there may be other dangerous dusts in the area where restoration and conservation work is carried out. If work is carried out in a confined space, protection should be provided with continuous ventilation and equipment that can collect dust in the environment. When the amount of dust reaches or exceeds the limit level, the work should be stopped and the health screening of the personnel in the working environment should be carried out within the program deemed appropriate by the occupational physician.

4. Natural stones

Natural stones can be defined as naturally occurring solid mineral or mineral-like assemblages (Lutgens et al., 2021). They consist of a combination of various minerals or particles of minerals and stones or a large number of deposits of a single mineral. For example, granite

and basalt varieties are natural stones composed of minerals, sandstone from different sand grains, marble and quartzite from a single mineral (Ketin, 1994). Besides being used as building blocks in historical buildings, natural stones appear as aggregates in mortars. In the light of this information, it is necessary to take precautions especially against dust in the works to be done with the natural stones taking into account the results of the petrographic examination made before the restoration. Exposure to the dust of a silica-based stone such as sandstone will create a risk of silicosis. Inert dusts are dusts that do not cause structural and/or functional disorders in the lungs although they reach the lungs by respiration (Dust Removal Regulation, 2013). As these dusts are dusts that can accumulate in the body, they are considered harmful to human health and the amount of dust that can be found in the working environment is limited (Ediz et al., 2001). For whittings originating from marble or limestone, the total dust amount (TWA/ZAOD) value is 15 mg/m³, while the respirable dust amount (TWA/ZAOD) value is 5 mg/m³ (Dust Removal Regulation, 2013). Accordingly, in addition to the measures to be taken according to the scope of the repair project in areas where rock dust is present, it will be appropriate to use at least FFP3 type dust masks or half face masks with dust protective filters throughout the work to protect the respiratory system from rock dust considering that there may be other dangerous dusts in the area where restoration and conservation work is carried out. If work is carried out in a confined space, protection should be provided with continuous ventilation and equipment that can collect dust in the environment. By rock type, when the amount of dust reaches or exceeds the limit level, the work should be stopped and the health screening of the personnel in the working environment should be carried out within the program deemed appropriate by the occupational physician.

5. Paints

Paints are colored chemical mixtures whose main ingredients are organic or inorganic based pigments, binders and thinners. The paints used to colour clothing were commonly extracted either from botanical sources, including plants, trees, roots, seeds, nuts, fruit skins, berries and lichens, or from animal sources such as crushed insects and molluscs. Pigments for paints were obtained from coloured minerals, such as ochre and haematite which are mostly based on iron oxides, giving yellows, reds and browns, dug from the earth, ground to a fine powder and mixed into a crude binder. Charcoal from burnt wood provided the early forerunners of carbon black pigments (Christie, 2015). Paints, which are the most common element in conservation and restoration works, can also contain many different dangers and risks. It should not be forgotten that the exposure element in the conservation and restoration of paints can be both harmful dust and toxic chemicals. Even small exposure to dyes containing

harmful chemical components has the potential to cause great harm to human health. While the work done in areas where dyes are concentrated is evaluated in terms of occupational health, the hazards of the elements that make up the mixture should be evaluated together. Three primers/paints, which are frequently encountered in the conservation and restoration of cultural heritage, are examined in detail below. The risk of paint in the area to be restored should be handled separately and measures should be taken to eliminate the risk of each and studies should be carried out.

5.1. Lead White (lead (II) carbonate)

When lead carbonate is considered as a chemical material, it is highly harmful when it enters the body through respiration, ingestion or skin, has a toxic effect on long-term exposure and is classified as harmful to the environment when mixed with soil, water and air (European Chemicals Agency (ECHA) Substance Infocard EC / List no: 209-943-4, 2022). Blood lead level is normally 10-15 mcg/dl. Those working over 40 mcg/dl should be suspended from work (Occupational Diseases and Work-Related Diseases Diagnostic Guide, 2012). In the existence of this dust, it is necessary to use suitable particulate filter respirator to protect the respiratory system and to prevent dusting (ILO-WHO International Chemical Safety Cards (ICSC):0999, 2001). When working with paints containing this material, it will be appropriate to use protective clothing, half-face masks with suitable particle filters to protect the respiratory system, protective glasses or shields and protective gloves to prevent skin contact throughout the work considering that there may be other dangerous dusts in the area where restoration and conservation work is carried out in addition to the safety measures taken in accordance with the whole of the work. The amount of lead in the environment should be checked regularly, when it reaches or exceeds the limit level, the work should be stopped and the health screening of the personnel in the working environment should be carried out within the program deemed appropriate by the occupational physician.

5.2. Vermilion (mercuric sulphide)

There are three kinds of mercuric sulfide pigment: 1- the natural mineral form, which is simply finely ground cinnabar; 2- a synthetic form, made by the dry-process, commonly-calledvermilion; and 3- a synthetic form, made by a wet-process, also called vermilion. The artificial products are derived indirectly from native cinnabar (Roy, 1993). When coming across such a material, there are two situations that should not be forgotten, the first is to be exposed to these substances as harmful dust and the second is to be exposed to these substances as harmful chemicals. When mercury enters the body in the form of molecular, organic or

inorganic components, it causes quite harmful effects. Therefore, all precautions should be taken according to all the possibilities that the chemical may enter the body while working with this material. Ambient air samples of mercury and its compounds can be analyzed by AAS or colorimetric method. Quick test strips can also be used. The ambient limit value accepted in our country is 0.075 mg/m³ for mercury and 0.01 mg/m³ for mercury organic compounds (Occupational Diseases and Work-Related Diseases Diagnostic Guide, 2012). In all conservation and restoration works where mercury is present as a component, the control of the environment and personal hygiene facilities should be planned in advance and the relevant personnel should be trained on these issues, in addition to the safety measures taken in accordance with the whole work, it will be appropriate to use protective clothing, at least FFP3 type dust masks to protect the respiratory system or half-face masks with dust-protective filters, safety glasses or shields and protective gloves to prevent skin contact throughout the work. The amount of mercury in the environment should be checked regularly, when it reaches or exceeds the limit level, the work should be stopped and the health screening of the personnel in the working environment should be carried out within the program deemed appropriate by the occupational physician.

5.3. Titanium white (Titanium oxide)

Titanium dioxide white pigments are products of twentieth-century industrial development. Because of their high hiding power, nontoxic nature and reasonable cost, they have eclipsed other traditional white pigments in use worldwide. Titanium dioxide whites can be found in a variety of artists' materials that include inks, pastels, and paints in media such as oil, lacquer, acrylic and watercolor. Titanium dioxides have also been used in contemporary art objects as fillers and coatings for photographic, book, and fine papers, as colorants and opacifiers in ceramic glazes and glass, as delustrants in synthetic textile fibers, and as colorants in waxes, rubber, and plastic materials (West FitzHugh, 2012). Titanium dioxide, which is frequently used in paint production due to its material properties, is frequently found in historical buildings and in paints produced with today's technology. In works with paints containing titanium dioxide, which is classified as a hazardous dust, the TWA value is classified as 10 mg/m³ (ILO-WHO International Chemical Safety Cards (ICSC):0338, 2019). It is not classified as a carcinogenic for people, but may cause respiratory tract damage through prolonged or repeated exposure through inhalation of dusts and is also suspected to cause cancer (ILO-WHO International Chemical Safety Cards (ICSC):0338, 2019; European Chemicals Agency (ECHA) Substance Infocard EC / List No: 236-675-5, 2023). Although it is not directly classified as a cancer-causing chemical, inhalation of the dust and contact with the skin should be

avoided when working with titanium dioxide, which is a dangerous powder. In addition to the safety measures taken in accordance with the whole of the work, it will be appropriate to use protective clothing, at least FFP3 type dust mask to protect the respiratory system or half-face masks with dust-protective filters, safety glasses or shields, and protective gloves to prevent skin contact throughout the work. The amount of dust in the environment should be checked regularly and necessary precautions should be taken when it reaches or exceeds the limit level.

6. Wood

In areas where wood materials are found, the approach should be versatile, as with the preservation of many historical materials. Wood dust alone is classified as a substance that can cause occupational asthma and occupational cancer (Occupational Diseases and Work-Related Diseases Diagnostic Guide, 2012). The amount of respirable dust in the working environment where wood dust is found is limited to 5 mg/m³ with TWA/ZAOD value (Dust Removal Regulation, 2013). In works where only raw wood is not available, paint, impregnation material, fungicide, etc. chemical risk factor on the wood surface and deterioration in wood, if any, should be considered as biological risk factor and measures to be taken before starting the work program should be determined. In addition to the safety measures taken in accordance with the whole of the work, it will be appropriate to use protective clothing, at least FFP3 type dust mask to protect the respiratory system, or half-face masks with dust-protective filters, safety glasses or shields, and protective gloves to prevent skin contact throughout the work. The amount of dust in the environment should be checked regularly and necessary precautions should be taken when it reaches or exceeds the limit level. Furthermore, risks in the safety data sheet of the materials planned to be used for paint, preservatives, etc. various chemicals to be used for protection purposes should be included in the study and all necessary protective measures should be taken. If work is carried out in a confined space, protection should be provided with continuous ventilation and equipment that can collect dust in the environment. When the amount of dust reaches or exceeds the limit level, the work should be stopped and the health screening of the personnel in the working environment should be carried out within the program deemed appropriate by the occupational physician.

7. Metal

It is important to take occupational safety measures in accordance with the work program and project-specific in the works to be carried out with metal materials encountered in conservation and restoration works. Welding and cutting of metals carries high risks. During these processes, toxic gases and metal fumes, vapors and particles are released

and siderosis may occur as a result of inhalation of metal fumes. Many metal fumes are classified as toxic fumes and when they enter the body through inhalation, they are directed to different organs in the body, interact with some chemical systems and cause poisoning. Heavy metal dusts such as lead, chromium, nickel, cadmium are examples of this group. Apart from that, it may be possible to be exposed to metal dusts that come out in processes such as sanding and polishing. For example, siderosis, a type of pneumoconiosis, may occur as a result of the accumulation of iron powders and iron oxides in the lungs. For this reason, protective clothing while working with metals, dust masks of at least FFP3 type to protect the respiratory system or half-face masks with dust-protective filters, safety glasses or shields and protective gloves to prevent skin contact should be used throughout the work in addition to the security measures taken in accordance with the whole of the work. The amount of dust in the environment should be checked regularly, and necessary precautions should be taken when it reaches or exceeds the limit level. Furthermore, works shall be carried by taking necessary protective measures by including the risks in the safety data sheet of the materials planned to be used for various chemicals such as paint, rust remover and preservative to be used for protection. If work is carried out in a confined space, protection should be provided with continuous ventilation and equipment that can collect dust in the environment. When the amount of dust reaches or exceeds the limit level, the work should be stopped and the health screening of the personnel in the working environment should be carried out within the program deemed appropriate by the occupational physician.

8. Glass

Different raw materials such as silica, clay, aluminum oxide, limestone, alkaline powders, heavy metals are used in glass production. In addition, various chemicals are used as pigments in colored glasses. Silica dusts are formed in the processes performed to smooth the glass surface and can cause silicosis when exposed to these dusts without protection. Since working with glasses will be exposed to silica dust intensively, respiratory protection should be provided in works containing silica dust as well as the safety measures taken in accordance with the whole work. In addition to the safety measures taken in accordance with the whole work, it will be appropriate to use protective clothing, at least FFP3 type dust mask to protect the respiratory system, or half-face masks with dust-protective filters, safety glasses or shields, and protective gloves to prevent skin contact throughout the work. The amount of dust in the environment should be checked regularly and necessary precautions should be taken when it reaches or exceeds the limit level. If work is carried out in a

confined space, protection should be provided with continuous ventilation and equipment that can collect dust in the environment. When the amount of dust reaches or exceeds the limit level, the work should be stopped and the health screening of the personnel in the working environment should be carried out within the program deemed appropriate by the occupational physician.

9. Taking occupational health and safety precautions and developing an approach to prevent occupational diseases by utilizing material analysis information in restoration conservation studies

It is possible to encounter many different types of materials with different periods and construction techniques encountered in restoration conservation studies. Correctly analyzing the threats and risks that may arise from these different materials will help to plan a full and complete occupational health and safety measures in conservation works. Even when examined only on the basis of material, it is seen how important it is to include material analysis results in these plans. It is possible to prepare a complete occupational safety and risk prevention plan before the repair process begins with the conservation and repair team working in full cooperation with the occupational safety specialist and the occupational physician by considering the results of material analysis and structural examination in conservation and repair works. These planning steps are summarized under the seven headings discussed below.

9.1. Job description and risk assessment

In occupational health and safety planning, the correct definition of the job is of great importance both in terms of law and practice. This fact becomes even more important in the context of conservation and restoration works. In the definition of the work, first of all, the detail information of the work or architectural structure to be repaired (plan and material sheets for architectural structures, etc.) should be discussed step by step. Especially in areas where direct application will be made, using material analysis results, if necessary, taking special precautions should be ensured before the work starts and during the work plan stage. The works planned to be carried out within the scope of the project and the information obtained from the material analyzes should be evaluated together, taking into account the hazards specific to the structure or the artifact and a multilateral risk analysis study should be carried out by taking the opinions of the experts in charge of the project. Application studies should not be started before risk assessment study and related measures are determined.

9.2. Training of employees - special trainings

The dangerous and very dangerous works that can be carried out subject to professional competence are determined by the regulations, according to these principles, people who do not have a professional qualification certificate cannot be employed in these works throughout the conservation project. If there are special risks in the risk assessment prepared by making use of the material analysis results, in addition to a job induction and basic occupational health and safety training for all employees along with other project-specific information after risk assessment studies. The absence of personnel other than those who are certified to carry out asbestos removal/work on works or architectural structures in which the presence of asbestos is detected, details such as special training on personal and environmental hygiene should also be included in the training plans.

9.3. Employment inspection and periodic inspections

Before starting the conservation and restoration works, health screening programs to be arranged by the occupational physician in accordance with the results of the risk assessment should be carried out. Detailed health screenings must be done at the intervals recommended by the occupational physician according to the content and duration of the project. According to these screening results, special solutions should be developed for the personnel at risk, if any, with the support of the occupational physician.

9.4. Ambient measurements and personal measurements

Quantitative and qualitative determination of physical factors such as all kinds of noise, vibration, lighting, non-ionizing radiation; chemical factors such as steam and biological factors such as viruses, bacteria, fungi that may adversely affect the health of employees in the working environment are called personal exposure and ambient measurement (Regulation on Occupational Hygiene Measurement, Test and Analysis Laboratories, 2017). Especially in jobs where there is a risk of exposure to dangerous dusts such as silica and asbestos, personal environment measurements should be made before starting the work, taking into account the risk assessment results, and work should be started within safe limits and after the work has commenced, the project should be carried out by following the personal exposure measurements of the personnel working in risky areas and the renewed ambient measurement values. If necessary, the works should be stopped for the values that are determined above the limit by measurements during the studies and the work should be started after the values detected in the environment are taken to the legal limits. In cases where the limit values are exceeded, if necessary, the results of the health examination to be carried out in accordance with the

opinion of the occupational physician should be evaluated, the work plan should be updated and the works should be continued.

9.5. Control of occupational hygiene and personal hygiene conditions

In restoration and conservation works, whether the activities are carried out indoors or outdoors, some special precautions should be taken in addition to taking basic precautions. It is important to review and plan occupational hygiene conditions in the light of the results obtained from material analysis and ambient measurements. It is very important to provide clean air to the environment with the establishment of a general ventilation system in areas where work will be done indoors and environments with hazardous dusts such as wood, iron, silica and similar dusts. Beside this, personal hygiene facilities should be arranged according to the conditions. It is important to have changing rooms, separate protective clothing for work and shower facilities if necessary especially in environments where dusty and dangerous chemicals and fumes are present. It should be ensured that the personnel receive special training on environmental and personal hygiene and fulfill the requirements of these special trainings and the order of working conditions should be observed with regular checkups. In work environment where carcinogen dusts such as asbestos are present, work must be carried out in conditions where asbestos is not present and all special works such as dismantling, removal, packaging and destruction must be carried out by authorized and specially trained certified persons and/or establishments. Conservation and restoration works to be carried out in areas where such a situation is in question; it can only be done under conditions where asbestos is completely removed from the environment and this is documented by environmental measurements or when no work will be done in asbestos-containing areas and its dust, breakage or particles will not spread to the environment by being damaged for some reason. Otherwise, the health of the employees and their families, as well as the people living in the area where the work is carried out, will be endangered.

9.6. Personal protective equipment

The use of personal protective equipment should be in order to reduce the risks to an acceptable level after collective protection measures are taken. As discussed in the previous articles, the selection of personal protective equipment should be made according to the characteristics of the project being carried out and even the material properties of the areas where restorations are made. Where necessary, personal protective equipment should be used in full with additional measures to be taken partially. Personal protective equipment, which will be determined as a result of the joint work of the experts on the application, the occupational

safety specialist and the occupational physician, according to the project and the material properties to be encountered, will provide full protection when used throughout the studies, together with the collective protection measures taken from the planning stage.

9.7. Control and job safety culture

After the risk assessment and occupational health and safety measures plan, which are made by taking into account all the elements including material information, are completed, the dangers, risks and precautions to be taken against these activities should be shared with all employees before starting the conservation and restoration works. The better the details of the dangers and risks to be encountered can be understood, the more successful the activities to be carried out with the participation of the staff. At this stage, the awareness that the controls are not only under the control of field managers and occupational safety experts should be conveyed to the staff. In a work environment where the dangers and risks of the work to be done are fully understood and the precautions to be taken are determined with a participative approach, occupational safety culture will also be a part of the work and every stage planned for the work will be implemented as a whole. Especially for large-scale projects for work environments with very dangerous materials, the control and implementation mechanisms will work properly only by taking full precautions in works involving public health. The generalization works to spread the awareness that each employee first protects himself, then his colleagues, and then public health. Thus, it will be possible to convey the difficulties and problems encountered in the field to the right people in the hierarchy and to take the right measures, including the temporary suspension of the work if necessary. It will be possible to state whether the work plan outside of these activities is implemented correctly and in the presence of materials with legal limits in the work area, especially in the presence of materials with legal limits, it will be possible to state that healthy work is carried out in conditions where personal exposure measurements and health screenings are carried out regularly.

10. Results

In restoration and conservation works, material types are encountered, where the hazards and risks that may be encountered can vary greatly, regardless of the size of the job, and which can have very harmful effects on human health even with a small amount of exposure. Undoubtedly, the most important factor in works that include so many risk factors will be the risk analysis study in which the experts and employees share ideas and information, and the material information is included before starting the works and specific for each project. It is important for the development of occupational safety culture and healthy business conduct

that each employee can follow the occupational safety measures in the field, with special training of the employees about the dangers, risks and precautions to be taken for them. Risk protection measures to be determined as a result of a multi risk analysis study can be reviewed throughout the process and works aiming at full protection will provide an opportunity to combat risks at their source. It is the basic approach to eliminate the identified risks if possible and to replace them when disposal is not possible and these approaches are the steps of protection that are not always possible to apply in the conservation and restoration of a cultural heritage. For this reason, occupational health and safety measures will be taken in the conservation and restoration works, especially with the complete and regular use of personal protective equipment, where technical and administrative measures are effectively used with an approach open to continuous improvement, health surveillance is carried out and selected regularly in accordance with the risks in the field.

References

- Asbestle Çalışmalarda Sağlık ve Güvenlik Önlemleri Hakkında Yönetmelik (Regulation on Health and Safety Precautions in Working with Asbestos), Official Gazette dated 25.01.2013 and numbered 28539.
- Christie, R. M. (2015). *Colour Chemistry* 2nd Edition, Robert M. Christie, The Royal Society of Chemistry, Cambridge.
- Domone, P., & Illston J. (2010). *Construction Materials Their Nature and Behaviour*, 4th Edition, Edited by, Spon Pres, Oxon.
- Duggal, S.K. (2008). *Building Materials*, 3rd revised edition, New Age International (P) Limited Publishers, New Delhi.
- Ediz, İ.G., Beyhan, S., Yuvka, Ş. (2001). Madencilikte Tozlara Bağlı Meslek Hastalıkları (Occupational Diseases Connected to Dust in Mining), Dumlupınar University Journal of Science, Issue 002.
- Edwin C., & Eckel, E. C. (1922). *Cements, Limes and Plasters, Manufacture and Properties*, Second Edition, John Wiley&Sons, London.
- Erdoğan, S.T., Erdoğan, T.Y., 2007. Bağlayıcı Malzemelerin ve Betonun Onbin Yıllık Tarihi (Ten Thousand YearHistory of Binding Materials and Concrete) (Ten Thousand Year History of Binding Materials and Concrete), ODTÜ Geliştirme Vakfı Yayıncılık.
- European Chemicals Agency (ECHA) Substance Infocard EC / List No: 236-675-5, CAS: 13463-67-7, ECHA, 18.02.2023, <https://echa.europa.eu/substance-information/-/substanceinfo/100.033.327>
- European Chemicals Agency (ECHA) Substance Infocard EC / List no: 209-943-4, CAS: 598-63-0, ECHA, 06.05.2022
- ILO-WHO International Chemical Safety Cards (ICSC):1217, CAS: 26499-65-0, ILO, October2004, https://www.ilo.org/dyn/icsc/showcard.display?p_lang=en&p_card_id=1217&p_version=2
- ILO-WHO International Chemical Safety Cards (ICSC):0409, CAS: 1305-78-8, ILO, September 1997, https://www.ilo.org/dyn/icsc/showcard.display?p_lang=en&p_card_id=0409&p_version=2
- ILO-WHO International Chemical Safety Cards (ICSC):0408, CAS: 1305-62-0, ILO, September 1997, https://www.ilo.org/dyn/icsc/showcard.display?p_lang=en&p_card_id=0408&p_version=2

- ILO-WHO International Chemical Safety Cards (ICSC):0999, CAS: 598-63-0, ILO, March 2001, https://www.ilo.org/dyn/icsc/showcard.display?p_lang=en&p_card_id=0999&p_version=2
- ILO-WHO International Chemical Safety Cards (ICSC):0338, CAS: 13463-67-7, ILO, November 2019, https://www.ilo.org/dyn/icsc/showcard.display?p_lang=en&p_card_id=0338&p_version=2
- İş Hijyeni Ölçüm, Test ve Analiz Laboratuvarları Hakkında Yönetmelik (Regulation on Occupational Hygiene Measurement, Test and Analysis Laboratories), Official Gazette dated 24.01.2017 and numbered 29958
- Ketin, İ. (1994). Genel Jeoloji Yerbilimlerine Giriş (Introduction to General Geology Earth Science), İTÜ Vakfı Yayınları.
- Lutgens, F. K., Tarbuck, E.J., & Tasa, D. (2021). *Translation Editor: Helvacı, C.* Genel Jeoloji Temel Kavramları (Basic Concepts of General Geology), Nobel Yayınevi.
- Moropoulou, A., Bakolas, A., Anagnostopoulou, S. (2005). Composite materials in ancient structures, *Cement&-Concrete Composites* 27, 295–300.
- Öztürk A., Çımrın A.H., Tür M., & Güven R. (2012). Kuartz ve feldspat değirmenlerinde çalışanlarda silikoz sıklığı ve silikoz ile ilişkili faktörler (Frequency of silicosis and related factors related to silicosis in quartz and feldspar mills), *Tüberküloz ve Toraks Dergisi (Journal of Tuberculosis and Thorax)* 60(3): 224-229.
- Roy, A. (Ed.). (1993). *Artists' Pigments A Handbook of Their History and Characteristics*, Vol. 2, National Gallery of Art, Washington, Archetype Publications, London.
- Sumner, E. M. (2001). *Handbook of soil science*. CRC Press, Boca Raton, London, New York, Washington DC.
- T.C. Çalışma ve Sosyal Güvenlik Bakanlığı İş Sağlığı ve Güvenliği Genel Müdürlüğü (T.C. Ministry of Labor and Social Security General Directorate of Occupational Health and Safety), 2012. *Meslek Hastalıkları ve İş ile İlgili Hastalıklar Tanı Rehberi (Occupational Diseases and Work-Related Diseases Diagnostic Guide)*, Ankara.
- Tišlová, R. (2008). Hydration of natural cements, PHD Thesis, Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences, Krakow.
- Torraca, G. (2009). *Lectures on Materials Science for Architectural Conservation*, The Getty Conservation Institute, Los Angeles.
- Tozla Mücadele Yönetmeliği (Dust Removal Regulation), ANNEX 1, Official Gazette dated 05.11.2013 and numbered 28812.
- Tý-Mawr. (2016). Lime and its Production, <https://www.lime.org.uk/community/the-lime-cycle/lime-and-its-production.html>
- West FitzHugh, E. (Ed.). (2012). *Artists' Pigments A Handbook of Their History and Characteristics*, Vol. 3, National Gallery of Art, Washington, Archetype Publications, London, 1997, Reprinted in 2012 by the National Gallery of Art, Washington, in association with Archetype Publications Ltd.

INVESTIGATIONS

CHAPTER 10

IDENTIFICATION OF PIGMENTS IN ARCHAEOLOGICAL CERAMIC AND STONE ARTEFACTS FROM LATE ANTIQUITY, ISLAMIC PERIOD AND MODERN AGE BY RAMAN SPECTROSCOPY (U. COIMBRA COLLECTION)

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Abstract

Raman (micro)-spectroscopy is nowadays one of the most powerful techniques available for the analysis of artwork objects. It provides a fast, non-invasive, inexpensive, and accurate method to find the chemical signatures of the different constituents of a given sample while preserving its integrity. In this chapter, the application of Raman (micro)-spectroscopy to the identification of decoration pigments of a series of representative objects of the archaeological collection of the Rectory of the University of Coimbra (Portugal) belonging to several historical periods, namely Late Antiquity, Islamic period and Modern Age, is described. First, the fundamentals of Raman spectroscopy are addressed concisely, focusing on the essential features that make the technique appropriate for this investigation. The objects of study are then described from the archaeological standpoint, including a brief historical description of the archaeological sites and the selected artefacts. Finally, the results of the Raman spectroscopy analyses are presented and discussed from a historical contextual perspective, highlighting the power of the used experimental approach for the examination of the objects under study.

Keywords: Raman (micro)-spectroscopy; pigment analysis; archaeological collection of the University of Coimbra (Portugal)

1. Introduction

This chapter focuses on the study, by Raman spectroscopy, of representative objects of the archaeological artefacts of the University of Coimbra (Portugal), recovered from different archaeological surveys, dated from several historical periods (between Late Antiquity and Modern Age), aiming at the identification of the pigments used in their decoration.

A pigment can be defined as the component of a paint that gives colour. Usually, a pigment is a solid material, completely or nearly insoluble in water, which can retain its colour when ground to a fine powder (typically between 1 and 40 μm). In general, pigments are inorganic compounds and minerals of natural occurrence or synthetic. To produce paint, the pigment is typically mixed with a binder (resin), a solvent, and additives (*e.g.*, driers, flow enhancers, flash rust inhibitors, anti-spatter ingredients, etc.). The colour of pigments results from the absorbance of only certain wavelengths of visible light. Most of times, the electronic structure of the material determines the wavelength and efficiency of light absorption, while the light of other wavelengths is reflected or scattered, defining the colour we observe.

Since early in human history, pigments have been used for many different applications as a vehicle for humans to express themselves through marks left in the landscape, their bodies or on objects. Modern humans were not the first species to use pigments. Pigments and paint grinding equipment dated 350,000 to 400,000 years old, *i.e.*, at least 50,000 years before the emergence of *Homo sapiens*, were found in a cave near Lusaka, in Zambia (Barham 2002), while in the Iberian Peninsula paintings older than 64,800 years were found and credited to the Neandertal (Hoffman et al. 2018). The most representative pigments of prehistorical and ancient historic value include the ochres (Fe_2O_3 and $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$, with colours ranging from light yellow to red), charcoal (carbon, black), and lapis lazuli (a semi-precious metamorphic rock, whose main mineral component is lazurite, a blue feldspathoid silicate mineral). On the other hand, the first known synthetic pigment is the Egyptian blue (or cuprorivaite), which was found on an alabaster bowl in Egypt (Hierakonpolis) dated to the late pre-dynastic period of Naqada III (*ca.* 3250 BCE) (Eastaugh et al. 2004), and is a calcium copper silicate ($\text{CaCuSi}_4\text{O}_{10}$) that can be produced by heating a mixture of silica, lime, an alkali, and a copper source, such as malachite or azurite (Berke 2007). This pigment was the mostly used blue pigment in dynastic Egypt (where it was known as artificial lapis lazuli) and in the Roman antiquity (where it was known by *caeruleum*) but it fell from use and its formula was lost during the Middle Ages (McCouat 2018) and was only rediscovery during excavations in Egypt and also in Pompeii and Herculaneum in the 19th century (Dariz & Schmid 2021).

Since pigment production, popularity and uses vary over time, the study of pigments is a powerful tool for historical investigation and has become a well-established field of research, in particular for the study of art objects from an archaeological perspective. Several reviews have been published on this subject, including some recent ones (*e.g.*, Berrie 2012; Milani et al. 2018; Siddall 2018), and a recent special issue of the journal *Heritage*, edited by Diego Tamburini, has also been published on this topic (Tamburini 2021). The most important analytical techniques used for the analyses of pigments (either naturally occurring minerals or synthetic materials) are polarised light microscopy (PLM), Raman (micro)-spectroscopy, X-ray diffraction (XRD) and X-ray fluorescence spectroscopy (XRF). Raman spectroscopy has the advantage of requiring minimal to no preparation of the sample and being essentially non-destructive in nature. The analyses can be undertaken in the field using a Raman portable instrument, and are also cheap and fast. Because of that, a large amount of literature is available on the identification of pigments using Raman spectroscopy, and Raman spectral databases of pigments have been developed, such as the Infrared and Raman Users Group Spectral Database (IRUG; Price et al. 2007) and those resulting from the work of Robin Clark and coworkers at the University College London (RSL; Bell et al. 1997; Bulgio & Clark 2001).

Raman spectroscopy is one of the two major techniques of vibrational spectroscopy (together with infrared spectroscopy) and provides a signature of the vibrations experienced by the atoms that constitute a given material. The technique can be used to investigate both simple small molecules in environments where the intermolecular interactions are negligible (*e.g.*, in the gas phase) and large and complex organic molecular systems in the condensed phase, where intermolecular interactions dominate, as well as inorganic materials, including minerals. A Raman spectrum contains detailed information on the nature of the system under investigation, its chemical composition, relevant intra- and intermolecular interactions, stereochemistry, symmetry, spatial orientation (for single crystals), etc., providing a unique signature of the examined material. A Raman spectrum is a plot of the amount of radiation scattered inelastically by the sample as a function of the difference in the energy of the excitation-laser photons and of the scattered photons. In general, this energy difference is expressed in units of wavenumber (usually cm^{-1}) and is designated by Raman shift.

When a photon reaches a material, it can promote it to a so-called virtual vibrational energy level, which has a very short lifetime and quickly decays to the original vibrational state or another one, with the generation of the scattered photon. The first possibility results in a photon with the same energy as the incident one, corresponding to the elastic (energy-conserving) Rayleigh scattering, which is the most probable case. However, in average, 1 in every 10^7

photons is scattered inelastically (Raman scattering), with the energy difference to the incident photon being exactly equal to the difference between the energies of the initial and final vibrational energy levels (Figure 1). Since at room temperature (and below room temperature) the population of the lowest energy vibrational level (ground state) is usually much larger than those of the remaining energy levels (excited vibrational states), most of the Raman transitions imply a net energy gain by the material. These transitions are designated by Stokes Raman transitions, while those occurring in the opposite direction are designated by anti-Stokes Raman transitions. Because the Stokes and anti-Stokes transition taking place between the same energy levels have Raman shifts whose absolute value is equal, and the Stokes transitions are more probable than the corresponding anti-Stokes transitions (then, resulting in a higher intensity spectral signal), the Raman spectra are usually only obtained in the Stokes region.

The most important point to note here is that the energy differences between the vibrational energy levels are a property of a given material, with the corresponding Raman spectrum being a characteristic signature of that material. Hence, this property is the basis for the use of Raman spectroscopy as an analytical technique. In addition, since the intensity of a given spectral band is proportional to the amount of scattering units, Raman spectra can also be used for quantitative analysis. Other important features of Raman spectroscopy for pigment analysis are: *i*) its appropriateness for studying low-energy vibrations (below 400 cm^{-1} , a region usually not easily accessible to infrared spectroscopy, the alternative technique to explore molecular vibrations), which are typical for minerals and inorganic materials containing heavy metal atoms, *ii*) the fact that the technique is rather insensitive to water, unlike infrared spectroscopy (this is particularly useful for field analysis in humid places like caves), and *iii*) the possibility it offers to use the polarization properties of the laser light to obtain additional information on the crystalline materials. Raman spectroscopy has gained special protagonism in archaeological chemical analysis with the advent of portable micro-spectrometers with fiberoptics light guides, which allow the use of the technique *in situ* in practically all environments and in a non-destructive way.

The specific use of Raman spectroscopy for pigment analysis (or analysis of coloured materials in general) shall also take into account the fact that when the pigment has the complementary colour of the excitation laser light (*i.e.*, the pigment absorbs light at the excitation frequency) the so-called resonance conditions are met and the Raman spectra obtained in these conditions (resonance Raman spectra) exhibit band intensities that may differ substantially from those observed in the Raman spectra of the same material obtained under normal (non-resonant) conditions. Inherent fluorescence of the material may also occur, following

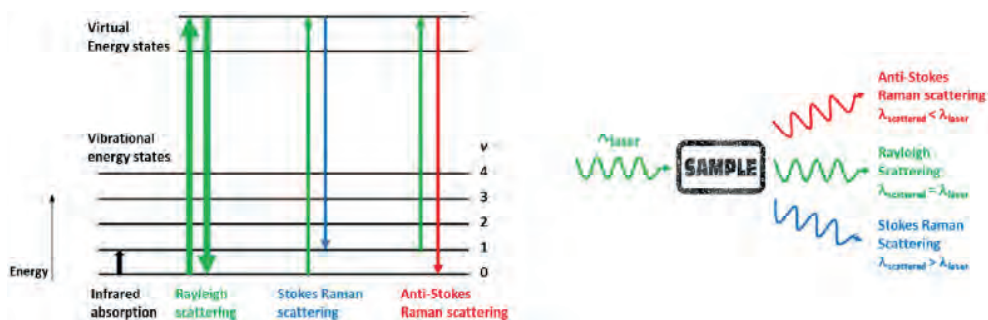


Figure 1. Energy-level diagram showing the states involved in Raman spectra. The vibrational quantum number v defines the energy of the levels. The coloured arrows indicate transitions between energy levels giving rise to the different scattered photons (which are also illustrated in the scheme shown in the right side of the figure). The figure also includes the representation of the direct $v = 0 \rightarrow v = 1$ transition, observable by infrared spectroscopy.

absorption, which is frequently a limiting factor in Raman spectroscopy since fluorescence signals are intrinsically much more intense than the Raman ones. However, as mentioned above, Raman signals are dependent on the frequency of the excitation light (they are relative values to the excitation frequency), while fluorescence occurs at an absolute fixed wavelength, so changing the excitation frequency may overcome the fluorescence interference in a Raman investigation. In any case, it is clear that the study of a given coloured material implies a judicious choice of excitation frequency to take maximum advantage of the technique.

Coloured glazes offer additional challenges to the analysis by Raman spectroscopy. Coloured glazes are amorphous silicate materials (a glass), mixed with chemical species that are responsible for their colour, or simply “pure” glaze layers covering the coloured surface of the artwork. The chemical species that can be mixed with the glaze base material can be molecular in nature (crystalline or nanosized particles) or ions dispersed within the glass material. Frequently, the amount of the colouring agent is very small, being less than 0.5 wt%, for example in the case of Co^{2+} and Cu^{2+} ions or metal nanoparticles. In some less favourable cases, the Raman signature of the colouring agent might not be observable experimentally, and the spectrum reflects only the glassy nature of the glaze, with its typical broad Raman bands. Moreover, since the Raman spectrum results from the vibrational movements of the atoms within a molecule, isolated simple ions are not detectable by the technique. This limitation assumes special importance in the study of coloured glazes, because some of the most frequently used colouring agents, both in antiquity and in modern times, are ionic species (Co^{2+} and Cu^{2+} ions, for example). Nevertheless, also since antiquity certain colours have been obtained

with crystalline phases formed by precipitation during the firing of the glass material, as a result of the saturation in certain elements (*e.g.*, tin giving precipitation of cassiterite (SnO_2), lead and tin giving precipitation of lead-tin yellow ($\text{Pb}_2\text{Sn}_2\text{O}_6$, also called Naples yellow), and, alternatively, a specific glaze preparation method might include the mixing of the ‘*anima*’ (rich in colouring agent) with the ‘*corpo*’ (the glassy matrix). In these two last cases, features due to both the colouring agents and the glassy matrix shall in principle be observed in the Raman spectra of the glaze.

As mentioned above, this chapter describes a study of representative items of the archaeological collection of the University of Coimbra dated from several historical periods, namely Late Antiquity, Islamic Period and Modern Age, undertaken by Raman spectroscopy, aiming the identification of the pigments used to decorate these objects. The following sections present a brief historical context of the city of Coimbra and, in particular, of the specific locations where the artefacts were recovered, followed by a general description of the studied items and of the used analytical procedures. The results of the performed Raman analyses are then presented and discussed in the last sections of the chapter.

2. Brief historical context

The foundation of the city of Coimbra dates back to the Roman occupation of the Iberian Peninsula, at the time of Augustus (27 BCE – 14 CE). Named *Aeminium*, the *civitas* was a neighbour of the roman city of *Conimbriga*. The latter was sacked by the Suevi and Visigoths between 465 and 468, losing some of its importance and prominence (Evans 2004). Until the parish of the *diocesis* of *Conimbriga*, *Aeminium* became, in this period, the Visigothic episcopal see. With the decline of the Roman Empire, Coimbra became part of the sphere of influence of the Suevian Kingdom in the 5th century and, in the 6th century, became part of the Visigoth Kingdom. During this period, the city, the seat of a vast territory that extended from Gaia to Tomar and from the Ocean to the foot of the Serra da Estrela, was known as Colimbria. In 714, the city fell into Muslim rule, being the largest agglomerated centre of the *Al-Andalus* along the northern *Tagus* River valley. During this period there were several political changes between Muslims and Christians, until, in 1064, Coimbra was conquered by the Christian King Ferdinand I of León and Castile (Mattoso 1997), and in 1096 the County of Coimbra was merged with the County of *Portucale* into one dominion and offered to Henry of Burgundy by King Alfonso VI of León and Castile, after Henry had married Alfonso’s illegitimate daughter Theresa. Henry and Theresa’s son, Afonso Henriques, later became Portugal’s first king (Afonso I of Portugal) and, in 1139, and Coimbra was chosen as the capital-city of the country. For this reason and because of

its military and commercial importance, the 12th century is generally considered the golden period of Coimbra's history (Mattoso 1997). Afonso Henriques used the former *Alcáçova* (fortified palace where the governor of the city lived during the Muslim period and that was built in the late 10th century) as his Royal Palace (Catarino & Filipe 2005/2006). Presently, this building is integrated in part of the central building of the University of Coimbra, the place of the Rectorate, which nowadays also includes St. Miguel Chapel and the Baroque Library (1716–1723) (Filipe 2015).

In the 15th and 16th centuries, during the golden period of the Portuguese *discoveries*, under King Manuel I, Coimbra regained importance as an artistic and cultural centre, with important Manueline (a Portuguese late Gothic style, seen, for example, in the emblematic Tower of Belém in Lisbon, but also used in the remodelling of the Santa Cruz Monastery in Coimbra downtown, which lodges the tomb of King Afonso Henriques and of his son, King Sancho I) and Renaissance works being developed in the city. During this period the University of Coimbra played a major role in the development of the town and of the country. Very interestingly, the University of Coimbra was first founded in Lisbon, in 1290, by King Dinis I, being later relocated to Coimbra, in 1308, and again to Lisbon in 1338. In 1537, the University was definitively transferred to Coimbra by King John III, and in 1544 it was established in the Coimbra Royal Palace. With the permanent settlement of the University in Coimbra, the urban space registered significant growth, with the construction of several colleges to host students, as St. Bento and Holly Trinity colleges (Mattoso 1997). In 1772, the Marquis of Pombal, prime minister of King José I, undertook a major reform of the University, which also resulted in a very expressive demolition of Coimbra's medieval city walls and medieval castle, from which very little remains today. Since 2013, the University of Coimbra has been recognized as a UNESCO World Heritage Site.

During the 20th and 21st centuries, archaeological excavations were carried out in several locations in the University of Coimbra area and its buildings. The 9 pieces investigated in the present study belong to different historical periods (Late Antiquity, Muslim and Modern Age periods) present in the sedimentary substrate corresponding to the evolution of Coimbra's urban space. The entire set comes from archaeological excavations carried out by the Rectory of the University of Coimbra, between 2000 and 2011, in various spaces under its jurisdiction and resulting from the need to intervene in these spaces, allowing to deepen knowledge about the diachrony of human occupation of the hill of the old city of Coimbra over the last two millennia. The excavated sites with the most significant results, and from where the pieces studied came from, are located in the *Pátio das Escolas* of the University of Coimbra



Figure 2. Plant (A) and aerial view (B) of the University of Coimbra area, with indication of the excavation sites, and modern photographs of the sites: Largo Marquês de Pombal (C), Pátio das Escolas (D), and Colégio da Santíssima Trindade (E).

(Helena Catarino and Sónia Filipe [2000-2001]), *Colégio da Santíssima Trindade* (Helena Catarino, Sónia Filipe and Vera Santos [2002-2006], and in *Largo Marquês de Pombal*, in the space between the *Laboratório Chimico* and the former *Colégio da Companhia de Jesus* (Sónia Filipe [2010-2011]) (Figure 2).

3. General description of the studied archaeological objects

Figure 3 shows the images of the 9 objects studied throughout this work. The pieces with references 1, 2 and 3 correspond to ceramics framed in the chronological horizon corresponding to the Middle Ages, particularly the Suevian-Visigothic period, which took place between the 5th and 7th centuries. Pieces 4-8 are also ceramic and belong to the Islamic and Islamic-reconquest period, which lasted from the 8th century to the end of the 11th century. Finally, piece 9, which corresponds to a stone fragment, in limestone, belongs to the Modern Age and has been dated between the 16th and 17th centuries. The stone fragment was

originally integrated into a construction of the Jesuit complex of Coimbra, in a fountain of the *Colégio da Companhia de Jesus*, which in 1759 was expropriated and integrated into the Portuguese Crown (Catarino & Filipe 2003; Catarino et al. 2009; Filipe 2006; Filipe 2007).

As can be seen in Figure 3, pieces 1, 2 and 3 are quite similar in terms of figurations, typology and aesthetic appearance, since in all three there is a similar decorative pattern, corresponding to lines with a red hue. Piece 3 shows also a white line, nearby the red one, which is absent in the other two pieces. These pieces are also quite homogeneous regarding the characteristics of the paste, with pieces 1 and 2 presenting a beige tone and piece 3 showing a more reddish brown colour. The archaeological record and comparative stylistic analysis indicate that those may be imported ceramics, in particular in the case of pieces 1 and 2, which correspond to fragments of tableware, with folders and thin surfaces of beige colour and fine traces of red paint, in the form of a spike, with a possible allusion, certainly stylized, to the life tree. The known parallels for these pieces, framed in late antiquity, point to realities and contexts of the Mediterranean and Byzantine world.

The pieces belonging to the Islamic period also share some similarities. All of them have a red-brownish paste, and pieces 4, 5 and 6, show the most common type of decoration in the region of Coimbra, *i.e.*, the white painting of a set of linear patterns. The paint strokes were applied directly to the surface of the piece or with an engobe covering of the same colour as the paste, or slightly darker (Catarino et al. 2009). More specifically, the piece with reference number 4 corresponds to a fragment of a jug, with a homogeneous red paste and white paint on the neck and body of the piece, presenting a decorative motif formed by parallel and wavy bands applied over reddish engobe. Comparative studies allowed this piece to be defined in a chronological horizon between the 10th and 11th centuries. Piece 5 corresponds to a pitcher of homogeneous red paste, exhibiting another engobe on which white paint has been applied, with wavy bands on the neck of the piece. We can frame it in a cultural horizon corresponding to the 12th century (Catarino et al. 2009). Fragment 6 corresponds to the head of a small zoomorph (an equid) and is part of a piece whose initial shape was not possible to reconstitute. Pieces of this nature can be framed in chronological-cultural horizons attributable to the Islamic and Medieval periods, as well as later, in contexts of production of the Modern period. The stratigraphic unit from which the piece was exhumed, as well as its dimensions and formal characteristics, do not allow us to safely exclude any of the possible scenarios.

Contrary to pieces 4-6, fragments 7 and 8 feature decorative paintings on glazed support surfaces. In the archaeological substrate of the city of Coimbra known so far, this type of decoration can be monochromatic or dichromatic, standing out, as in the case of the studied



Figure 3. Images of the studied archaeological objects.

pieces, open shape objects decorated in green and white, and in dry rope, total or partial. The fragment of *ataifor*/dish number 7 has a monochromatic glazed exterior surface, in a luscious tone, and an interior showing green and black traces on white, that correspond to the common production in the 10th/11th century. Fragment 8, on the other hand, corresponds to a plate, made of red homogeneous paste, with an exterior surface also glazed in monochromatic, in a honeyed tone, but an interior surface decorated with a total dry rope. It corresponds to a ceramic production marked out between the 11th and 12th centuries. The piece has different coloured regions, in orange, black, white and green tones.

Finally, piece 9 is the only one that is not a ceramic fragment, corresponding to a stone, limestone nature, with gold inlays, red-tone painting and some yellow-orange, black and white areas. It was obtained from an architectural structure that would correspond to a diving fountain, with a water chest, dismantled after 1759, when a royal order determined the expulsion of the Jesuits and the incorporation of their assets in the Portuguese Crown. Between that period and the end of the 18th century, the entire area of the Jesuit complex in Coimbra underwent a profound remodelling, with its spaces and buildings becoming almost entirely part of the University's heritage. It was in that space that various essential equipment for the functioning of the renovated University was installed, such as the *Laboratório Chimico*, the Natural History Museum, the Pharmaceutical Dispensary, the Hospital and others (Catarino & Filipe 2003; Catarino et al. 2009; Filipe 2006; Filipe 2007).

4. Research procedures

The objects were investigated without any preliminary preparation. They were placed directly on the platform of the open microscope of the Raman system in the required position for the analysis of the different regions of the samples. The Raman spectra were obtained in the 100-1800 cm^{-1} Raman shift range, at room temperature, in a Horiba LabRam HR Evolution spectrometer, equipped with a confocal microscope, a diffraction grating of 600 gr mm^{-1} , an appropriate edge filter, a high stability BXFM CCD detector kept at -70°C , and a 50 $\times$ long working distance objective (1-2 μm spot size diameter). During the spectra collection, the room was kept in the dark. Excitation was performed at 532, 633 or 785 nm, using a laser power at the sample in the 0.5-50 mW range, while the number of component-spectra accumulated per spectrum was in the range 100-25000, the acquisition time 1 s, and the spectral resolution 1 cm^{-1} . Calibration of the spectrometer was done using a silicon crystal wafer (reference peak: 520.5 cm^{-1}) as reference.

The obtained Raman spectra were baseline corrected whenever required using the OMNIC software (Thermo Fisher Scientific Inc.), and compared with reference spectra obtained from the RRUFF (Lafuente et al. 2015), IRUG (Price et al. 2007), PCMA (CHSOS 2023) and RSL (Bell et al. 1997; Bulgio & Clark 2001) Raman spectral databases, for the identification of the pigments.

5. Raman spectroscopy analyses

The different painted areas of the studied pieces were subjected to analysis using Raman spectroscopy, according to the description given in Section 4. Spectra from the non-pigmented areas of the objects were also obtained for reference.

5.1. Pieces from the Late Antiquity period (pieces 1, 2 and 3)

The red decorative lines of pieces 1, 2 and 3, dated from the Suevian-Visigothic period (5th and 7/8th centuries), were found to contain mostly hematite ($\alpha\text{-Fe}_2\text{O}_3$), which is the main constituent of the traditional pigment *red ochre*. Characteristic bands of this mineral are observed at 225, 245, 292, 409, 500, 612, 820, 1108 and 1327 cm^{-1} (Figure 4), which match well those of the reference spectra for hematite (Lafuente et al. 2015). In the case of the darker red lines of pieces 1 and 3, the spectra also indicate the presence of a significant amount of magnetite (Fe_3O_4), a mineral that appears frequently as a minor constituent of the *red ochres*, and whose most characteristic Raman bands are observed at 526 and 667 cm^{-1} (Lafuente et al. 2015) (Figure 4). Magnetite was also found to be present, in smaller amounts, in the lighter red risks of the three pieces. In addition, in the spectra of the red decorations of piece 3, the characteristic bands of *cinnabar* (HgS) at *ca.* 245 and 290 cm^{-1} (CHSOS 2023) are also seen (Figure 4), indicating that this pigment was also present in the paint mixture.

Red ochre is the hematite-rich member of the series of earth pigments usually designated as “ochres”. Naturally occurring ochres are mixtures of minerals, with a dominant component that is responsible for their characteristic colour. As a pigment, *red ochre* has been used continuously since the Pleistocene, and in the Iberian Peninsula cave paintings created with *red ochre* have been dated from around 70,000 years ago (Siddall 2018; Hoffman et al. 2018). During both the European Classical and Medieval periods and also in the Renaissance, *red ochre* integrated the standard palette of artists all around Europe, and painters like Michelangelo and Rembrandt, for example, used this pigment to produce some of the most coveted drawings in the world today (Somervill 2005; Czernichowska, Dmowska & Nowicka 2011). The main constituent of *red ochre*, hematite (the alpha polymorph of iron(II) oxide; $\alpha\text{-Fe}_2\text{O}_3$), is a common naturally occurring and the most important iron oxide mineral. Its name is derived from the Greek word “αἷμα” (haima), which means “blood”, due to the red colouration found in some of its varieties. Some of the most relevant properties of the *red ochre* pigment, besides its prompt and inexpensive availability, are its simple processing, stability (iron oxides are stable at high temperatures, though they are not resistant against acids), and facility of mixing with other pigments (Cornell & Schwertmann 2003). Ochres vary widely in transparency, some being quite opaque, while others are valued for their use as glazes. Because of their very long history of use and geographical dispersion, ochres are considered as unsuitable for dating objects and searching for their provenance (their mineralogical variability in relation to possible natural genesis also remains unrecognized in practice) (Siddall 2018; Hradil et al. 2003). Interestingly, in the

case of the red variety, the Iberian Peninsula has historically been one of the major sources of the raw material (Hradil et al. 2003).

Magnetite, like hematite, is a natural iron oxide mineral that also has a long history of use as a pigment. The mineral has the interesting feature of bearing both iron(II) and iron(III) in equal proportions in its constitution. It exhibits a black colour and is well-known for its ferrimagnetic properties (Jacobsen et al. 2005). The black iron oxide *magnetite pigment* has a cool, neutral, strong, transparent, and fast-drying black tone, suitable for different painting techniques and media. It became popular as a pigment for ceramics after being used in the painted terracotta pottery in ancient Greece (Jones 2021). Paints and inks made with magnetite are prized for their resistance to water, as well as mild acids and bases. The *magnetite pigment* is the natural version of *Mars Black* synthetic pigment, which has been produced only at the beginning of the 20th century. Besides its use as a black pigment, magnetite is frequently found associated with hematite in natural *red ochres*, including those used during the Early Medieval period (Scrivano, Gaggero & Volpe 2019), convening the pigment a darker tone. Hence, its detection in the studied pieces was not surprising.

As mentioned before, together with the *red ochre* pigment, *cinnabar* (mercurium sulphide; HgS) was also found as a minor constituent of the paint used in the red motifs of piece 3, which is, among the three studied pieces of this period, the most dissimilar one. *Cinnabar* is a bright red mineral that is found abundantly in the Iberian Peninsula, which has historically been an important location for the exploitation of *cinnabar* as a pigment (Sidall 2018). *Cinnabar* produces a bright red, opaque paint that is known for its exceptional luminosity, surpassing even the best red ochres. It can thus be supposed that the pigment was added to the paint mixture to enhance the brightness of the decorations. Both the naturally occurring pigment and its synthetic equivalent are known since antiquity, with the latter being called *vermilion*. Both varieties have been used in many regions of the world and, in particular, during the Iron and Early Middle Ages in the Iberian Peninsula, for wall paintings and post-firing decoration of ceramics (Tuñón et al. 2016). Extracted from the mercury mines of Almaden, *cinnabar* became an important pigment in the European Classical world also to produce documents, where red lettering signified important text (Sidall 2018). The pigment was also identified in a late 10th century Visigothic manuscript from northern Spain (Clarke 2004). Due to the toxicity of the mercury component, which was indeed recognized as early as in ancient Rome (Stewart 2014) despite of its extensive use during that period, the use of *cinnabar* (or *vermilion*) has declined in some extent in modern times in favour of alternative, less toxic pigments, though it is still included in the artist's palette nowadays.

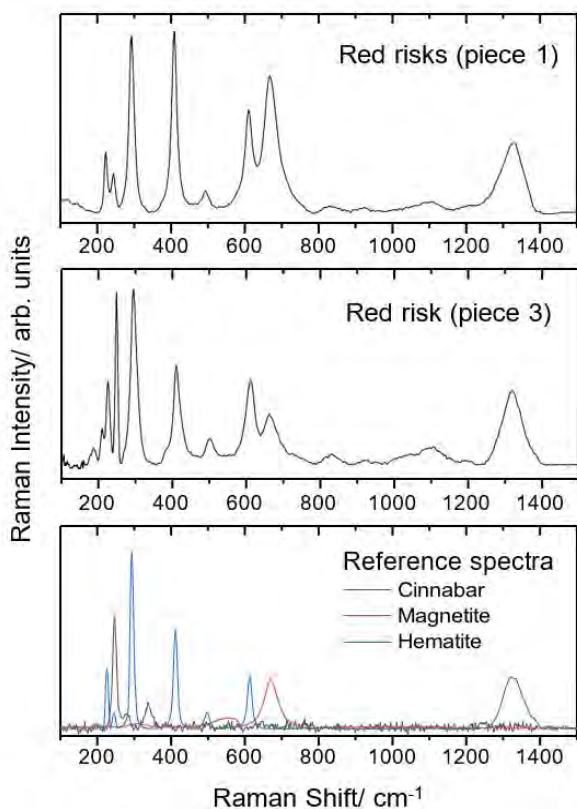


Figure 4. Raman spectra of the red risks of piece 1 (*top*) and of the red risk of piece 3 (*middle*), compared with reference spectra of hematite, magnetite and cinnabar minerals (Lafuent et al. 2015; CHSOS 2023) (*bottom*). The Raman spectra of the red decorations of piece 2 are similar to that of piece 1 shown in the figure.

The white risk present in piece 3 has as major constituent *anatase* (TiO₂), easily identifiable by the main Raman band-mark of this mineral at 142 cm⁻¹, but also by its lower-intensity characteristic bands at 390, 511 and 634 cm⁻¹ (Lafuente et al. 2015), with all these bands being observed in the Raman spectra of the decoration (Figure 5). The spectra of the risk also show bands ascribable to *calcite* (CaCO₃), which are observed at 1082, 709 and 277 cm⁻¹ (the band of this mineral at 156 cm⁻¹ is buried underneath the intense 142 cm⁻¹ band of anatase) (Lafuente et al. 2015).

Anatase is a titanium oxide (TiO₂) mineral. Three other polymorphs of titanium dioxide are known to occur naturally: brookite, akaogiite, and rutile, with rutile being the most common and most stable of them (Mandarino & Black 2004). *Anatase* is a relatively rare mineral and, for some time, it has been considered that it was not used as a pigment in the ancient world

(Gettens & Stout 1966; Ravindran et al. 2011). Its first synthesis was reported only in 1908, and it was considered that in European art *anatase* (and *rutile*) replaced the traditionally used *lead white* pigment just at the beginning of the 20th century. Because of that, the titanium dioxides were considered good date markers to distinguish between ancient and more recent art, and also in detecting forgeries (Gettens & Stout 1966). However, more recently, in particular after the introduction of Raman spectroscopy in pigment analysis, the signatures of *anatase* and *rutile* have been recognized to be present in artwork specimens from antiquity, including those dating from the Roman period (Edwards, Hassan & Middleton 2006; Zuo et al. 1999; de Waal 2004). In some cases, the pigment was found mixed with a minor amount of *calcite* (Edwards, Hassan & Middleton 2006; McCrone 1974; McCrone 1988), as appears to be the case of the studied piece 3. However, the origin of the bands assigned to *calcite* in the spectra of the white decoration of this piece can also result from spectral contamination from the paste material

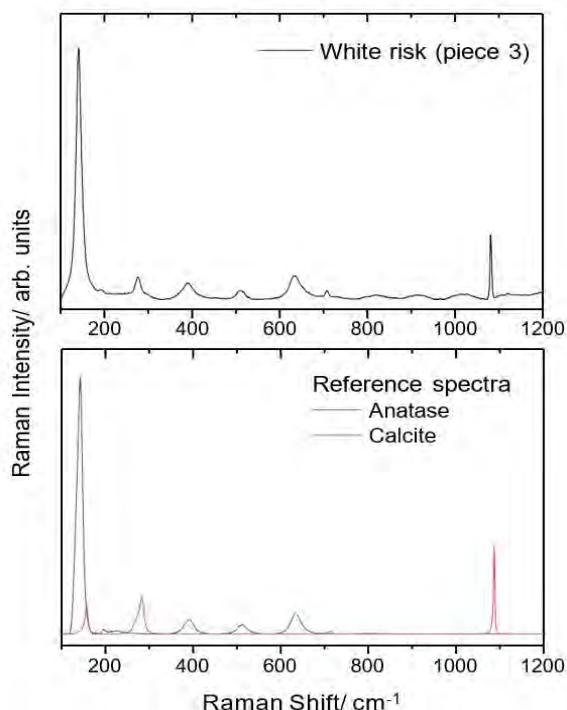


Figure 5. Raman spectra of the white risk of piece 3 (top), compared with reference spectra of *anatase* and *calcite* minerals (Lafuent et al. 2015) (bottom).

The pastes of pieces 1-3 were found to contain both white pigments (specifically *anatase* and *rutile*, which are dominant in the beige pastes of pieces 1 and 2) and red pigments (*hematite*, which appears in a larger amount in the reddish-brown paste of piece 3, and, in this latter piece, also traces of *cinnabar*).

5.2. Pieces from the Islamic period (pieces 4-8)

Among the studied pieces belonging to the Islamic period, and contrarily to pieces 7 and 8, pieces 4, 5 and 6 do not feature a glazed surface. These pieces are also comparatively simple in their decoration, exhibiting only white motifs on a red-brownish paste.

The Raman spectra obtained for these three pieces revealed *anatase* as the main white pigment, which in the case of piece 4 was merged with *bone white* (major component: hydroxyapatite, $\text{Ca}_5(\text{PO}_4)_3(\text{OH})$, which gives rise to a very characteristic Raman band at 962 cm^{-1} ; Lafuente et al. 2015), and in the case of piece 6 with *rutile* (Raman main mark-bands at 445 and 611 cm^{-1} ; Lafuente et al. 2015) (Figure 6). The potassium feldspars orthoclase and microcline (the higher- and lower-temperature monoclinic and triclinic polymorphs of KAlSi_3O_8 , which are commonly observed together) and quartz (SiO_2) were also identified in some spectra collected in the white regions of piece 4, and pieces 5 and 6, respectively, but this most probably resulted from spectral contamination by the ceramic pastes of the objects.

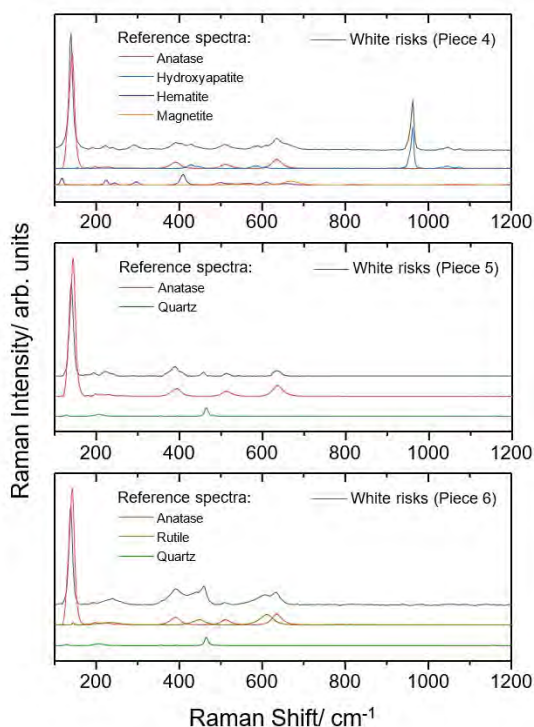


Figure 6. Raman spectra of the white risks of pieces 4-6, compared with reference spectra of the identified minerals present in the pigments (*anatase*, *hydroxyapatite* and *rutile*) and of spectral contaminations originated by minerals present in the paste of the pieces (*hematite*, *magnetite*, and *quartz*) (Lafuente et al. 2015).

Red ochre (with variable amounts of *hematite*, as the prime component, and *magnetite* in its composition) was found to be the predominant pigment of the pastes of the three pieces, with piece 5 showing also vestiges of *red lead* (or *minium*, Pb_3O_4 , also called *stupium* by the Romans; Thompson 1970), whose most characteristic Raman band occurs at 136 cm^{-1} (Lafuente et al. 2015). *Red lead* was one of the earliest pigments artificially prepared and it was used thoroughly since antiquity, in particular during the Middle Ages among the Byzantines and Persians, becoming less popular, due to lead toxicity and also because it tends to become darker upon ageing, since the end of the 19th century (Dunn 1973; Feller 1986).

Both pieces 7 and 8 have white, black and green glazed decorations. The white motifs of the two pieces share the main pigment constituent, *cassiterite* (SnO_2), with their Raman spectra exhibiting the characteristic bands of this mineral at 473 , 633 and 773 cm^{-1} (Lafuente et al. 2015), with *rutile* being also present in the white regions of piece 7 (Figure 7). White-pigmented glazes based on *cassiterite* are common in ceramics from antiquity, where tin oxide was used to offer opacity to the glaze, and were used frequently in Islamic medieval cultures (Gradman 2016; Wen & Pollard 2016; Coentro et al. 2014). The characteristic Raman spectrum of a glass silicate glaze consists of two broad bands around 500 and 1000 cm^{-1} , corresponding to modes of deformation (bending) and elongation (stretching) of the Si–O bonds of the SiO_4 forming the amorphous silicate network (Colomban 2022). The chemical composition of the majority of glazes (namely in dry rope) can be divided into two groups according to their SnO_2 content, with blue and white glazes having higher SnO_2 contents (*ca.* $> 5\text{ wt.}\%$), and most green, amber and brown glazes exhibiting lower values ($< 2\text{ wt.}\%$) (Coentro 2017). White glazes, in particular, owe their opacity to small agglomerates of tin oxide particles in the form of *cassiterite*, which strongly scatters the incident light. These *cassiterite* particles precipitate in the glaze during firing and can form agglomerates of different sizes which can be distributed throughout the glaze in different degrees of homogeneity (Vendrell et al. 2000).

The pigments of the black decorations of the two pieces are mixtures of iron and manganese oxides and *carbon black*. *Carbon black* is a form of paracrystalline carbon used as a pigment since prehistorical times and traditionally produced from carbonizing organic materials such as wood or bones. Its characteristic Raman bands are observed at *ca.* 1355 and 1580 cm^{-1} (Hu et al. 2009) (Figure 7). The iron and manganese (and mixed iron-manganese) minerals identified in the black regions of the pieces are *pyrolusite* (the β -polymorph of MnO_2), *braunite* ($\text{Mn}_7[\text{O}_8|\text{SiO}_4]$), *hausmannite* (Mn_3O_4), *jacobsite* (MnFe_2O_4), *magnesioferrite* (MgFe_2O_4) and *manganite* ($\text{MnO}(\text{OH})$). *Pyrolusite* has a long history as pigment and was found in some

of the most famous early cave paintings in Europe, as well as frequently at Neanderthal sites (Gázquez, Calaforra & Rull 2012), corresponding to the most important and worldwide distributed manganese source (Pérez-Arantegui et al. 1999; Tite et al. 2009). The major Raman band of this mineral is observed at 657 cm^{-1} , with other bands being observed at 296 and 404 cm^{-1} (Lafuente et al. 2015). *Braunite* can be formed from the reaction between *pyrolusite* and a silica rich glaze matrix above 1000 °C (Molera et al. 2013) and has been identified before in Islamic tin-glazed ceramics from Mallorca and Murcia dated from the 10th-11th centuries, as well as in later Hispano- Moresque glazes from the 13th-17th centuries (Molera et al. 2013; Pradell et al. 2010), with its most characteristic Raman bands occurring at 222, 625 and 693 cm^{-1} (Lafuente et al. 2015). *Hausmannite* (most intense Raman band: 661 cm^{-1} ; Lafuente et al. 2015) can also result from firing *pyrolusite* at a temperature of *ca.* 1000 °C (Molera et al. 2013), while *jacobsite* can be formed by firing together manganese and iron oxides above 600 °C (Anthony et al. 2003; Buzgar, Apopei & Buzatu 2013; Molera et al. 2013, Molera, Martinez-Manent & Vendrell-Saz 1993). *Magnesioferrite* (Raman band mark; 619 cm^{-1} ; Lafuente et al. 2015) can be produced upon firing together iron and magnesium oxides (Coentro 2017), and its presence in pigments based on iron oxides has been described (Marketou, Kouzeli & Facorellis 2019). Finally, *manganite* is also known to be used as a pigment since prehistoric times, often associated with *pyrolusite*, *braunite* and *hausmannite* (Klein & Hurlbut 1985), as in the case of the studied pieces 7 and 8.

In the green regions of the two pieces and the orange zone of piece 8, the obtained Raman spectra correspond to that of the glaze amorphous material, with traces of cassiterite. Compared to the white regions, the amount of cassiterite present in the green and orange regions is much smaller, which is consistent with the higher transparency of the glaze in these regions and with the traditional manufacturing procedures (Colomban 2022). The green colour can be attributed to the presence of Cu^{2+} ions dissolved in the glaze, considering the XRF elemental analysis results obtained by Marques 2020 that demonstrated the presence of copper in the green regions of the pieces. As already mentioned, Raman spectroscopy probes the vibrational movements of the atoms within a molecule, so that isolated simple ions are not detectable by the technique.

The paste of piece 7 was found to contain *anatase* (as white pigment) and *red ochre* (as red colourant), while in the paste of piece 8, only *red ochre* was detected, in line with its more reddish appearance. Although no Raman spectra of the orange risk of piece 8 could be obtained to reveal the presence of a specific pigment, as mentioned above, its colour is most probably attributable to iron oxides (*red ochre*).

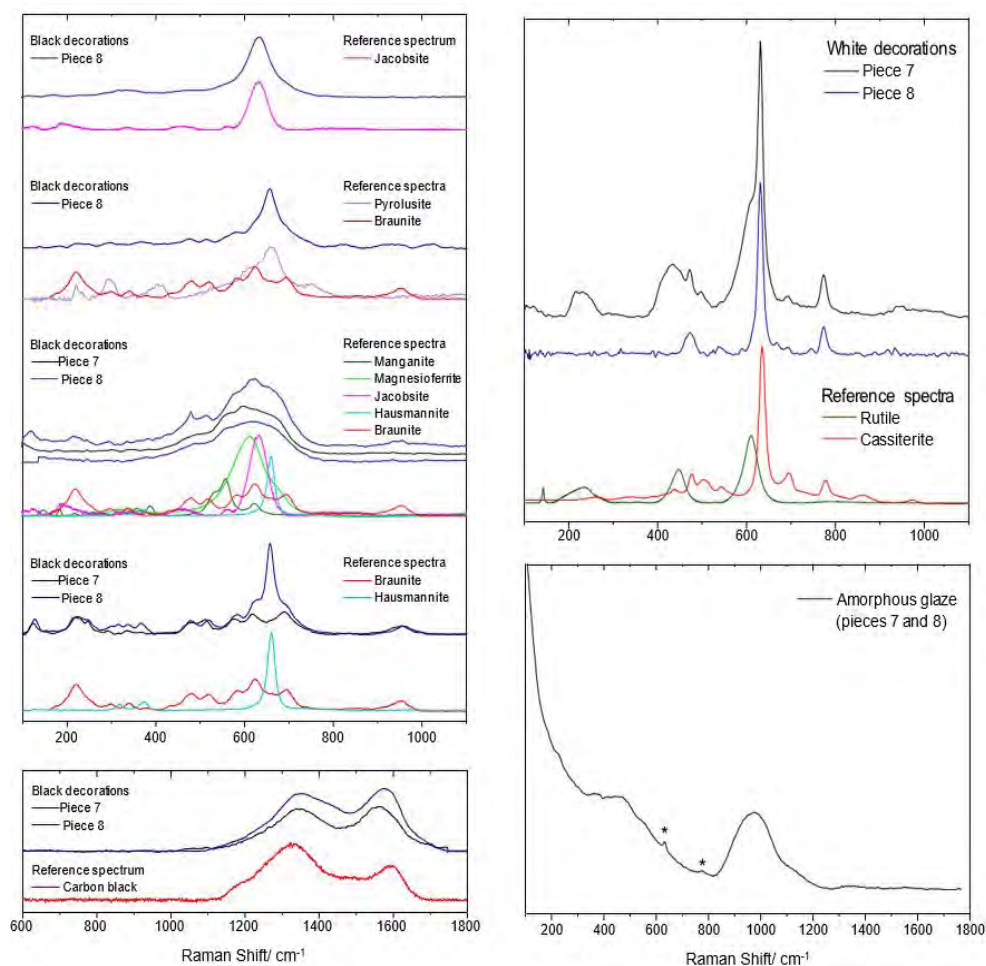


Figure 7. Raman spectra of the white and black decorations of pieces 7 and 8, compared with reference spectra of the identified minerals present in the pigments (Lafuent et al. 2015). In the case of the black areas, different spectra were obtained, which revealed the presence of different minerals (see text for discussion), and these spectra are presented in separate. In the green regions of the two pieces and in the orange zone of piece 8 the obtained Raman spectra corresponds to that of the glaze with traces of cassiterite (the two major bands due to this mineral are indicated in the figure by the asterisks) (see text for discussion).

5.3. Piece from the Modern Age (piece 9)

The studied piece of the diving fountain from the Modern Age period is limestone, with gold enamels (XRF determined to be 24 carats, according to Marques 2020), and red, white, black and yellow-orange decorations. The Raman spectra revealed that the red areas contain *hematite* and *red lead* (Pb_3O_4) pigments, the latter being the origin of the bands observed at 136, 276 and 376 cm^{-1} , in good agreement with the reference spectrum of this

pigment (Lafuente et al. 2015) (Figure 8). The white regions were found to contain *white lead* ($2\text{PbCO}_3 \cdot \text{Pb}(\text{OH})_2$), a complex lead salt containing both carbonate and hydroxide ions. $2\text{PbCO}_3 \cdot \text{Pb}(\text{OH})_2$ occurs in nature as the rare mineral hydrocerussite, but its counterpart paint pigment *lead white* has been produced artificially since early historical times (Bailey 1932; Moon 3009). *Lead white* is considered to be the most important of all lead pigments and, historically, it is also the most important of all white pigments (Gettens, Kühn & Chase 1967). It was the only white pigment used in European easel painting until the 19th Century and it was also listed in almost all of the source materials and catalogues of pigments from ancient times. Combined with blue pigments, *lead white* was often used to produce the shades of skies in paintings and prints, while when mixed with red pigments it produced the tones of flesh. It was only in the 20th century that it was extensively replaced by titanium oxides, partially because of the best properties of these pigments, and partially because of problems associated with the lead toxicity. The most characteristic Raman band for *white lead* is found at 1050 cm^{-1} (Lafuente et al. 2015; Bell et al. 1997; Bulgio & Clark 2001) (Figure 8).

In the black areas of piece 9, iron and manganese oxides were identified. Although the mixture of these oxides in the paint used in the black regions of the artefact may be even more complex because of the similarity of the Raman spectra of this type of oxides (Post, McKeown & Heaney 2020; Gao, Fjellvag & Norby 2009), the major constituents are *hematite* (as iron oxide), *pyrolusite* (manganese oxide), and *jacobsite* (the mixed iron-manganese oxide MnFe_2O_4 , which offers the dark tone to the paint) (Figure 8). The three identified oxides are common constituents of dark-brown and black pigments designated generically by manganese ochres (also called *umbers*), which have been used since the prehistory (Sidall 2018; Heyes et al 2016). They were important in Eastern Anatolia and the Balkans in antiquity and were also used in Etruscan art (Schwezer & Rinui 1981; Molera, Martinez-Manent & Vendrell-Saz 1993). Although the use of manganese ochres in art declined during the Middle Ages, mostly due to the preference of medieval artists for bright and vivid colours, these pigments regained popularity among the European artists during the 15th-17th centuries. Hence, the *umbers* were included in the *palette* of the greatest master painters from the Renaissance, including Leonardo da Vinci (1452- 1519), Caravaggio (1571-1610) and Rembrandt (1606-1669).

Finally, the Raman analysis of the yellow-orange areas of this piece revealed that the pigments they contain are different varieties of iron oxides, specifically *hematite*, *goethite* and *magnetite*, in what can be considered as a mixture of red and yellow ochres (Figure 8). The precise colour of the yellow-orange zones of the piece is variable, indicating that they contain combinations of the different oxides in different proportions.

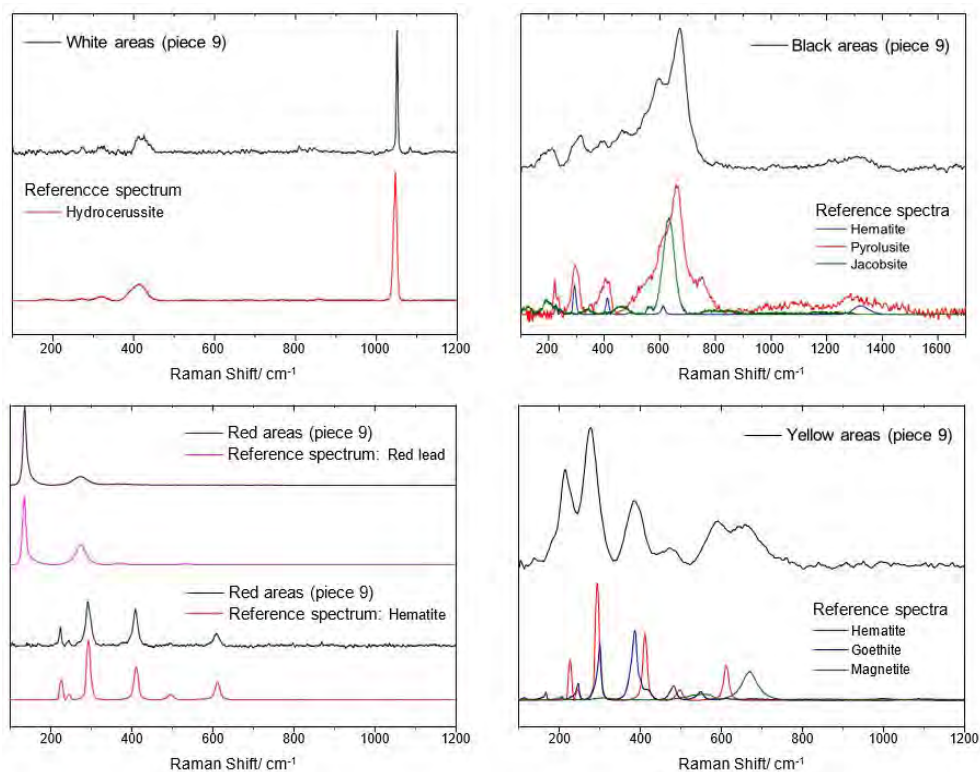


Figure 8. Raman spectra of the white, red, black and yellow areas of piece 9, compared with reference spectra of the identified minerals in each one of the areas (Lafuent et al. 2015; Bell et al. 1997; Bulgio & Clark 2001). In the red areas of the piece, two typical spectra were obtained, corresponding to *hematite* and *red lead*.

6. Concluding remarks

In this chapter, the relevance and analytical power of Raman (micro)-spectroscopy in the study of artwork materials has been highlighted, as applied to the investigation of the pigments present in the decorations of a series of pieces belonging to the archaeological collection of the University of Coimbra (Portugal) dated from the Late Antiquity, Muslim and Modern Age periods. Besides the collected archaeological information, the technique was used in a stand alone way, demonstrating its power as a tool for qualitative analysis in this type of investigations. Raman spectroscopy has been progressively gaining importance as a major tool to obtain fundamental information on the composition of artwork objects, facilitating their subsequent detailed (quantitative) analysis, which requires the use of other experimental approaches, in particular XRF spectroscopy and ICP-OES (inductively coupled plasma optical emission spectrometry), for elemental analysis, and powder X-ray diffraction, for minerals quantification, for example.

Piece	Historical period	Paste	Decorations				
			Red	White	Black	Green	Orange Yellow
1 (Tableware fragment)	Late Antiquity (Byzantine/ Mediterranean imported) (5th-7/8th century)	Anatase Rutile Red ochre ^a	Red ochre ^a				
2 (Tableware fragment)		Anatase Rutile Red ochre ^a	Red ochre ^a				
3 (Tableware fragment)		Anatase Rutile Red ochre ^a Cinnabar	Red ochre ^a Cinnabar	Anatase Calcite ^b			
4 (Jug fragment)	Islamic (10th-11th century)	Red ochre ^a		Anatase Bone white			
5 (Pitcher fragment)	Islamic (12th century)	Red ochre ^a Red lead		Anatase			
6 (Fragment of an equid sculpture)	Islamic (uncertain)	Red ochre ^a		Anatase Rutile			
7 (Rim of atai for dish)	Islamic (10th-11th century)	Red ochre ^a Anatase		Cassiterite Rutile	Carbon black Braunite Hausmannite Magnesioferrite Jacobsite Manganite	Cu ²⁺ c	
8 (Fragment of a plate)	Islamic (11th-12th century)	Red ochre ^a		Cassiterite	Carbon black Pyrolusite Braunite Hausmannite Magnesioferrite Jacobsite Manganite	Cu ²⁺ c	Red ochre ^{a,b}
9 (Fragment of a Jesuit diving fountain)	Modern age (16th-17th century)		Hematite Red lead	White lead	Umber ^d		Gold Red/ Yellow Ochres ^e

of the technique were also mentioned here, in particular its inability to determine simple ionic species dispersed, for example, in a glaze. This limitation prevented the direct vibrational spectroscopic identification of the colouring species present in the green regions of two of the studied pieces. In this case, both XRF and ICP-OES are advantageous techniques over Raman spectroscopy, allowing to access the elemental composition of the probed materials.

Table 1 summarizes the obtained results, which are consistent with the historical and stylistic data of the objects.

Experimental details for the presented spectral data and reference sources

Spectra of the red decorations: piece 1, 633 nm, 500-1000 accumulations, laser power 2 mW; piece 2, 633 nm, 500 accumulations, laser power 2 mW; piece 3, 633 nm, 500 accumulations, laser power 2 mW; piece 9, 785 nm, 200-750 accumulations, laser power 2-20 mW. *Spectra of the white decorations:* piece 3, 532 nm, 500-25000 accumulations, laser power 5 mW; piece 4, 532 nm, 1000-3000 accumulations, laser power 5 mW; piece 5, 532 nm, 100-1000 accumulations, laser power 5-50 mW; piece 6, 532 nm, 250-5000 accumulations, laser power 5 mW; piece 7, 532 nm, 500 accumulations, laser power 50 mW; piece 8, 532 nm, 500 accumulations, laser power 50 mW; piece 9, 785 nm, 250-750 accumulations, laser power 2-20 mW. *Spectra of the black decorations:* piece 7, 532 nm, 500-1000 accumulations, laser power 5-50 mW; piece 8, 532 nm, 500-1000 accumulations, laser power 5-50 mW; piece 9, 532 nm, 500 accumulations, laser power 5 mW. *Spectra of the green areas:* piece 7, 532 nm, 100-1000 accumulations, laser power 12.5-50 mW; piece 8, 532 nm, 500-5000 accumulations, laser power 5-50 mW. *Spectra of the yellow-orange areas:* piece 9, 532 nm, 100-2000 accumulations, laser power 5-50 mW. All spectra were obtained with acquisition time of 1 s and resolution 1 cm⁻¹ using a 50× long working distance objective.

Reference spectra: Cinnabar, CHSOS 10610_532; magnetite, RRUFF R060653-3; hematite, RRUFF R040024-3; red lead, CHSOS 42500_532; anatase, RRUFF R070582, calcite, RRUFF R150075; hydroxyapatite, RRUFF R060180; Quartz, RRUFF R050125-3; Rutile, RRUFF R110109; hydrocerussite, RRUFF R070059; cassiterite, RRUFF R040017; carbon black, CHSOS 47100_785; jacobsonite, RRUFF R120170; pyrolusite, RRUFF R040153; goethite, RRUFF R120086; braunite, RRUFF R050385; hausmannite, RRUFF R040090; manganite, RRUFF R060827; magnesioferrite, R070127.

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References

- Anthony, J. W., Bideaux, R. A., Bladh, K. W., Nichols, M. C. (2003), Handbook of Mineralogy, Mineral Data Publishing, Tucson (USA).
- Bailey, K. C. (1932), The Elder Pliny's chapters on chemical subjects, Part II, Arnold, London, UK, Cloth 15S, p. 75.
- Barham, L. S. (2002), Systematic pigment use in the Middle Pleistocene of south-central Africa, *Curr. Anthropol.*, 43, 181–190.
- Bell, I. M., Clark, R. J. H., Gibbs, P. J. (1997), Raman spectroscopic library of natural and synthetic pigments (pre~1850 AD), *Spectrochim. Acta Part A*, 53, 2159–2179.
- Berke, H. (2007), The invention of blue and purple pigments in ancient times. *Chem. Soc. Rev.*, 36, 15–30.
- Berrie, B. H. (2012), Rethinking the history of artists' pigments through chemical analysis, *Ann. Rev. Anal. Chem.*, 5, 441–459.
- Burgio, L., Clark, R. J. H. (2001), Library of FT-Raman spectra of pigments, minerals, pigment media and varnishes, and supplement to existing library of Raman spectra of pigments with visible excitation, *Spectrochim. Acta Part A*, 57, 1491–1521.
- Buzgar, N., Apopei, A.I., Buzatu, A. (2013). Characterization and source of Cucuteni black pigment (Romania): vibrational spectrometry and XRD study, *J. Archaeol. Sci.*, 40, 2128v2135.
- Catarino, H., Filipe, S. (2005/2006), Madinat Qulumbriya: arqueologia numa cidade de fronteira, Al-Ândalus espaço de mudança. Balanço de 25 anos de História e Arqueologia medievais, Seminário de homenagem a Juan Zozaya Stabel- Hansen (Mértola, 2005), Campo Arqueológico de Mértola, Mértola, Portugal, 2006, pp. 73–85.
- Catarino, H., Filipe, S. (2003), Arqueologia. Segredos e lições do Pátio da Universidade (Caderno Temático: O Paço das Escolas Revisitado), *Rua Larga*, 1, 2–4.
- Catarino, H., Filipe, S., Santos, C. (2009), Coimbra islâmica. Uma aproximação ao estudo dos materiais cerâmicos Xelb 9, 6º Encontro de Arqueologia do Algarve, pp. 333–378.
- Clarke, M. (2004), Anglo-Saxon manuscript pigments, *Stud. Conservat.*, 49, 231–244.
- Coentro, S. X. (2017), An Iberian heritage: Hispano-Moresque architectural tiles in Portuguese and Spanish collections, PhD. Thesis, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa.
- Coentro, S., da Silva, R. C., Relvas, C., Ferreira, T., Mirão, J., Pleguezuelo, A., Trindade, R., Muralha, V. S. F. (2018), Mineralogical characterization of Hispano-Moresque glazes: A μ -Raman and scanning electron microscopy with X-ray energy dispersive spectrometry (SEM-EDS) study, *Microsc. Microanal.*, 24, 300–309.
- Coentro, S., Trindade, R. A. A., Mirão, J., Candeias, A., Alves, L. C., da Silva, R. C., Muralha, V. S. F. (2014), Hispano-Moresque ceramic tiles from the Monastery of Santa Clara-a-Velha (Coimbra, Portugal), *J. Archaeol. Sci.*, 41, 21–28.
- Colomban, P. (2022), Full spectral range Raman signatures related to changes in enameling technologies from the 18th to the 20th century: Guidelines, effectiveness and limitations of the Raman analysis, *Materials*, 15, 3158.
- Colomban, P., Tournié, A., Caggiani, M. C., Paris, C. (2012), Pigments and enamelling/gilding technology of Mamluk mosque lamps and bottle, *J. Raman spectrosc.*, 43, 1975–1984.

- Cornell, R. M., Schwertmann, U. (2003), The iron oxides: structure, properties, reactions, occurrences and uses; John Wiley & Sons: Hoboken, NJ (USA).
- Cultural Heritage Science Open Source (CHSOS), Pigments Checker - Modern & Contemporary Art, Spectral databases Raman-785 and Raman-532, Viagrande, Italy. <https://chsopensource.org/pigments-checker/> (retrieved: March 2023)
- Czernichowska, J., Dmowska, R., Nowicka, A. (2011), Two paintings by Rembrandt: “Girl in a picture frame” and “Scholar at his writing table” from the collection of the Royal Castle in Warsaw – history, examination and conservation, *Zeszyty Naukowe Uniwersytetu Jagiellońskiego MCCCXX*, *Opuscula Musealia* Z. 19.
- Dariz, P., Schmid, T. (2021), Trace compounds in Early Medieval Egyptian blue carry information on provenance, manufacture, application, and ageing, *Sci. Reports*, *11*, 11296.
- de Waal, D. (2004), Raman investigation of ceramics from 16th and 17th century Portuguese shipwrecks, *J. Raman Spectrosc.*, *35*, 646–649.
- Dunn, E. J. (1973), Red lead in pigment handbook, vol.1, Ed. Patton, T. C., New York, NY (USA), pp. 837-842
- Eastaugh, N., Walsh, V., Chaplin, T., Siddall, R. (2004), “Egyptian blue”. The pigment compendium: Optical microscopy of historical pigments. Oxford, UK. Elsevier Butterworth Heinemann. pp. 147–148.
- Edwards, H. G. M., Hassan, N. F. N., Middleton, P. S. (2006), Anatase - a pigment in ancient artwork or a modern usurper?, *Anal Bioanal. Chem.*, *384*, 1356–1365.
- Evans, D. J. J. (2004), Cadogan Guides Portugal, ISBN 9781860111266, p. 221.
- Feller, L. (Ed.) (1986), Artists’ pigments - a handbook of their history and characteristics, Vol. 1, Cambridge University Press, London, United Kingdom, pp. 109-139.
- Filipe, S. (2006), Arqueologia Urbana em Coimbra: Um testemunho na Reitoria da Universidade, Conimbriga, XLV (2006), Instituto de Arqueologia da FLUC, pp. 337-357.
- Filipe, S. (2007), Intervenção arqueológica no Colégio da Trindade - Resultados preliminares, *Rua Larga*, *15*, 21-23. Filipe, S. (2015), Arqueologia urbana em Coimbra: um testemunho na Reitoria da Universidade, *Conimbriga Rev. Arqueol.*, *45*, 337–357.
- Gao, T., Fjellvag, H., Norby, P. (2009), A comparison study on Raman scattering properties of α - and β -MnO₂, *Anal. Chim. Acta*, *648*, 235–239.
- Gázquez, F., Calaforra, J. M., Rull, F. (2012), Boxwork and ferromanganese coatings in hypogenic caves: An example from Sima de la Higuera Cave (Murcia, SE Spain), *Geomorphol.*, 177-178, 158–166.
- Gettens, R. J., Kühn, H., Chase, W. T. (1967), Lead white, *Stud. Conservat.*, *12*, 125–139.
- Gettens, R. J., Stout, G. L. (1966), Painting materials: a short encyclopaedia, Dover Publ., New York, NY (USA).
- Gradman, R. (2016), Analysis of historical Islamic glazes and the development of a substitution material, PhD. Thesis, Institute of Geography and Geology, Department of Geodynamics and Geomaterial Research, Julius Maximilians University Würzburg, p. 173.
- Heyes, P. J., Anastasakis, K., de Jong, W., van Hoesel, A., Roebroeks, W., Soressi, M. (2016), Selection and use of manganese dioxide by Neanderthals, *Nat. Sci. Rep.*, *6*, 22159.
- Hoffman, D. L., Standish, C. D., García-Diez, M., Pettitt, P. B., Milton, J. A., Zilhão, J., Alcolea-González, J. J., Cantalejo-Duarte, P., Collado, H., de Balbín, R., et al. (2018), U–Th dating of carbonate crusts reveals Neandertal origin of Iberian cave art. *Science*, *359*, 912–915.
- Hradil, D., Grygar, T., Hradilová, J., Bezdicka, P. (2003), Clay and iron oxide pigments in the history of painting, *Appl. Clay Sci.*, *22*, 223 – 236.
- Hu, S., Tian, F., Bai, P., Cao, S., Sun, J., Yang, J. (2009), Synthesis and luminescence of nanodiamonds from carbon black, *Mater. Sci. Eng. B*, *157*, 11–14.
- Jacobsen, S. D., Reichmann, H. J., Kantor, A., Spetzler, H. A. (2005), A gigahertz ultrasonic interferometer for the diamond anvil cell and high-pressure elasticity of some iron-oxide minerals, in Chen, J., Duffy, T. S., Dobrzinetskaya, L. F., Wang, Y., Shen, G., Eds., *Advances in high-pressure technology for geophysical applications*. Elsevier Science. pp. 25–48.

- Jones, R. (2021), The decoration and firing of ancient Greek pottery: a review of recent investigations, *Adv. Archaeomater.*, 2, 67–127.
- Klein, C., Hurlbut, C. S., Jr. (1985), *Manual of Mineralogy*, John Wiley and Sons Ltd., New York (USA), 20th Ed., p. 317 Lafuente, B., Downs, R. T., Yang, H., Stone, N. (2015), The power of databases: the RRUFF project. In: *Highlights in Mineralogical Crystallography*, T Armbruster and R M Danisi, Eds., Berlin, Germany, W. De Gruyter; pp 1-30.
- Mandarino, J. A., Back, M. E. (Eds) (2004), *Fleischer's glossary of mineral species*. 9th edn. The Mineralogical Record Inc., Tucson, AZ (USA).
- Marketou, A. K., Kouzeli, K., Facorellis, Y. (2019), Colourful earth: Iron-containing pigments from the Hellenistic pigment production site of the ancient agora of Kos (Greece), *J. Archaeol. Sci.: Reports*, 26, 101843.
- Marques, U. F. (2020), Estudo de peças do espólio arqueológico da Universidade de Coimbra por espectroscopia de Raman e espectroscopia de fluorescência de raios-X, PhD. Thesis, Department of Chemistry, University of Coimbra, Coimbra, Portugal, p. 50.
- Mattoso, J. (1997), *História de Portugal. Antes de Portugal*, Editorial Estampa, Lisbon, Portugal, Volume I–III, p. 452. McCouat, P. (2018), “Egyptian blue: The colour of technology”. *Journal of Art in Society*, www.artinsociety.com/egyptian-blue-the-colour-of-technology.html (retrieved: September 2022).
- McCrone, W. C. (1974), *Chemical analytical study of the Vinland map*, Report to Yale University Library, New Haven, CT (USA).
- McCrone, W. C. (1988), The Vinland map, *Anal. Chem.*, 60, 1009–1018.
- Miliani, C., Monico, L., Melo, M. J., Fantacci, S., Angelin, E. M., Romani, A., Janssens, K. (2018), Photochemistry of artists' dyes and pigments: towards better understanding and prevention of colour change in works of art, *Angew. Chem., Intl. Ed.*, 57, 7324–7334.
- Molera, J., Coll, J., Labrador, A., Pradell, T. (2013), Manganese brown decorations in 10th to 18th century Spanish tin glazed ceramics, *Appl. Clay Sci.*, 82, 86–90.
- Molera, J., Pradell, T., Martinez-Manent, S., Vendrell-Saz, M. (1993), The growth of sanidine crystals in the lead of glazes of Hispano-Moresque pottery, *Appl. Clay Sci.*, 7, 483–491.
- Moon, R. O. (2009), Pliny on chemistry - The Elder Pliny's chapters on chemical subjects. Part II. Edited with translation and notes by Bailey, K.C., *Class. Rev.*, 46, 276.
- Pérez-Arantequi, J., Soto, M., Ramón Castillo, J. (1999), Examination of the ‘cuerda seca’ decoration technique on Islamic ceramics from al-Andalus (Spain), *J. Archaeol. Sci.*, 26, 935–941.
- Post, J. E., McKeown, D., Heaney, P. J. (2020), Raman spectroscopy study of manganese oxides: Tunnel structures, *Amer. Mineral.*, 105, 1175–1190.
- Pradell, T., Molera, J., Salvadó, N., Labrador, A. (2010), Synchrotron radiation micro-XRD in the study of glaze technology. *Appl. Phys. A*, 99, 407–417.
- Price, B. A., Pretzel, B., Lomax, S. Q., eds. (2007), *Infrared and Raman Users Group Spectral Database*. Vol. 1 & 2. Philadelphia (USA): IRUG, 2009. *Infrared and Raman Users Group Spectral Database*. <www.irug.org>.
- Ravindran, T. R., Arora, A. K., Ramya, S., Subba Rao, R. V., Raj, B. (2011), Raman spectroscopic study of medieval Indian art of 17th century, *J. Raman Spectrosc.*, 42, 803–807.
- Schweizer, F., Rinuy, A. (1981), Manganese black as an Etruscan pigment, *Studies in Conservation*, 27, 118–123.
- Scrivano, S., Gaggero, L., Volpe, E. (2019), Paint relics on Middle Age building stones as proxies of commercial routes and artistic exchanges: a multi-analytical investigation, *Minerals*, 9, 663.
- Siddall, R. (2018), Mineral pigments in archaeology: their analysis and the range of available materials, *Minerals*, 8, Art. 201.
- Somervill, B. A. (2005), *Michelangelo: sculptor and painter*, Compass Point Books, Minneapolis, MN (USA).

- Stewart, S. (2014), Gleaming and deadly white: toxic cosmetics in the Roman world, in Wexler, P. (Ed.). History of toxicology and environmental health: toxicology in antiquity. Vol. II, Academic Press, New York, NY (USA). p. 84.
- Tamburini, D. (2021), Colour analysis: an introduction to the power of studying pigments and dyes in archaeological and historical objects, *Heritage*, 4, 4366–4371, and articles in the special issue “Pigments and Dyes in Archaeological and Historical Objects — Scientific Analyses and Conservation Challenges”.
- Thermo Fisher Scientific Inc., OMNIC (Version 8.2.0.387), Copyright © 1992-2010, Waltham, MA, USA.
- Thompson, D. V. (1970), The materials and techniques of Medieval painting, Dover Publications, New York, NY (USA), p. 102.
- Tite, M. S., Maniatis, Y., Kavoussanaki, D., Panagiotaki, M., Shortland, A. J., Kirk, S. F. (2009), Colour in Minoan faience, *J. Archaeol. Sci.*, 36, 370–378.
- Tuñón, J. A., Sánchez, A., Parras, D. J., Vandenabeele, P., Montejo, M. (2016), Micro-Raman spectroscopy on Iberian archaeological materials, *J. Raman Spectrosc.*, 47, 1514–1521.
- Vendrell, M. Molera, J., Tite, M. S. (2000). Optical properties of tin-opacified glazes, *Archaeometry*, 42, 325–340.
- Wen, R., Pollard, A. M. (2016), The pigments applied to Islamic minai wares and the correlation with Chinese blue-and- white porcelain, *Archaeometry*, 58, 1–16.
- Zuo, J., Xu, C., Wang, C., Yushi, Z. (1999), Micro-Raman spectroscopy and ancient ceramics, *J. Raman Spectrosc.*, 30, 1053–1055.

CHAPTER 11

IMAGING DIFFERENT TYPES OF MATERIALS IN CULTURAL HERITAGE WITH REFLECTANCE TRANSFORMATION IMAGING (RTI) TECHNIQUE

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Abstract

Reflectance transformation imaging (RTI) technology is a method used in the visual examination and documentation of cultural heritage. The method has a fixed camera setup. The artifact, which is placed opposite the camera, is illuminated from different angles using fixed equipment or labor. One photograph is taken for each angle of illumination. The photographs are processed with the help of software, and the color and shape information is saved in a file. Thanks to the advanced functions in the computerized imaging software, surface features and color information can be changed to bring to the fore details that would not be noticeable under normal conditions. The method can be used to document various works and contribute to the investigation of construction techniques and deterioration before restoration and conservation works. Fixed hardware was produced for use in this study. The body of the hardware is geodesic-dome-shaped. The LED lighting on the dome worked synchronously with the shooting device by communicating wirelessly. Using this equipment, ceramics, oil on wood, metal, and paper materials were imaged using the RTI method. Imaging different types of materials allowed us to compare the success of the method on different surfaces. At the same time, the method is expected to highlight the traces caused by production on the surface and the physical damages that occur afterward. The fact that various works had suffered some damage was considered to examine their construction techniques and distortions and that the color-shape properties were variable in object selection. The possible contribution of this method to conservation and restoration studies can also be evaluated.

Keywords: Reflectance transformation imaging, geodesic dome, conservation, cultural heritage

1. Introduction

Cultural heritage has a natural aging process. The aging process and the factors affecting this process cause changes on the surface of cultural heritage. Discoloration, abrasion, loss of parts, scratches, pitting, crusting by chemical effects, corrosion, and cracking are some of them. Assessing the current status of cultural heritage is important in determining the cause of its deterioration, protecting the work, and determining the repair method. The limits of the human eye require tools that can collect information from the surface. In this regard, reflectance transformation imaging (RTI) provides a virtual vision of the surface of artifacts by processing surface normals and color information. With the RTI method, oil paintings, textiles, paper, ceramics, metal, stone, wood, and many more can provide data on their surfaces. In works with complex textures and surfaces, such as oil paintings, the ability to extract color information from images makes abrasions and brush strokes visible with the movement of light. In addition, on surfaces with layered and rough textures, such as ceramics, much data from tool marks to layer losses can be provided by this method (Manrique-Tamayo et al., 2013).

2. RTI method's working principle

The RTI method, which is based on photometric stereo technology, does not use 3D geometry. In the RTI method, while the displayed object and the camera are stationary, the position of the light illuminating the object changes. Photographs are taken by illuminating the subject from different positions, and the surface reflection of the object is obtained by combining these photographs. The abbreviation RTI is used not only for the method but also for the format of the file obtained by using the method. In 2000, Tom Malzbender of HP Labs introduced Polynomial Texture Mapping (PTM), an alternative for compressing surface properties. Later on, at the University of Minho in Portugal, Cultural Heritage Imaging (CHI), together with a funded project contributed by the CHI team and Tom Malzbender of HP Labs, the open-source software package RTIBuilder was developed (Earl et al., 2011, pp. 147–148).

The RTIBuilder software can be downloaded from the CHI website. With this software, two different image processing techniques are presented to the user: PTM and RTI. In both methods, black or red spheres with a glossy surface that can be clearly seen are placed in the frame when the photograph is taken (Fig. 1). The developed software captures the reflection of the light hitting the placed spheres and determines from which direction the light hits the sphere. Known light directions can be processed by two different algorithms and saved as RTI or PTM file extensions. RGB values are recorded for each pixel in the file (excluding lighting conditions) (Mudge et al., 2012, pp. 644–648).

The angle between the surface of the lights to be used in the RTI/PTM method should be between 15° and 65° . The light sources should be positioned at a distance of two or four times the diameter of the object being imaged. A minimum of 16 images are needed to obtain an RTI/PTM file, and 24–60 images are enough to achieve a successful result. Meanwhile, hemispherical harmonics is a newer technique and gives better results on 3D surfaces. In this technique, the accuracy of surface normals is higher. However, when examining the image with the PTM technique, the software allows more tools to be used (Duffy et al., 2018).

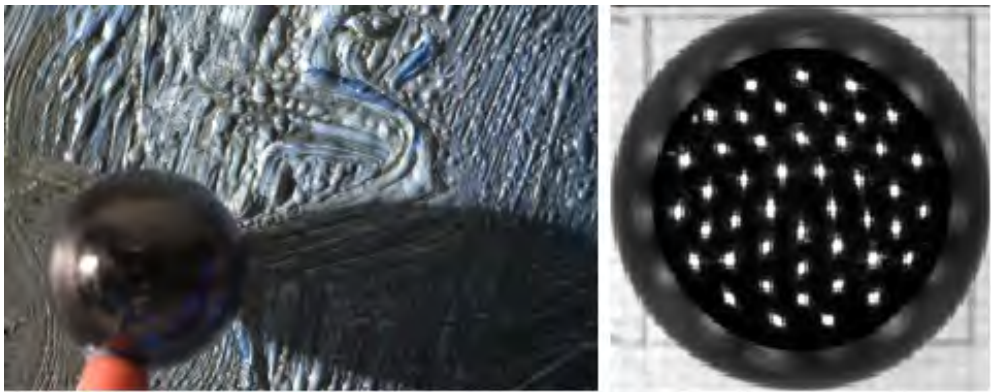


Figure 1. A sphere placed on the photographed surface (left) and the sphere (right) where the light reflections are combined in the processed image. (http://www.c-h-i.org/learn/media/RTI_Hlt_Capture_Guide.pdf) (Tamayo Manrique et al., 2013, p. 545)

2.1. Fixed equipment

Hardware with fixed light sources ensures fast and consistent viewing. Light sources can be positioned in hemispherical or geodesic domes. It can also be placed on fixed arms surrounding a camera (Earl et al., 2011). This equipment can be produced in different sizes according to the surface area of the work to be displayed. However, the area displayed by the camera should be at least $1/3$ of the size of each dome. In domes that are not produced three times the size of the imaged area, the reflection of light cannot be calculated correctly. Light sources can be selected by the hardware manufacturer without being tied to a specific standard. The choice of camera and lens is also determined according to the needs of the practitioner. These variables affect the color accuracy and depth of field. The camera placed at the top of the dome and the light sources placed at fixed distances are automatically triggered. The placed light sources are usually divided into 12 arms with the camera in the center. Three or four tilt points should be determined for each arm, and the light sources should be placed at these points. However, different designs are also available (Fig. 2). Although the

light placement, number, and temperature vary depending on the equipment, only one light source is active each time the camera is triggered. In addition to complex electronic systems, cost-effective codable electronic cards can also be used for triggering (Bentkowska-Kafel, 2018; Cultural Heritage Imaging, 2013a).

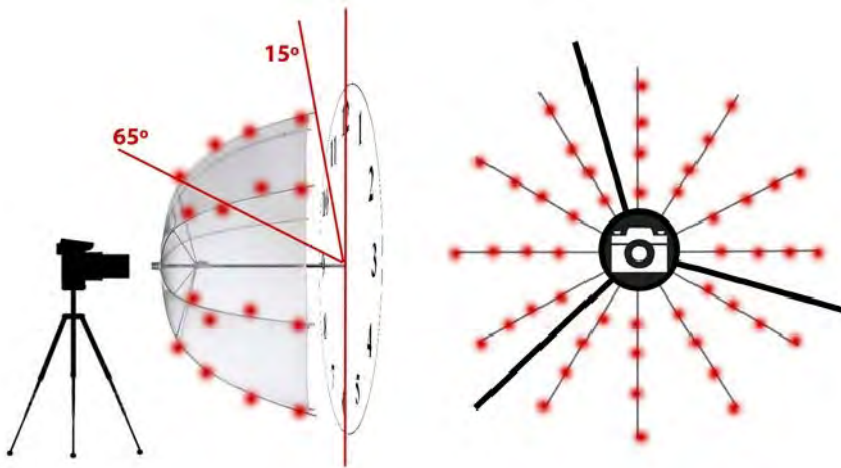
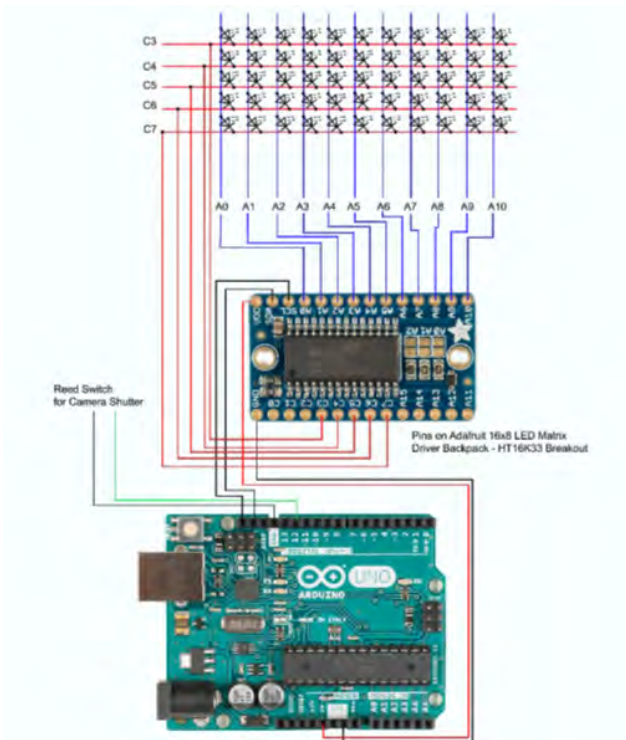


Figure 2. Schematic representation of the light layout of the dome. (http://culturalheritageimaging.org/What_We_Offer/Downloads/RTI_Hlt_Capture_Guide_v2_0.pdf.)

In low-cost hardware, the trigger is usually provided by Arduino boards and the illumination is provided by codable LED lights. These circuit boards can trigger any type of lighting used simultaneously with the camera. In the display of small-sized works, addressable strip LEDs (WS2812B) that Arduino boards can power are preferred (Fig. 3). Such lighting includes integrators that can be coded in each LED. Because a 5-V power supply provides enough energy for both Arduino and LED, there is no need for an extra power supply in the system. It also allows the installation of portable systems without the need for complex wiring or an external electronic card. However, the white color produced by the LEDs in this system does not have high accuracy. Meanwhile, addressable LED, which consists of three diodes emitting green, red, and blue colors, cannot provide homogeneous white color distribution. In this regard, a color calibration table can be placed in the photo frame to eliminate color-related problems. Color calibration can be performed with software support. In large-sized equipment where high light intensity is required, chip on board (COB) technology is used. COB illuminations operate at high lumen values. These can be produced with different voltage, amperage, and temperature values. Such LED lights must

be triggered externally as they do not have built-in integrations. Arduino and similar various electronic boards can be used for triggering.

There have been many studies on hardware in these applications. Although the shape of the hardware varies, the orientation of each light source must be centered. Half-dome-shaped hardware is often preferred for this reason. With the ease of the manufacture and use of this hardware, geodesic hemispheres have become popular. The connection points of geodesic domes and the middle parts of the interconnected apparatus are suitable for use by directing light to the center (Fig. 4). Online software that can do calculations for the production of geodetic domes and connection apparatus in accurate dimensions is also available. The materials used in the production of the dome also vary, but the interior is usually made of black matte materials to prevent light reflection. There should not be any light source in the environment that may cause misleading reflection other than the lighting of the hardware. Thus, the outer part of the dome is closed with materials that will not pass light (Kinsman, 2016; Corregidor et al., 2020).



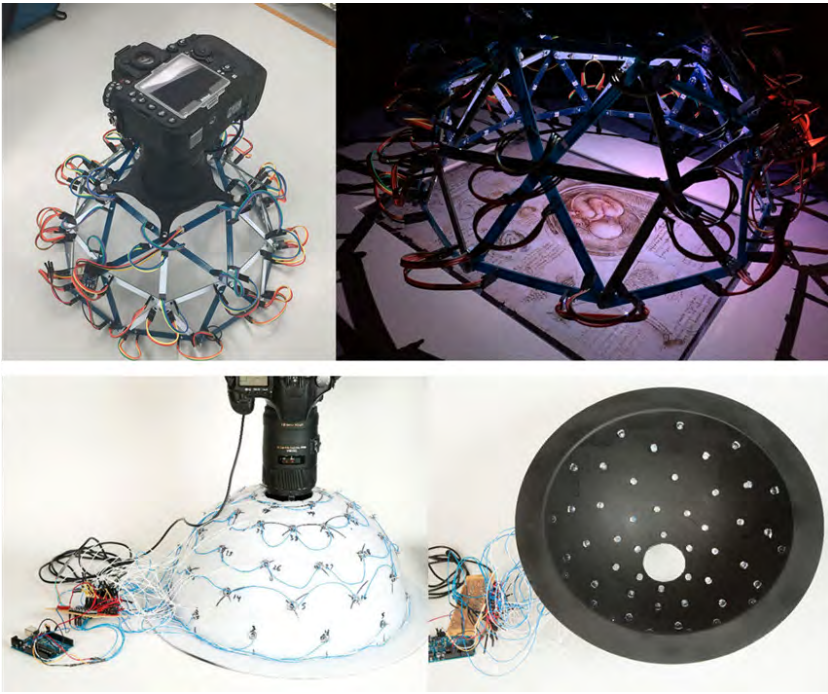


Figure 4. Geodesic dome (top) and hemispherical dome (bottom). (Kinsman, 2016, pp. 12–13)

With stationary equipment, there is no need for black or red glossy spheres used to calculate the angle of light. After processing a series of images shot with fixed hardware with the RTIBuilder software, creating an LP file and defining this file to the program are sufficient as the direction of the light does not change in subsequent studies.

2.2. Manual imaging

Although fixed hardware provides speed and high accuracy, imaging can be performed without the use of such systems. In this method (where the camera is fixed), the light is moved manually for each photo. Para flash or continuous light sources can be used (Fig. 5). Spheres with black or red glossy surfaces are placed close to the subject so that they enter the frame. Then, at the same distance from the center, the light source is reflected on the object's surface from different angles. In each frame, the light source causes a point-shaped reflection on the spheres with a bright surface. These reflections can be determined by the algorithms of the RTIBuilder software, and the stroke angles of the light can be determined. When applying the method, the distance of the light from the center is different in each frame and the overlap of the reflections in the spheres with bright surfaces causes errors in the RTI file (Earl et al., 2011, pp. 149–150; Cultural Heritage Imaging, 2013a).



Figure 5. RTI shooting without fixed hardware. (Schroer, 2012)

2.3. Microscopic imaging

To obtain microscopic images using the RTI method, optical microscopes capable of zooming with a large working area are needed (Fig. 6). In this method, spheres with black or red glossy surfaces are required to calculate light angles. When shooting with a microscope, a dome shape can be created or the subject can be illuminated from the desired distance and angle with a small light source (Min et al., 2021; Earl et al., 2011).

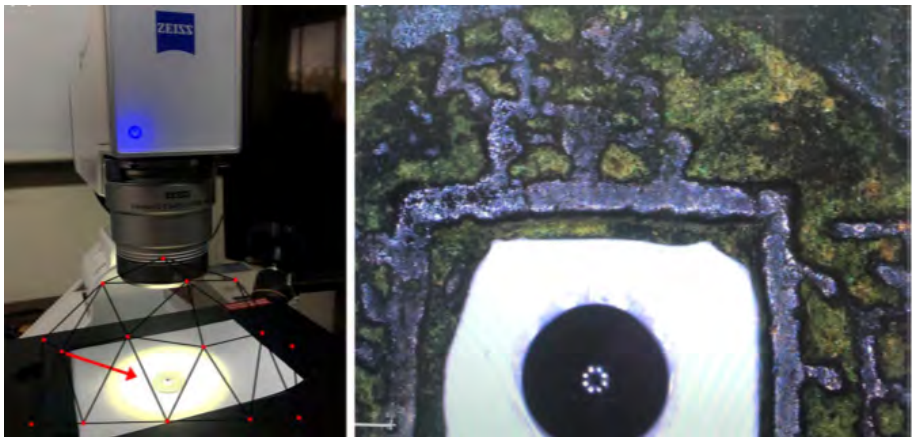


Figure 6. Microscope used for imaging, geodetic reference points created for the light (left), and details of the surface being imaged (right). (Min et al., 2021)

2.4. Image processing and inspection

A series of images obtained by automated or manual systems were processed using algorithms owned by the RTIBuilder software on the CHI team's website. The software, which can work with Windows and MacOS operating systems, supports RTI and PTM technologies. The processed images were saved with file extensions of the same name according to the preferred method. Because the PTM algorithm is patented by HP Labs, it was not included in the RTIBuilder software package. The display of the files used RTIViewer software, which can be downloaded from the CHI team's website.

The RTIViewer software includes a virtual light router that allows changing the angle of the light hitting the object. The software provides different reflection characteristics by editing RGB color information and surface normals. In this way, more details can be displayed than those of software that filters with color data. Depth perception can be increased by changing the surface slope using the diffuse gain tool (Fig. 7). Using the specular enhancement tool, surface distortions that are difficult to see on very glossy or matte surfaces due to color information become visible by removing the RGB information from the image and moving the light in the desired direction (Cultural Heritage Imaging, 2013b) (Figs. 8 and 9).

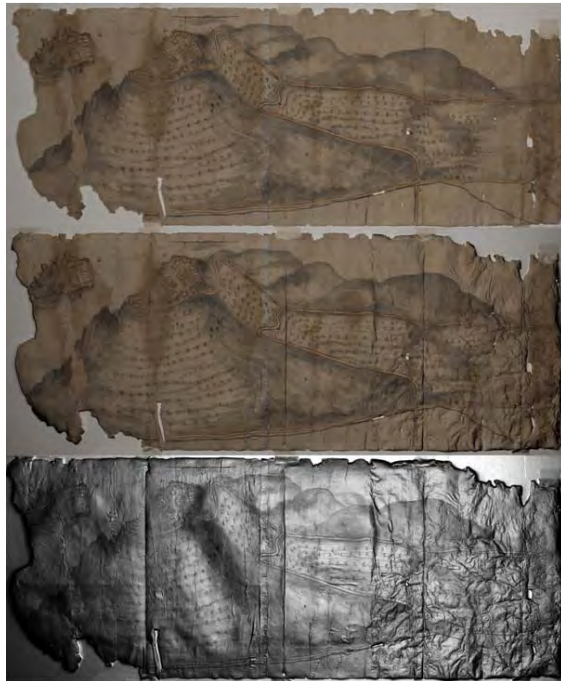


Figure 7. Viewing a watercolor work in plain light (top) and at the same light angle as the diffuse gain tool (middle) and specular enhancement tool (bottom). (Tamayo Manrique et al., 2013)

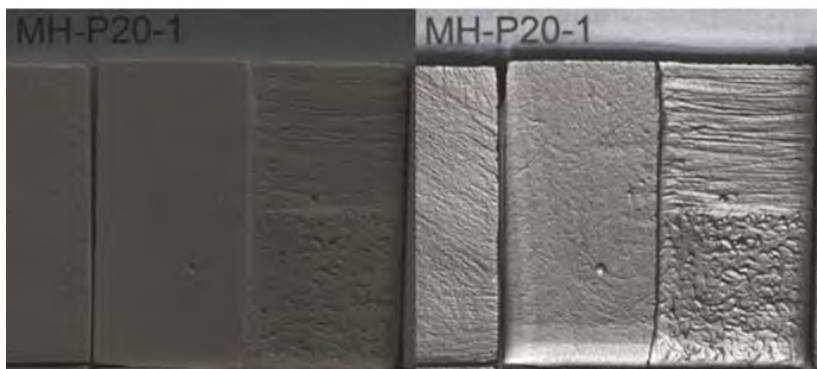


Figure 8. View of bone tissue under normal light (left) and after processing with RTI (right).
(Tamayo Manrique et al., 2013)



Figure 9. A piece of ceramic depicting Dione and Aphrodite under normal light (left) and after processing with RTI (right). (www.timesofisrael.com/imaging-technology-reveals-birth-of-athena-on-2300-year-old-shard-from-galilee/.)

3. Investigation of dome imaging on various materials

Within the scope of the broadcast, ceramics, paper, metal objects, and one oil-on-wood work were imaged using the RTI method. The equipment used in the display was a geodesic dome with 60 LED light sources and was manufactured by us (Fig. 10). The geodesic dome used in the shootings was low-budget, and various surfaces were imaged with RTI using this equipment.

3.1. Dome structure

The use of low-budget equipment and the results obtained show that advanced imaging techniques can be applied without high costs in the imaging of cultural heritage. A smartphone camera, 60 codable LEDs (WS2812B) for lighting, a Bluetooth trigger to control the smartphone camera, and an Arduino UNO to control all this hardware were used to obtain the images. The shape of the structure where the codable LEDs were positioned was geodesic. The preference for this shape was because the distance of the LEDs from the center of the dome must remain constant. The body of the geodesic dome consisted of compressed paper. Such a material provided both sufficient body strength and a lightweight structure. Starting from the base of the 60 LEDs on the dome, they illuminated the object from different angles for 2 s in turn. The LEDs were controlled with the help of an Arduino-based microcontroller. Arduino UNO can be coded with a software installation tool, and tasks can be assigned to the hardware to be triggered. The flashing speed of the LEDs can be customized according to the camera used with corrections to be made on the software.

The designed geodesic dome had two shooting modes. One of the two buttons on the dome's control was coded to trigger all LEDs, whereas the second button was coded to not trigger 10 LEDs close to the floor. The second button, which allowed shooting with 50 LEDs, was used to display three-dimensional subjects. Otherwise, an apparatus was needed to raise the dome. The color, light intensity, and light temperature can also be changed by coding the microcontroller. In this way, a more flexible working opportunity was created to emphasize the details of the object being imaged. The Bluetooth trigger in the hardware received commands from the Arduino UNO microcontroller. It was triggered 1 s after the smartphone camera started being illuminated by each LED. This allowed time for each photograph to allow the camera to receive sufficient light. The flashing times of the LED light sources during shooting and the trigger time of the Bluetooth module could be adapted to the exposure time. A 5-mm black ball earring with a glossy surface was used so that RTI algorithms could predict the direction of illumination. A 5-mm sphere was sufficient for a dome with a diameter of about 1 m. The angle of the reflections falling on the sphere could be recorded as an LP file. In this way, there was no need to use a sphere for each shot on the fixed equipment. Defining the LP file in the program while processing the images shortened the processing time.

The features of the hardware could be arranged according to the need through the software. Because it has an easy installation, it can be updated to shoot ultraviolet or infrared.



Figure 10. RTI dome in the geodesic structure. (Photo. Emirhan Çetinkaya)

3.2. Viewed materials and reviews

The handmade ceramic object in Figure 11 had a height of 12 cm. The RTI file of the ceramic object was created using a total of 50 photographs. In examinations made with color information, the details on the surface became visible at different light angles. The RTI image of the object gave information about the tools used and their angle of use and shape. At the same time, fingerprints could be seen in detail. The emphasis on detail could be replaced by the tools available to the RTI Viewer software. When the surface properties were examined with the specular enhancement tool without color information, the depth of the traces created by the instruments became clear. At the same time, the illusion created by glossy or matte areas was minimized. With the examinations, one fracture was seen in the arm and leg parts of the object. The lines on the legs were made with the help of a tool, and their depth differed from that of the fractures. The lines on the body had variable depths and angles. The tool depths show that about three different tools were used to make the object (Fig. 12). Fingerprints seen in areas where tool

marks were not dense show that these areas were shaped by hand. This recording of fingerprints by the RTI method could also contribute to the work of researchers working in this field. The method allows a qualitative examination of the object because it does not provide metric data and does not contain precision. However, with the data obtained about the details of the object, one can comment on the construction technique and the deformations it has undergone. On this basis, this method can be considered a safe method that can be used in due diligence in ceramic works that have already been repaired. In particular, it can be a useful method for comparing damages before restoration, the applications made during restoration, and the physical changes that occurred on the surface after restoration. Routine checks can also be observed with a fixed dome and camera parameters. Images can be obtained with embossed surfaces or written terracotta works with emphasis on the desired details.



Figure 11. Ceramic object seen under flat light (left) and at the same light angle as the specular enhancement tool (medium) and normals visualization tool (right). (Photo. Emirhan Çetinkaya)



Figure 12. Detailed view of the ceramic object with the specular enhancement tool. (Photo. Emirhan Çetinkaya)

Two RTI files for the front and back of the banknote in Figure 13 were created by combining 60 images each. When examined with the naked eye, folding marks, tears, and some surface damage over time were noticeable on the surface. When the RTI image was examined, some tears were deeper and the folding marks were more than visible. In this way, details that may be overlooked during the determination of the methods and materials to be used in the repair of paper money were documented. Detecting damages on the paper surface made it possible to predict possible deterioration situations and implement preventive interventions. The physical damage caused by the areas with colored patterns and pictures on paper money was not clearly visible in the photographs. However, the specular enhancement tool included in the RTIViewer software allowed the surface to be examined without color information (Fig. 14). In this way, damage assessment images required for publication, exhibition, and documentation can be obtained. At the same time, the success of the intervention after repair applications can be documented with RTI images. In post-restoration controls, the physical results of the change that the works undergo under the influence of humidity and temperature in warehouse or exhibition conditions can be viewed using this method.



Figure 13. Appearance of the front and back of banknotes at the same light angle as the flat light (top), specular enhancement tool (middle), and normals visualization tool (bottom).

(Photo. Emirhan Çetinkaya)



Figure 14. Detailed view of the front and back of a banknote in plain light (left) and with the specular enhancement tool (right). (Photo. Emirhan Çetinkaya)

To display the front and back sides of a stamp and coins in Figures 15 and 16, 50 photographs were used in the creation of the RTI file. Scratches on the surface of the coins were formed due to use. There were no mold marks as they were up-to-date materials. However, besides the traces on the stamp due to use, mold traces were also seen. These marks could be distinguished from the scratches that occurred later because they were more pronounced and deeper. Errors or marks on the mold gave information about the place of production of the coins and similar metal artifacts. Mold defects and marks on the surface of stamps can be examined together with a group of stamps of the same type and thus can provide information about their place and date of production. The surface of coin number 2 in Figure 17 shows distortion in the color images. However, when examined without color information, this deterioration did not cause any change in the surface. The physical change caused by the deterioration of the edges of coin number 1 on the surface can be clearly seen. When metal artifacts are photographed, detailed information about color change and corrosion cannot be stored. When viewed using the RTI method, the surface changes caused by corrosion can also be recorded. The extent of the damage in surface deterioration can also be monitored by this method. Thus, visual examinations using the RTI method are useful in limiting the cleaning on the surface of metal artifacts. This method can also be used to document the physical deterioration caused by different types of corrosion and to determine the intervention method.

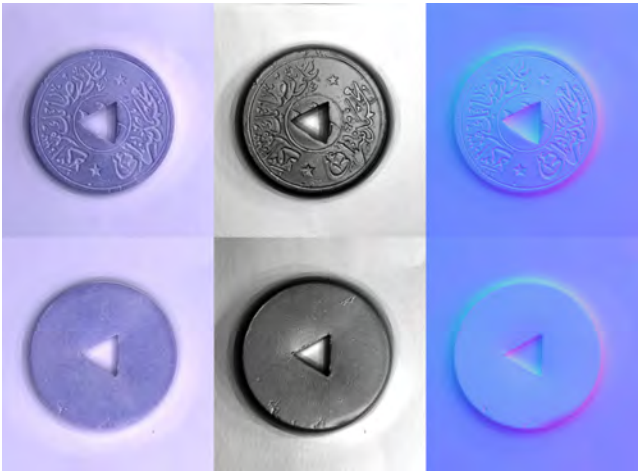


Figure 15. Appearance of the front and back surface of an Ottoman metal stamp in plain light (left) and at the same light angle as the specular enhancement tool (center) and normals visualization tool (right). (Photo. Emirhan Çetinkaya)



Figure 16. View of various coins in flat light (left) and at the same light angle as the specular enhancement tool (medium) and normals visualization tool (right). (Photo. Emirhan Çetinkaya)

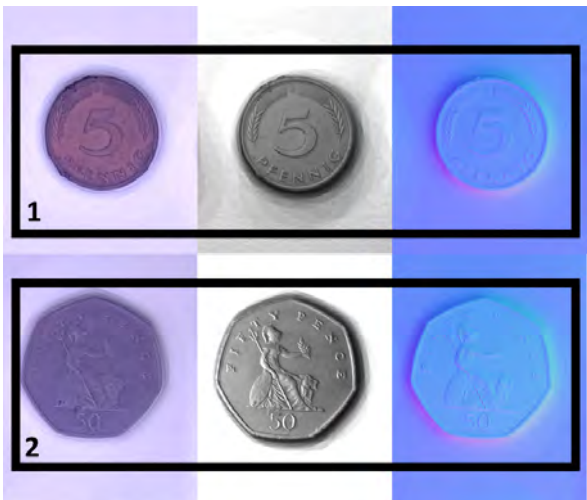


Figure 17. Appearance of coins 1 and 2 in plain light (left) and at the same light angle as the specular enhancement tool (medium) and normals visualization tool (right). (Photo. Emirhan Çetinkaya)

The RTI file of the oil-on-wood painting in Figure 18 consisted of 50 images. The surface of the oil painting work was covered with varnish. In the RTI image, when the subject was illuminated from different angles, the brush strokes and the height of the paint were noticeable. When the oil painting work was illuminated from the left side using the specular enhancement tool, the varnish dripping onto the surface became visible (Fig. 19). No deformation was observed on the surface. Macro shooting was required to examine the brush strokes in more detail. A DSLR camera and a macro lens can be used for this type of examination. The geodesic dome was strong enough to carry a DSLR camera.

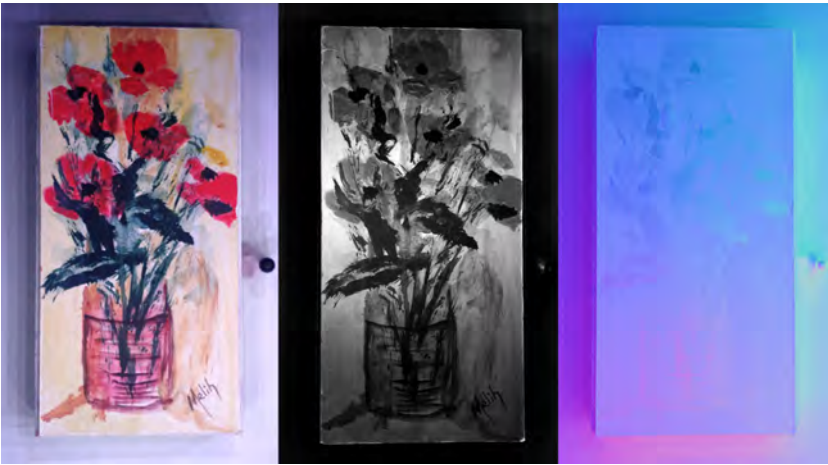


Figure 18. Oil painting on wood in plain light (left) and with the specular enhancement tool (medium) and normals visualization tool (right) at the same light angle. (Photo. Emirhan Çetinkaya)

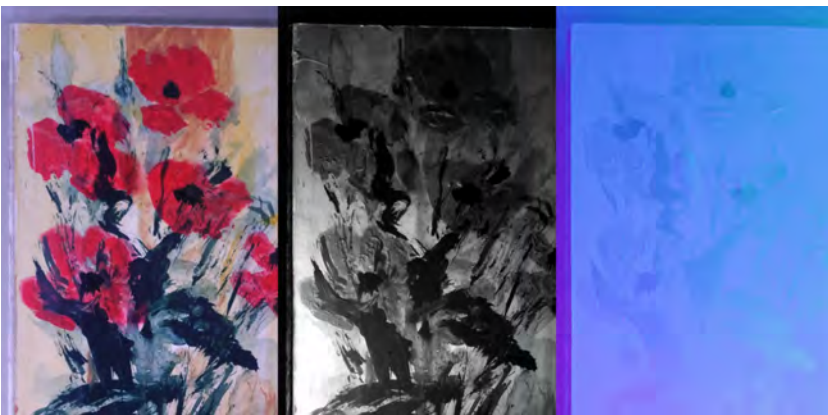


Figure 19. Paint and varnish heights in appearance with the specular enhancement (medium) and normals visualization (right) tool of the oil painting on wood. (Photo. Emirhan Çetinkaya)

4. Conclusion

RTI is a method used to examine the properties of an object's surface and to document the displayed object. Many images taken at different light angles can be stored together, and surface details that emerge in different reflection properties of the surface can be examined.

Documenting the surface properties in detail while examining cultural heritage means recording various data, such as the construction technique of the work, the tool traces used during production, the writings or signs that cannot be noticed in examinations made with the naked eye, and the destruction suffered by the surface in a single file.

The RTI technique, which is used in documenting cultural heritage, takes photographic documentation one step further by allowing the recording of not only RGB information but also surface normals. Processing recorded surface normals makes the characteristic features of the object surface apparent. This feature can be used in the examination of physical deterioration, construction techniques, and restoration interventions of cultural heritage. Precise data cannot be obtained by the method that cannot be measured metrically. Only evaluations that support scientific data can be made.

This method can be used as an alternative in archaeological excavations or laboratories where photographic documentation is conducted. The low-cost fixed installation introduced in the article allows for quick and detailed documentation in such places as it may not be possible to photograph artifacts again during excavations or laboratory work. In such cases, the RTI file has the advantage of having many images illuminated from many angles. To enrich narration in academic publications, the modes of the RTI Viewer software can be used to make the surface details more visible. In addition, RTI files can be adapted to digital publications, offering the reader the opportunity to examine various cultural works.

References

- Bentkowska-Kafel, A., De-Almeida, V. M., Macdonald, L., Del Hoyo-Meléndez, J. M. (2018). Beyond photography: an interdisciplinary, exploratory case study in the recording and examination of roman silver coins. *In Digital Techniques for Documenting and Preserving Cultural Heritage*, (pp.35-66). ARC. Amsterdam University Press.
- Borschel-Dan, A. (2018). Imaging Technology Reveals Birth of Athena on 2,300-Year-old Shard from Galilee. The Times of Israel. Retrieved from: <https://www.timesofisrael.com/imaging-technology-reveals-birth-of-athena-on-2300-year-old-shard-from-galilee/>.
- Corregidor, V., Dias, R., Catarino, N., Cruz, C., Alves, L. C., Cruz, J. (2020). Arduino-controlled reflectance transformation imaging to the study of cultural heritage objects. *SN Applied Sciences*, 2(9), 1-10.

- Cultural Heritage Imaging. (2013A) Reflectance Transformation Imaging, Guide to Highlight Image Capture, Document Version 2.0, San Francisco. Retrieved from: http://culturalheritageimaging.org/What_We_Offer/Downloads/RTI_Hlt_Capture_Guide_v2_0.pdf.
- Cultural Heritage Imaging. (2013B) Reflectance Transformation Imaging Guide to RTIViewer, Document Version 1.1, San Francisco. Retrieved from: http://culturalheritageimaging.org/What_We_Offer/Downloads/rtviewer/RTIViewer_Guide_v1_1.pdf.
- Duffy, S. M., Goskar, T., Backhouse, P., Kennedy, H. (2018). *Multi-light imaging highlight-reflectance transformation imaging (H-RTI) for cultural heritage*. Historic England.
- Earl, G., Basford, P., Bischoff, A., Bowman, A., Crowther, C., Dahl, J., Hadgson, M., Isaksen, L., Kotoula E., Martinez K., Pagi H., Piquette, K. E. (2011) Reflectance transformation imaging systems for ancient documentary artefacts. *Electronic Visualisation and the Arts (EVA 2011)*, p.147-154. <https://doi.org/10.14236/ewic/EVA2011.27>
- Kinsman, T. (2016). An easy to build reflectance transformation imaging (RTI) system. *Journal of Biocommunication*, 40(1), 10-14.
- Manrique-Tamayo, S. N., Valcárcel-Andrés, J. C., Osca-Pons, M. (2013). Applications of reflectance transformation imaging for documentation and surface analysis in conservation. *International Journal of Conservation Science*, 4, 535-548.
- Min, J., Jeong, S., Park, K., Choi, Y., Lee, D., Ahn, J., Har, D., Ahn, S. (2021). Reflectance transformation imaging (RTI) for documenting changes through treatment of Joseon dynasty coins, *Heritage Science*, 9(1), 1-12.
- Mudge, M., Schroer, C., Noble, T., Matthews, N., Rusinkiewicz, S. M., & Toler-Franklin, C. (2012). Robust and scientifically reliable rock art documentation from digital photographs. J. McDonald & P. Veth (ed) *In A Companion to Rock Art*, (pp. 644-659), John Wiley and Sons. <https://doi.org/10.1002/9781118253892.ch36>
- Schroer, C. (2012). Advanced imaging tools for museum and library conservation and research. *Bulletin of the American Society for Information Science and Technology*, 38(3), 38-42.

CHAPTER 12

EVALUATION OF THE DETERIORATION DETECTED IN HISTORICAL STONE STRUCTURES BY THERMOGRAPHIC INVESTIGATIONS: THE CASE OF ISTANBUL UNIVERSITY FACULTY OF LETTERS SOUTH FACADE

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Abstract

The thermal imaging method, which is a non-destructive diagnostic method for the investigation of historical stone structures, measures the heat dissipation of the materials examined and creates colored heat maps for analysis of the data. The method allows to evaluate the deterioration state of the structures, gathering information about their current preservation state and allowing to predict in advance sensitive areas of the structures where deterioration may arise in the future. Since there are differences in the heat transfer of original limestone materials, and repair mortars or imitations, the regions where dirt deposits form in the different materials and deformations of their surfaces are also different. The thermographic analyses (in particular, thermal mapping) thus allow to evaluate deterioration in the materials and help determining the factors that cause the deterioration of the structure, providing relevant data for the design of an effective conservation planning for the structures and helping the protection-repair works. This study applies the thermographic method to the evaluation of the deterioration state of the Faculty of Letters of the Istanbul University South external facade, with was built under the influence of the Second National Architecture movement and investigated by Architects Sedat Hakkı Eldem and Emin Onat. The factors causing

deterioration in the structure were also investigated by visual examination, soluble salt tests, moisture analysis and conductivity measurements, the results obtained with all methods being compared. The present study is also a contribution for the identification and evaluation the possible deterioration factors acting on historical stone structures in general.

Keywords: Thermographic investigations, historical stone structures, deterioration evaluation, Istanbul University Faculty of Letters

1. Introduction

The geological and mineralogical structure of the stones, the extraction and processing from the quarry, the ambient conditions and environmental factors cause physical, chemical and biological deterioration in the stones over time. The deterioration of stones is observed in different forms, such as cracking, fouling, crusting, dusting and fragmentation, both on the surface and internal structure of the stones (Siedel and Siegesmund, 2014, pp. 349-364).

In order to remove, prevent or alleviate the deterioration factors that might act in historical stone buildings, their identification and evaluation constitutes the most important step of the conservation of the buildings. This information is also crucial for restauration. In the process of evaluation of the degradation state of a building, the identification and characterization of the deteriorated areas and the correct identification of the factors affecting the deterioration are fundamental to preserve appropriately the structures and also to guide the planning of the necessary interventions in the building or determine the zones that require emergency intervention. This diagnostic process contributes to the general planning of the conservation-restoration works to be carried out on the structures.

Limestones were widely used in the monumental structures built in the Istanbul region during the Roman, Byzantine, Ottoman and Republican periods. For the choice of the materials used in most of the monumental masonry structures, the proximity of the stone quarry from the construction area has been an important factor. However, many other factors have contributed to the choice of the limestone material (Angi, 2011).

Limestones are usually classified as dense, solid, loose, hollow, hard and semi-hard. After the limestones comes out of the quarry, they are light and soft, easy to cut and process, being low strength materials. After processing for use as building materials, tensile compressive strength and elasticity increase, while their permeability decreases. In addition, limestones increase their hardness after a second hydration process and absorption of CO₂ from the atmosphere (Arioğlu and Arioğlu, 1999: 6; Auburn, et al., 2019, p. 279). As a result, they acquire characteristics that preclude in large extent absorbance of moisture.

The building of the Faculty of Letters of the Istanbul University, which corresponds to the research area of this investigation, is a structure that has been actively used as a public building and dates back to the II Turkish architecture period. It is located at Balabanağa Mahallesi, Ordu Caddesi N° 6, Laleli-Fatih, Istanbul. The building was built on a rectangular land bordered by Ordu Street to the South, Kimyager Derviş Paşa Street to the East, Büyük Reşit Paşa Street to the West and Vezneciler Street to the North (Figure 1). The land on which the building was built is topographically on a slope from East to West, from Laleli to Aksaray. The western and eastern ends of the building are 27.69 and 23.56 m high, respectively, and the East-West axis is 74.62 m long. When the structure is viewed from the South side, the slope from the West to the East ends creates a height difference of 4.11 m. In Figure 2, the red tarnished area indicates this height difference. When looking at the South facade of the building from the side, it can be noticed that the building blocks are under the road from West to East.

The main material of the structure is limestone (Erguvanlı and Sayar, 1955: 19). The structure is very vulnerable to climatic (weather phenomena such as sunbathing, precipitation and wind), chemical and biological factors, environmental conditions in general and atmospheric pollutants in particular, as well as human influence due to the intensive human circulation inside and in the external vicinity of the building. The fact that the structure is a large-scale complex creates limitations to its preservation, such as affordable time, cost and labor force to examine and evaluate continuously the deterioration processes of the whole structure. For this reason, the working area has been limited to the southern exterior facade of the building, which is the one most exposed to atmospheric effects and where human and vehicle traffic is the most intense. This study aims to contribute to the ongoing conservation work, by evaluating the deterioration state of this facade by thermographic analyses, complemented by other more routinely-used methods for the evaluation of deterioration affecting stone buildings, e.g., visual examination, soluble salt tests, moisture analysis and conductivity measurements. The present study is also a contribution for the identification and characterization of the possible deterioration factors acting on historical stone structures in general, and appears of fundamental importance also for the design of conservation strategies to be implemented for the remaining areas of the building that are less exposed to deterioration factors and are in better state of preservation.

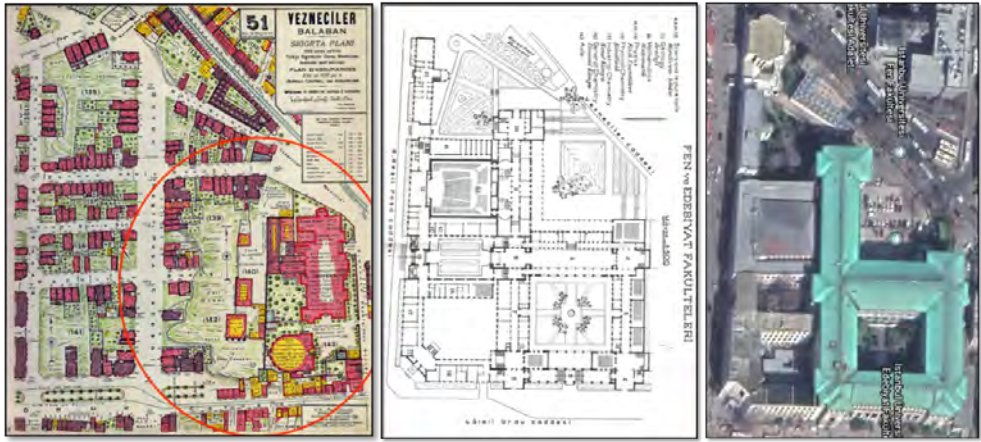


Figure 1. Site plan on the Pervititch Map of Zeynep Hanım Mansion (left), plan of Istanbul University Faculties of Science and Letters made by Architects Sedat Hakkı Eldem and Emin Onat (center), satellite image of Istanbul University Faculties of Letters and Sciences (right). Source: Pervititch, 2001: 192 (left); Günergun and Kadioğlu, 2006: 156 (center); <https://earth.google.com/web/@41.01093111,28.96025979,50.96022253a,407.35599698d,35y,86.33967065h,4.03465736t,360r> (right).

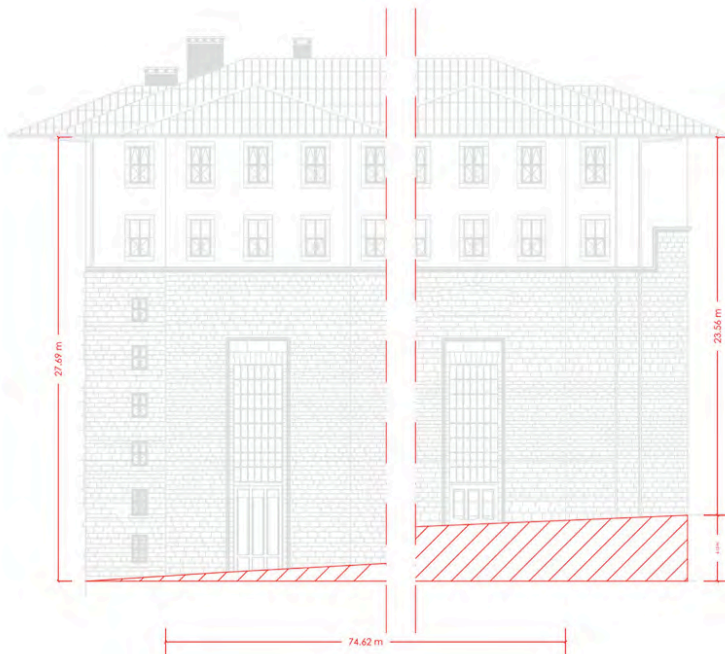


Figure 2. Istanbul University Faculty of Letters Southern Front elevation difference detail. Source: Drawing, Enes ŞENER.

2. Methods and analyses

This study focused on the southern facade of building of Faculty of Letters of the Istanbul University. This historical building was described in detail in terms of art and architectural history, from Zeynep Hanım Mansion period to the present day, by Çobanoğlu and Yılmaz, 2011. In all stages of the field study, drawing, photography, video images and documentation records were registered.

A total of 110 samples were taken from various parts of the studied facade, specifically areas where pollution has formed crusts, exhibit surface losses and erosion from chemical and atmospheric factors, and also from where stones are thought to be imitations. From the 110 samples collected, 48 were selected for investigation. The samples were numbered in the sequence 1, 2, 3, 4... from West to East along the South facade of the building (Figures 3 and 4).



Figure 3. Numbering of the places to be sampled on the structure. Source: Emre Veysel ŞENER.



Figure 4. Location of the samples taken from the southern facade of Istanbul University Faculty of Letters. Source: Drawing, Enes ŞENER.

3. Results

3.1. Qualitative and Semi-quantitative analyses of salts, proteins and oils and conductivity measurements

Salts, proteins and oils, which may be naturally present in porous building materials such as stone, mortar and plaster or subsequently enter the building in different ways, affect the decomposition of porous building elements. Investigation of the presence in the structure of water-soluble salts, such as chlorides (Cl^-), sulfates (SO_4^{2-}) and nitrates (NO_3^-), and carbonates (CO_3^{2-}), together with conductivity tests, moisture analysis, and oils and proteins' evaluation, provides a simple way to estimate its degree of deterioration. Table 1 summarizes the results of the investigations performed on the 48 selected samples. Qualitative and semi-quantitative analyses of soluble salts, proteins and oils have been carried out. In the table these substances are indicated as absent (-), present at the limit of perceptibility ($\pm$), present (+), present in relative abundance (++) , present in high abundance (+++) and present in the highest abundance (++++).

Table 1. Results of the qualitative/semi-quantitative analyses of presence of water-soluble salts, proteins and oils in the studied samples, and results of conductivity essays.							
Sample No	Chlorides	Sulfates	Carbonates	Nitrates	Conductivity ($\mu\text{S}/\text{cm}$)	Proteins	Oils
5	+	++	-	-	0.62	+	-
7	$\pm$	+++	-	-	2.29	+	-
8	-	+	+	+	0.31	+	-
9	+	++	-	+	0.59	+	-
10	+	++++	-	+	1.86	+	-
12	++	+++	-	-	0.86	+	-
14	-	$\pm$	-	-	0.21	+	-
15	+	++	-	-	0.64	+	-
16	++	+++	-	+	0.82	+	-
17	+	+++	-	-	2.24	+	-
20	+	++	++	-	0.48	+	-
22	-	-	-	-	0.19	+	-
26	$\pm$	+++	-	-	1.33	+	-
27	-	-	-	-	0.23	+	-
30	++	+++	-	++	1.44	+	-
32	+++	+++	-	-	1.08	+	-
35	+	+	++	-	0.20	+	-
40	-	$\pm$	-	-	0.37	+	-
43	$\pm$	+	+	-	0.33	+	-

44	±	-	-	-	0.16	+	-
45	-	+	-	-	0.44	+	-
47	-	++	-	-	0.49	+	-
48	++	++++	-	++	0.85	-	-
51	+	+	-	++	0.44	-	-
55	±	++	-	+	0.78	-	-
56	-	++++	-	±	1.63	+	-
57	-	++++	-	+	1.43	+	-
58	+	+	-	+	0.50	+	-
61	±	+	++	++	0.32	+	-
62	-	++	-	-	0.36	-	-
64	+	+++	-	+	0.54	+	-
67	-	-	-	-	0.22	+	-
68	+	+++	-	++	0.58	+	-
70	-	±	-	-	0.20	+	-
71	±	+++	-	+	0.67	+	-
72	-	-	-	-	0,20	+	-
73	+	++	++	-	0.50	+	-
74	-	+++	-	-	0.80	+	-
75	+	+++	-	-	0.70	+	-
77	-	+	±	±	0.52	+	-
78	-	-	+	±	0.46	+	-
82	+	+	-	+	0.45	+	-
83	±	+	++	+	0.37	+	-
84	-	±	-	-	0.22	+	-
94	-	±	-	-	0.15	+	-
102	+	++	-	-	0.27	+	-
108	+	+++	-	-	0.92	+	-
109	-	+++	-	-	0.70	+	-

Legend: absent (-), present at the limit of perceptibility (±), present (+), present in relative abundance (++), present in high abundance (+++) and present in the highest abundance (++++).

3.2. Moisture determination

Moisture analysis was performed on 30 samples. The samples were treated in an oven at 105 °C for 2 hours, the % humidity being determined according to the following equation:

$$\% \text{ Humidity} = (W - W_1) / W_1 \times 100$$

where W and W₁ are the weights of the samples before and after drying, respectively. The results are shown in Table 2.

Table 2. Moisture analysis evaluation table.				
	Moisture Analysis			
	Sample Number	Weight (g) Before oven drying	Weight (g) After oven drying	Moisture Amount (%)
1	5	2.6	2.6	0.00
2	12	2.1	2.0	5.00
3	14	8.0	8.0	0.00
4	15	5.3	5.2	1.92
5	20	6.4	6.3	1.59
6	22	4.7	4.7	0.00
7	27	23.0	22.9	0.44
8	30	12.5	12.4	0.81
9	32	10.6	10.5	0.95
10	35	3.2	3.1	3.23
11	40	6.6	6.6	0.00
12	45	2.2	2.2	0.00
13	47	14.9	14.8	0.68
14	48	4.0	3.9	2.56
15	51	6.3	6.3	0.00
16	55	8.8	8.7	1.15
17	56	5.4	5.4	0.00
18	57	5.0	4.9	2.04
19	58	4.1	4.1	0.00
20	62	4.4	4.4	0.00
21	64	3.7	3.7	0.00
22	67	8.5	8.5	0.00
23	70	14.5	14.5	0.00
24	73	5.3	5.2	1.92
25	74	3.3	3.2	3.12
26	75	4.0	4.0	0.00
27	77	7.5	7.4	1.35
28	82	14.5	14.4	0.69
29	83	0.7	0.7	0.00
30	84	6.4	6.4	0.00

3.3. Thermographic investigations

Thermography is a passive and non-contact technique, which generates images that show the temperature distribution at the surface of an object. Thermographic cameras detect radiations in the infrared range of the electromagnetic spectrum (~900-14000 nm) (Holst, 2000: pp. 15-16). The technique has been used successfully as a non-destructive method in the diagnosis of deterioration in buildings.

The basic working principle of the thermographic imaging system is to measure the amount of radiation emitted by an object or structure using thermal cameras. All objects above absolute zero (0 K, or -273.15 °C) emit electromagnetic radiation, whose characteristic

wavelength varies with the temperature. When the surface of the material is at approximate room temperature, the emitted radiation is in the infrared radiation zone of the electromagnetic spectrum. However, if there is heat flow from the inside to the outside or from the outside to the inside in the structure, the surface temperature of the structure will not be homogeneous due to different thermal conductivity of the different materials. In addition, the moisture content of the area under imaging causes an increase in the thermal conductivity, while a decrease in the thermal conductivity occurs in the case of formation of gaps in the materials. These features allow the technique to distinguish different materials present in a heterogeneous sample (such as stone, brick, iron and wood, and provide information about the surface morphology and microstructure of the measured sample (Moropolou, et al., 2013). Differences in surface temperature help to determine the factors that cause deterioration or deterioration in the structure, since the thermal mapping allows to identify the areas that have undergone deterioration and to estimate their degree of deterioration (Paoletti, et al., 2013; Aköz, 2005; Tavukcuoglu, 2009).

Thermal maps can be drawn black and white or color. In the black and white mode, the hottest regions are represented in light tones and the cold regions are shown in dark tones. Color (rainbow) imaging uses a palette of colors, in general based on yellow, red and blue tones. In the areas imaged, yellow shows the warmest regions and blue shows the coldest regions (Employee and Türkoğlu, 2011). The temperature differences can be easily observed in the maps, and water leakage, humid areas, air leakage, heat bridge and different materials or anomalies present in the region being examined can be diagnosed (Avdelidis, et al., 2003; Titman, 2001; Ersen, et al., 2009; Fitzner and Heinrichs, 2001; Fitzner, 2014).

In the present study, thermal measurements were made with a Thermal Camera Testo 875-2i, on 31 October 2019. In order to obtain accurate data about the studied stone surfaces, the images were processed by entering the emivite (e) data as 0.94 and the reflected temperature (RTC) parameter as 0. At the time of the measurements, the relative humidity in Istanbul was ca. 74.9%, and the temperature in the 12-15 °C range. In the measurements, particular care was taken in studying areas of the wall close to the ground, which may be a source of moisture in the structure, as well as to notoriously deformed surfaces and the areas formed by stones thought to be imitation or plastic repair. The thermographic shots allowed to determine the areas of the wall where the temperature and humidity differs substantially from the standard areas, then permitting to identify possible locations of moisture sources that are damaging the structure and to make the diagnosis of deterioration factors (Figures 5-11).

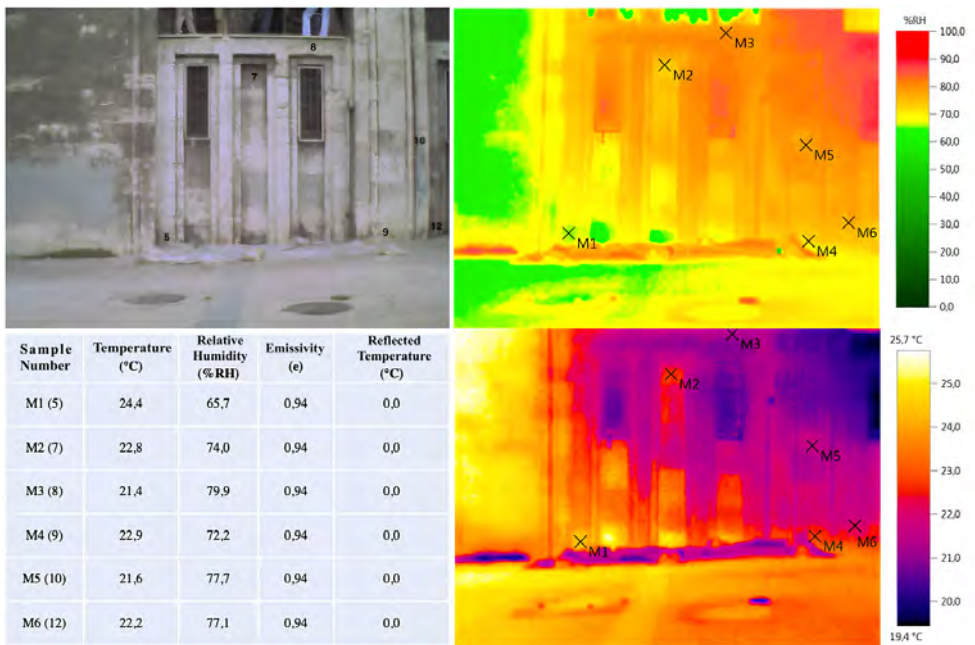


Figure 5. Thermographic examinations; examples 5, 7, 8, 9, 10 and 12.
Source: Emre Veysel ŞENER.

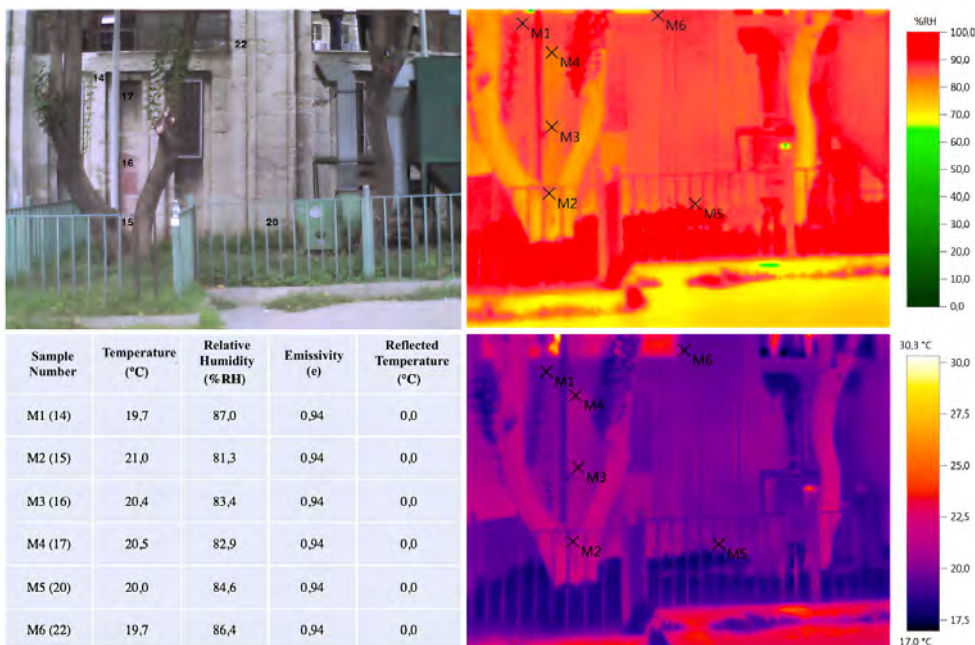


Figure 6. Thermographic examinations; examples 14, 15, 16, 17, 20 and 22.
Source: Emre Veysel ŞENER.

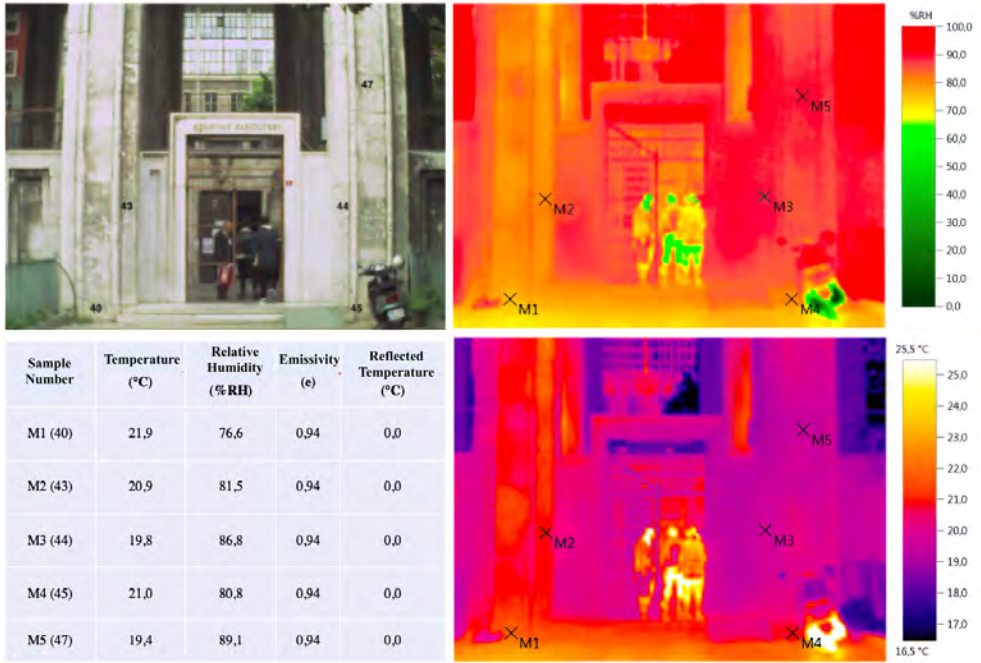


Figure 7. Thermographic examinations; examples 40, 43, 44, 45 and 47.
Source: Emre Veysel ŞENER.

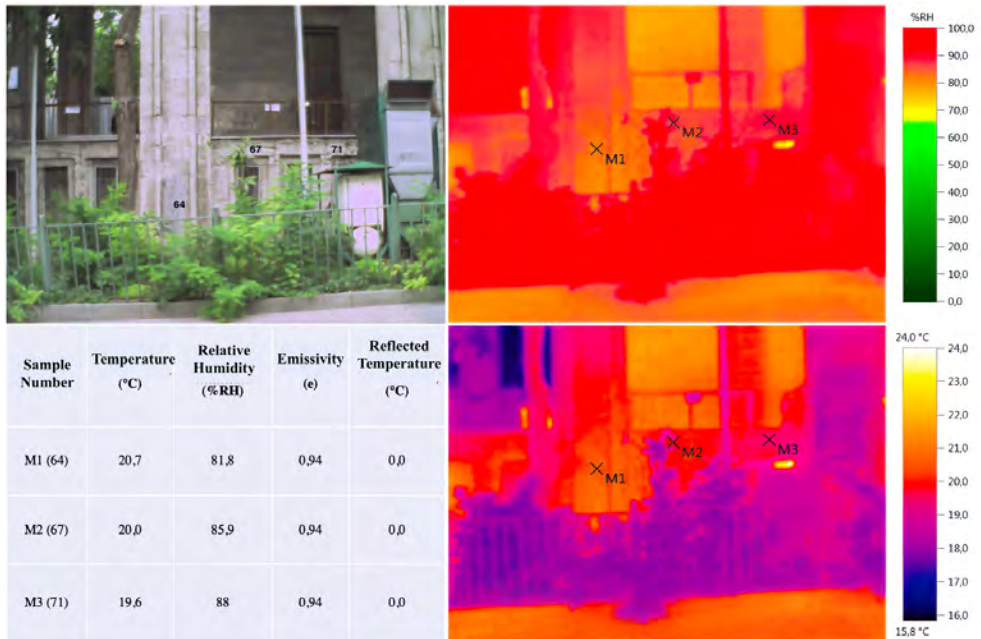


Figure 8. Thermographic examinations; examples 64, 67 and 71.
Source: Emre Veysel ŞENER.

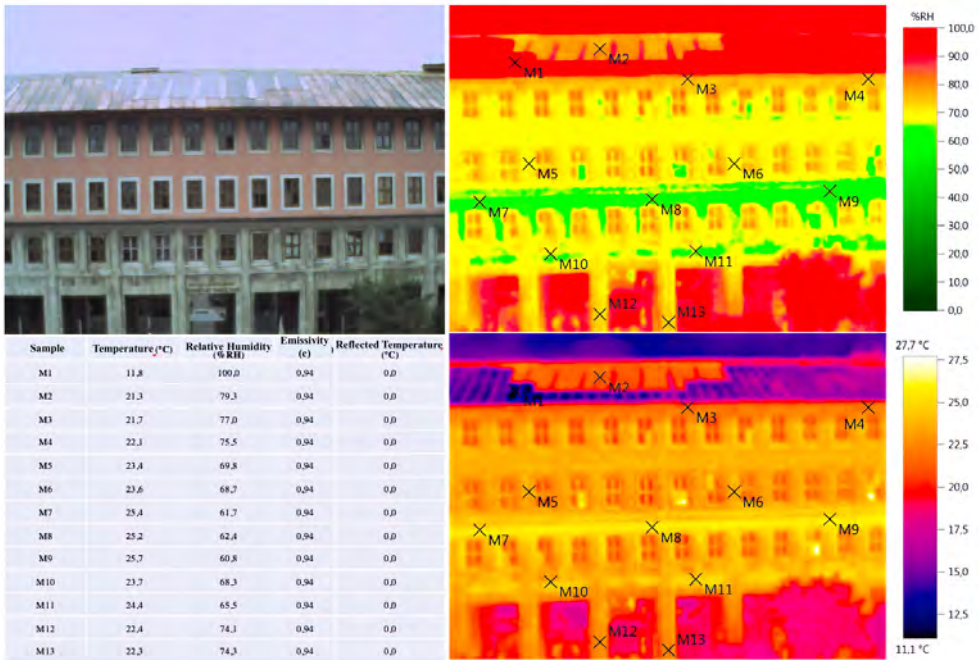


Figure 9. Thermographic surveys; south facade general 1.
Source: Emre Veysel ŞENER.

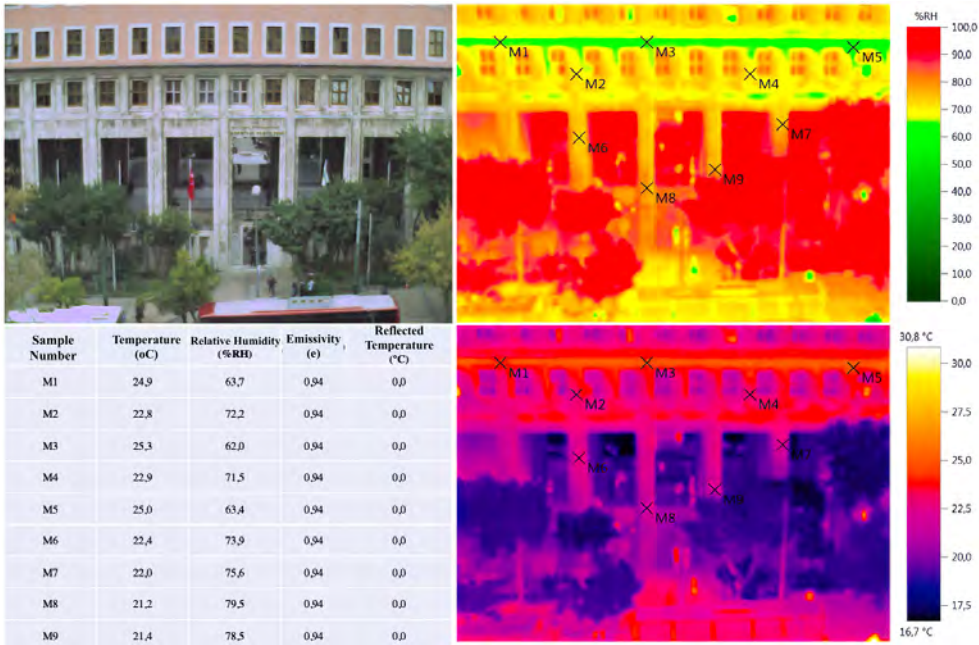


Figure 10. Thermographic surveys; south facade general 2.
Source: Emre Veysel ŞENER.

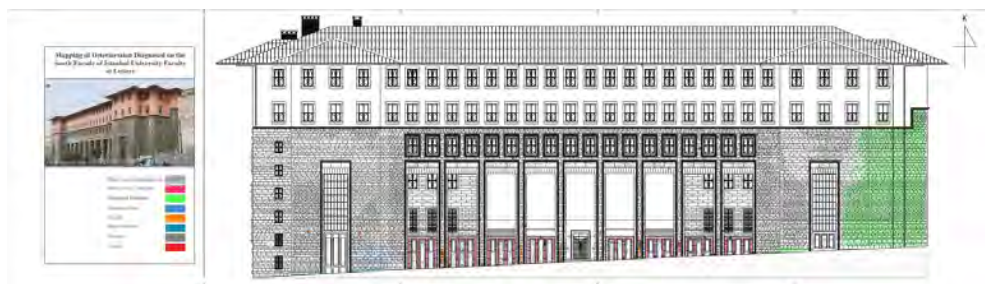


Figure 11. Mapping of the distortions detected in the southern facade of Istanbul University Faculty of Letters. Source: Drawing, Enes ŞENER.

4. Assessments

4.1. Qualitative and Semi-quantitative analyses of salts, proteins and oils and conductivity measurements

Determinations of sulfates, carbonates, chlorides and nitrates were undertaken as summarized in Table 1.

Sulfates were found in almost all samples studied. Sulfate salts show intense accumulation in the form of black or dark crust. Sulfate can be sourced from atmospheric pollutants such as coal, oil and the combustion of fossil fuels. Industrial chimneys, gases emitted from vehicles and particles in the air create air pollution and create dry and wet deposits on the surface of stone buildings. The Istanbul-Fatih-Laleli region, where the building is located, is a region where there is heavy human and vehicle traffic and, accordingly, low air quality. In limestones, sulfate salts react to form a shell in the form of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). On the studied facade of the building of the Faculty of Letters of the University of Istanbul, the areas exposed to atmospheric factors are washed by rain, snow and wind, so that dirt does not form large deposits on the surface. However, the same atmospheric effects can cause surface erosion. On the other hand, in areas where atmospheric factors cannot influence much, sulfate salts in the form of small black shells can still be observed, as in the studied structure.

Carbonates were detected in very few samples (see Table 1). Carbonate salts form deformations in soft areas and cracks between the hard parts of the stones, in the form of cavities and wormholes.

The presence of chloride salts in the structure was determined in 29 samples, at mean and low values (Table 1). Water, sea water fallout, cement-doped materials rising from the

ground or soil of the facade by capillary paths can be the source for the presence of chloride salts in the structure. One of the reasons why chloride salts have entered the structure of the building may be the heavy vehicle and human traffic in the Ordu Street, which, moreover, is also applied de-icing salts to prevent icing on the street during the winter season. In addition to this, the proximity of the building to the sea, allowing for the arrival of sea fallout onto the facade can also be among the reasons for the presence of chloride salts in the structure. Chlorides, which carry out a rapid recrystallization cycle in the structure, cause flaking on the stone surfaces.

The presence of nitrate salts was found to be scarce, being observed only in 19 samples (Table 1). The presence of nitrate salts in the structure results from the wastes of living beings living around the structure, wastewater leaks, living remains and fertilizers. The earthen area in front of the southern facade of the building constitutes the habitat of cats, dogs, mice, insects and pests. The fact that birds and bats build nests under the eaves or in hollow stones contributes to the presence of nitrates in the structure. Since nitrate salts are fast and highly soluble, likewise the chloride salts, they can also accelerate the activation of other soluble salts.

The conductivity values of the samples were also measured and are given in Table 1. An increase in conductivity was observed for samples where water-soluble salts are abundant and dense, as it could be anticipated. Although the salt tests of samples 7, 10, 17, 26, 30, 32, 56 and 57 are similar to those of other samples, it is observed that they show large conductivity values, thus suggesting that different salts may exist in these samples other than the probed salts.

In the fat (oils) and protein tests performed, no fat was detected in any of the samples (a somewhat unexpected result), while proteins were found in almost all samples, indicating incorporation in the surface of the stones of organic substances through contact with living beings.

4.2. Moisture determination

Moisture analyses were performed on 29 samples, and moisture was detected in samples 12, 15, 20, 30, 55, 73 and 82, at a height of 10 cm from the floor, and in samples 27, 32, 35, 47, 48, 57, 74 and 77, at a height of 250 to 400 cm from the floor (Table 2). The low levels of humidity values indicate that there is no excessive moisture problem in the structure. The moisture observed in samples at higher heights can be justified by the movement of water accumulated in the garden soil and ground in front of the structure by capillarity. In the long term, this situation may cause the deterioration of the soluble salts in the stones structure affecting the water circulation in the building.

4.3. Thermographic analyses

Samples from the area located at west of the main entrance door (Figure 5): When sample 5 (M1 in Figure 5), which is thought to be plastic repaired or an imitation stone, is compared with samples 7 (M2), 8 (M3), 9 (M4), 10 (M5) and 12 (M6), which correspond to samples of the original material, differences in temperature and relative humidity values are observed. Particularly significant are the differences between the properties of samples 5 and 9, which are located at almost the same elevation level, that amount to 1.5 °C in temperature and to 6.5% in relative humidity. On the other hand, the temperature and relative humidity values of the original building materials such as those constituting samples 7, 8, 9, 10 and 12 are similar. The temperature and relative humidity difference between samples 5 and 8 were as large as 3 °C and 14.2%.

Samples from the area located at east of the main entrance door (Figure 6): Samples 14 (M1 in Figure 6), 16 (M3), 17 (M4), 20 (M5) and 22 (M6) were found to have approximately the same temperature and relative humidity values, while sample 15 (M2), which is thought to be a plastic repaired or imitation stone, was found to have a temperature higher by 1.5-2 °C and a relative humidity lower by 1.6-5.7% than those of the samples of the original material.

Samples from the columns located on the right and left side of the main entrance (Figure 7): Sample 40 (M1 in Figure 7), which is also thought to be a plastic repaired or imitation stone, is seen to have a higher temperature and a lower relative humidity compared to samples 43 (M2), 44 (M3), 45 (M4) and 47 (M5), which are samples of the original stones. Interestingly, unlike sample 40, another specimen that is thought to be a plastic repaired or imitation stone (47 (M5)) was found to be at a lower temperature and higher relative humidity, testifying the different nature of the two samples of non-original material. Sample 47, like the other measured samples of this group (40, 43, 44 and 45), is located on the exterior, but contrarily to the other samples, it is located at a higher elevation value (400 cm above the ground). Very interestingly, this sample has a higher humidity than all the others, which are located closer to the ground level. Considering that at the level of sample 47 no other water source than rain exists, it can then be safely stated that the material of sample 47 must have a more porous and moisture-retaining structure compared to the other areas. In sample 44, where surface losses are observed, a high relative humidity and a low temperature were detected.

Additional samples from the area located at east of the main entrance door (Figure 8): According to thermographic data, when sample 64 (M1 in Figure 8) is compared with samples 67 (M2) and 71 (M3), a relative humidity difference of 4.1-6.2% and a difference in temperature of approximately 1 °C are noticed. Painted areas are observed on the surface of sample 64.

Samples (points) from the roof, under the eaves, fourth, third and second floors and part of the entrance section (Figure 9): Due to their location, these samples were not effectively collected, but only investigated by the thermal analysis method, corresponding to points in the structure. Differences are observed in the temperature and relative humidity values of points M1 and M2 (Figure 9) (9.5 °C and 20.7%, respectively), these values reflecting the different nature of the materials of the two points: M1 corresponding to a copper plate, while M2 is associated to the wood and membrane under the copper plate. The observed 100% relative humidity of M1 is also thought to be affected by the relative humidity in the atmosphere during the measurements.

The temperatures of the M3 and M4 points, located under the eaves of the roof, are similar, and a difference of 1.5% in the relative humidity values has been determined, while the values for points M5 and M6, on the plastered and painted surface of the wall, at the 3rd floor level of the structure were homogeneous.

The temperatures of M3 and M4 points under the eaves of the roof are at approximate values and a difference of 1.5% in relative humidity values was determined, and homogeneity is observed in the temperature and relative humidity values of the M5 and M6 points on the plastered and painted surface of the 3rd floor level of the building.

The points in the cornice (M7, M8 and M9), located at the upper level of the 2nd floor of the building, correspond to the area where the formation of dense black crusts is observed by the accumulation of dirt. The thermographic measurements show a clear differentiation between the properties of these 3 points and the others, with differentials of 4-5 °C in temperature and 4-18% in relative humidity. The data from points M10 and M11, in the details under the window jambs at the lower level of the 2nd floor, are also areas where the formation of light black shells is observed.

Points M12 and M13 belong to the columns on the left and right sides of the entrance door of the Faculty of Letters, and show temperatures and relative humidities that differ from those of the remaining samples in this group by 2.1-3.4 °C and 5.9-13.4%, respectively.

Samples (points) from the cornice at the upper level of the second floor of the building from the areas where deposited dirt is deposited and the part of the entrance door (Figure 10): In the cornice located at the upper level of the 2nd floor of the structure, points M1, M3 and M5 (Figure 10) are in the zone where the formation of dense black crusts by the accumulation of dirt is observed. The relative humidity of these points is different within 1.7%, and the temperature within 0.4 °C (M1 24.9 °C, M3 25.3 °C and M5 25 °C), i.e., the 3 points show almost the same temperature but different relative humidities. These results indicate that the accumulated black crust formation is not homogeneously distributed, suggesting also possible

different mechanisms for their formation. Points M2 and M4 correspond to measurements made between the windows on the 2nd floor. The thermographic data from these regions are at almost the same temperature and relative humidity values. On the other hand, points M6, M7, M8 and M9 were measured in the columns on the left and right sides of the entrance door of the Faculty of Letters at approximately the same elevation level. There is a difference of 0.4 °C in the temperature and of 1.7% relative humidity between points M6 and M7, and a temperature difference of 0.2 °C and 1% relative humidity between points M8 and M9.

4.4. Imitation and/or plastic repaired materials

As a result of visual examination, there are stones that were thought to be imitation or plastic repaired. In the body walls of the structure, it is highly likely that the stones from which samples 5, 15, 40 and 47 were taken are imitation or plastic repaired. The results from the thermographic data support this indication (Figures 5-7). After the thermographic shots were made, the regions where the temperature and humidity differ from the standard were subjected to detailed examination.

When the data of samples 5 and 15 are considered, it is seen that the relative humidity data are low and the temperature data are high, especially in areas with surface contamination. It is believed that repairs (mortar repairs, completion with stone) that were carried out on the facade in different moments introduced materials whose structure and porosity were distinct from the original ones. Samples 40 and 47 were compared with other samples (specifically samples 43, 44 and 45). Sample 40 is located near the ground and sample 47 is located at a height of about 400 cm from the floor. For 40, the temperature value was found to be high and the humidity value low, while for 47 the temperature was found to be low and the humidity high. When the positions of samples 40 and 47 in the structure are taken into consideration, the different temperature and relative humidity values can be explained by the different porosity of the materials of these samples and of their ability to moisture retention, clearly revealing that these samples correspond to non-original stones, plastic repaired or imitations resulting from restoration.

When the whole thermographic examination is taken into consideration, homogeneity is observed in the distribution of temperature and relative humidity in the plastered and painted areas of the 3rd and 4th floors of the building. Differences in temperature and relative humidity were detected under the eaves of the roof, along the cornice at the top of the 2nd floor and in areas where there are dirt deposits on the window jambs. The thermographic data also shows that the dirt accumulated along the cornice has a rather homogeneous structure (see Figure 10).

Mapping information about the current condition of the structure on the drawing of the building (Figure 11) is seen as an important information for the planning of conservation and repair works.

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References

- Angi, S. 2011 İstanbul Tarihi Yarımada'daki Antik Yapılarda ve Anıtlarda Kullanılan Doğal Taşların Özellikleri ve Korunmuşluk Durumları, *Restorasyon ve Konservasyon Çalışmaları Dergisi*, sayı 6, ss. 31-42.
- Aköz, F. (2005). Workshop on Damage Assessment in *Masonry Structures, Increasing the Earthquake Safety of Masonry Structures 17 February 2005 (YDGA2005)*, Middle East Technical University, Ankara, YDGA 2005.
- Arioğlu, E., Arioğlu, N. (1999). The Engineering Mystery of the Küfeki Stone Used by Mimar Sinan as a Carrier, *Mimar Sinan Period Building Activities Seminar*, May 1999, Yapı Merkezi, İstanbul, p. 1-19.
- Avdelidis, N., Moropoulou, A., & Theoulakis, P. (2003). Detection of Water Deposits and Movement in Porous Materials by Infrared Imaging, *Infrared Physics & Technology*, 44, pp.
- Employee, M., & Türkoğlu, İ. (2011). Thermal Cameras and Applications, *Electrical-Electronics and Computers*, Firat University, Elazığ.
- Çobanoğlu, A. V., & Yılmaz, H. F. (2011). Istanbul University Faculty of Arts and Sciences Art History Report, Istanbul University *Construction and Technical Department Archives*.
- Erguvanli, A. K., & Sayar, M. (1955). *Türkiye Marbleleri ve İnşaat Taşları*, Kutulmuş Printing House, Istanbul.
- Ersen, A., Güleç, A., Alkan, N., Kudde, E. (2009). The Importance, Content and Preparation Steps of the 2009 *Conservation Report, Restoration Conservation Studies Course*, Istanbul Metropolitan Municipality KU-DEB issue:2, p.3-16, Istanbul.
- Fitzner, B., & Heinrichs, K. (2001). Damage Diagnosis at Stone Monuments- Weathering Forms, Damage Categories and Damage Indices, *ACTA- Universitatis Carolinae Geologica 1*, Prague, pp.12-59.
- Fitzner, B. (2014). Diagnosis of Weathering Damage on Stone Monuments, *Conferencia-Diagnosis of Weathering Damage on Stone Monuments Bacteria*, pp. 21-28.
- Günergun, F., & Kadioğlu, S. (2006). Notes on the Settlement History of Istanbul University, *Ottoman Science Research VIII/1*, p. 135-163.
- Holst, G. C. (2000). *Common Sense Approach to Thermal Imaging*, Spie Optical Engineering Press, Washington.

- Kumral, M., Yalçın, C., Şans, G., Kaya, M., & Budakoğlu, M. (2019). The Effects of Physical and Chemical Properties on the Formation of the Historical Küfeki Stone in the Vicinity of Çatalca (Istanbul), *Ömer Halis Demir University Journal of Engineering Sciences*, Volume 8, Issue 1, p. 278-287.
- Moropolou, A., Labropoulos, K. C., Delegou, E. T., Karoglou, M., Bakolas, A. (2013). Non-destructive Techniques as a Tool for the Protection of Built Cultural Heritage, *Construction and Building Materials* 48, pp. 1222–1239.
- Paoletti, D., Ambrossini, D., Sfarra, S., Bisegna, F. (2013). Preventive Thermographic Diagnosis of Historical Buildings for Consolidation, *Journal of Cultural Heritage* 14, pp. 116–121.
- Pervititch, J. (2001). *Istanbul in the Insurance Maps of Jacques Pervititch*, translated by Jacques Pervititch. Zülal Kılıç, Axa Oyak, Istanbul.
- Siedel, H., & Siegesmund, S. (2014). Characterization of Stone Deterioration on Buildings, Siegfried Siegesmund and Rolf Snethlage, (eds.), *Stone in Architecture Properties, Durability*, Springer, Newyork.
- Tavukçuoğlu, A. (2009). Inspection of Historical Buildings with Non-Destructive *Methods, Conservation and Repair Seminar in Kargir Structures 28-29 September '09*, p. 187-200.
- Titman, J. D. (2001). Applications of Thermography in Non- Destructive Testing of Structures, *NDT&E International*, 34, pp.149-154.
- <https://earth.google.com/web/@41.01093111,28.96025979,50.96022253a,407.35599698d,35y,86.33967065h,4.03465736t,360r> retrieved 02/4/2020.

CHAPTER 13

CHARACTERIZATION OF ROMAN OVER-PAINTINGS AT LUXOR TEMPLE, LUXOR, EGYPT

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Abstract

In this study, we characterized the Roman over-paintings at the Luxor Temple, which is one of the most famous and archaeologically important Temples in Egypt. Herein, samples for the characterization were collected from the fallen fragments of Roman fresco in Luxor Temple. The cross-sections of the samples were analyzed using binocular imaging, scanning electron microscopy–energy dispersive X-ray spectroscopy, and computed tomography to identify different layers in the over-paintings and their compositions. In the case of the Roman over-paintings at the Luxor Temple, the coarse plaster layer, “arriccio,” comprised mainly quartz, gypsum, and calcium carbonate. However, the fine plaster layer, “intonaco,” was composed of calcite, quartz, and gypsum. Furthermore, the paint layer contained mainly calcium carbonate (lime) and traces of gypsum. The results suggested that probably, Coptic artists used the technique of “Secco Fresco” for developing the Roman over-paintings at Luxor Temple.

Keywords: Roman mural painting, Cross-section, Luxor Temple, Fresco, Scanning electron microscopy—Energy dispersive X-ray spectroscopy, CT scanning

1. Introduction

Roman over-paintings dating back to the late 3rd century were applied on pharaonic walls built during the reign of Amenhotep III (1402–1364 BC) at Luxor Temple (Jill, 1976). The technique of over-painting is observed at several sites in Upper Egypt. In this study, we characterized these over-paintings in two directions. First, the cross-section of the samples were collected from the fallen fragments of a Roman fresco in Luxor Temple; second, these samples were analyzed using three techniques, such as polarized light microscopy (PLM) (polarized microscopy (BM)), scanning electron microscopy–energy dispersive X-ray spectroscopy (SEM–EDX), and computed tomography (CT) scanning. Herein, the surfaces of the samples were observed using binoculars and SEM. Then, the cross-sections were observed using BM, SEM, and CT scanning.

The cross-sections of the samples were investigated using PLM, SEM–EDX, and CT scanning to study the crucial aspects of Roman over-painting, such as structure, characteristics, thickness, shape, number of layers, composition, and techniques utilized in the Roman over-paintings at Luxor Temple. The cross-sectional investigations revealed that three different layers were applied on the surface of the pharaonic wall. The surface of the pharaonic wall was prepared using different tools; the signs of the tools have been observed on the surface of the pharaonic wall. A coarse layer was applied on the surface of the pharaonic wall. This layer was then hatched and fine plaster composed of calcium carbonate (lime) and traces of gypsum was applied. Finally, the Coptic artists applied pigments on the wall, as shown in Fig. 1.



Figure 1. Layers of Roman over-paintings on the pharaonic wall at Luxor Temple

2. Materials and methodology

2.1. Materials

Epoxy Number 27-751, hardener, and sand paper (800, 1000, 2400, and 4000) were used to prepare the samples.

2.2. Sample preparation

The samples for cross-sectional analysis were divided into small pieces, and were then embedded in epoxy (Number 27-751, epoxy to hardener ratio of 100: 2 by volume). After the complete hardening and drying of the epoxy, the samples were ground and polished using wet-type sand paper (800: 4000) to obtain a smooth surface, as shown in Fig. 2. The surface of the samples was observed using BM. Then, the other side of the samples was polished. The polished samples were observed using BM and SEM.

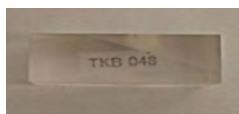


Figure 2. Preparation of the cross-section samples for microscopic observations

2.3. Observation

The surface of the samples was observed using the following three techniques.

Observation by Polarized microscopy (BM): The surfaces of the Roman frescoes were investigated using BM (OlympusBX3).

Observation by scanning electron microscopy—Energy dispersive X-ray spectroscopy (SEM–EDX): The surfaces of the Roman frescoes were observed using SEM (JEOL/JSM-6010LA). The acceleration voltage was 20 kV and the spot size was 50. The observations were carried out in the secondary electron image (SEI) and backscattered electrons (BSE) modes.

Observation by CT scanning: The surfaces of the Roman frescoes were observed by CT scanning (Perkinelmer, Quantum FX, Waltham, USA). The tube voltage was < 90 kV and the scan time was 4.5 min.

3. Data Analysis and interpretation

3.1. Experimental results

3.1.1. Observation by PLM (BMM)

Cross-sectional analysis is advantageous for the following reasons. (a) It is inexpensive and does not demand much technical expertise. (b) The samples can be stored for long time under the normal conditions. (c) It is extremely important to study and evaluate the compositions of over-painting technique. (d) It is useful in determining the structure, characteristics,

thickness, shape, and number of layers of over-paintings. (E) It helps in evaluating the current situation of mural paintings (Dilruba et al., 2011). PLM was used to examine the structure of the Roman over-paintings at Luxor Temple, as shown in Figs. 3, 4, and 5.

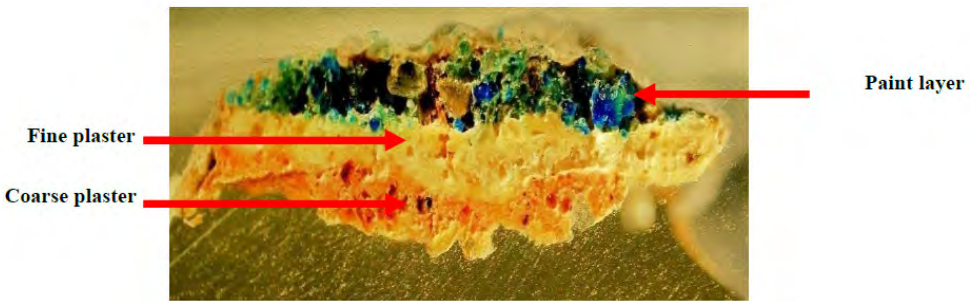


Figure 3. Photomicrograph of the cross-section image showing the three layers of the Roman over-paintings from bottom to top: coarse plaster, fine plaster, and paint layer under normal light using Polarized microscopy

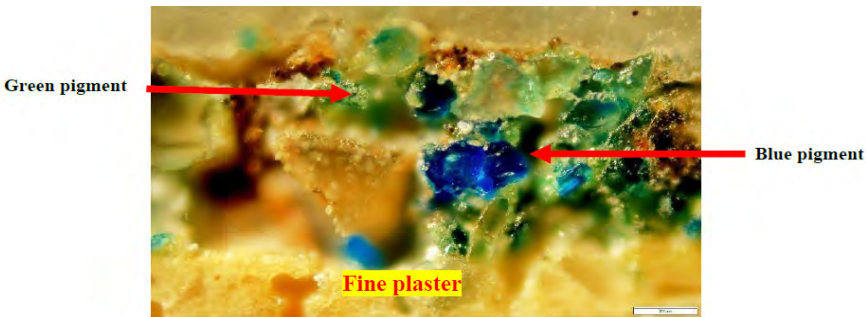


Figure 4. Photomicrograph of the cross-section image showing the fine plaster and pigment layers (blue and green) of the Roman over-paintings under normal light using PLM (BMM)

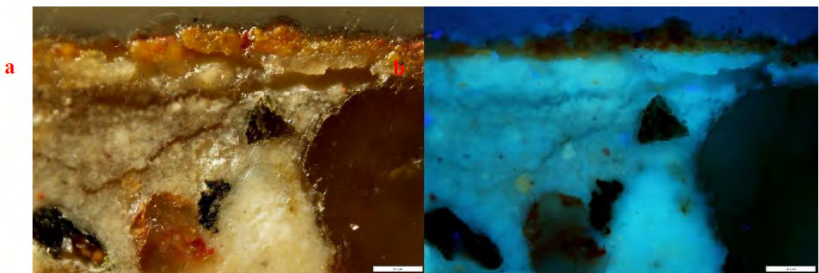


Figure 5. Photomicrograph of the cross-section image showing the yellow paint layer under (a) normal light and (b) ultra violet light using Polarized microscopy

3.1.2. Observation using SEM–EDX

The structure of the Roman fresco in Luxor Temple was observed using SEM. The microstructures and morphologies of the samples were investigated in the SEI and BSE modes. As can be observed from the SEM images (Fig. 6), the cross-section of the Roman paintings on the surface of the pharaonic wall was composed of three layers of the Roman over-paintings from bottom to top: coarse plaster, fine plaster, and paint layer (Sallam et al., 2016; Sallam et al., 2019; Sallam, A., Thanaa. A., 2019).

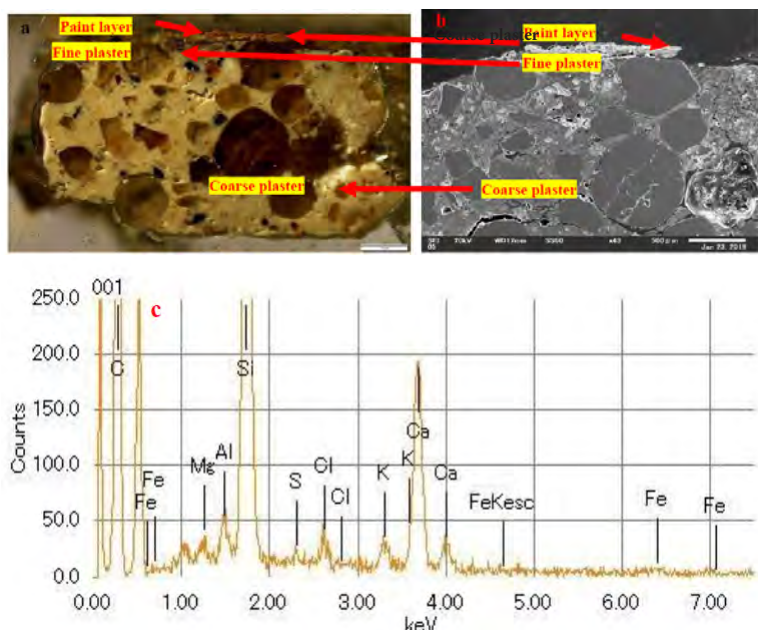


Figure 6. Observation of the cross-section of the sample using PLM and SEM: (a) PLM image showing the yellow paint layer; (b) SEM image showing the three layers of cross-section of the Roman over-paintings: coarse plaster, fine plaster, and paint layer; (c) EDX analysis of the sample

3.1.3. EDX analysis

The EDX analysis results suggested the following.

- 1- The coarse plaster of the arriccio differed throughout the wall in the amount of quartz (silicon), calcite (Ca), aluminum(Al), and K-feldspar.
- 2- The second layer of finer, smoother plaster, intonaco, was composed mainly of calcium carbonate and gypsum.
- 3- The third layer i.e., the yellow paint layer was composed of quartz, calcite, and iron oxide . The yellow color was due to goethite (α -FeOOH) (Ahmed et al., 2013; Basem et al., 2015) as shown in Figs. 7, 8, and 9.

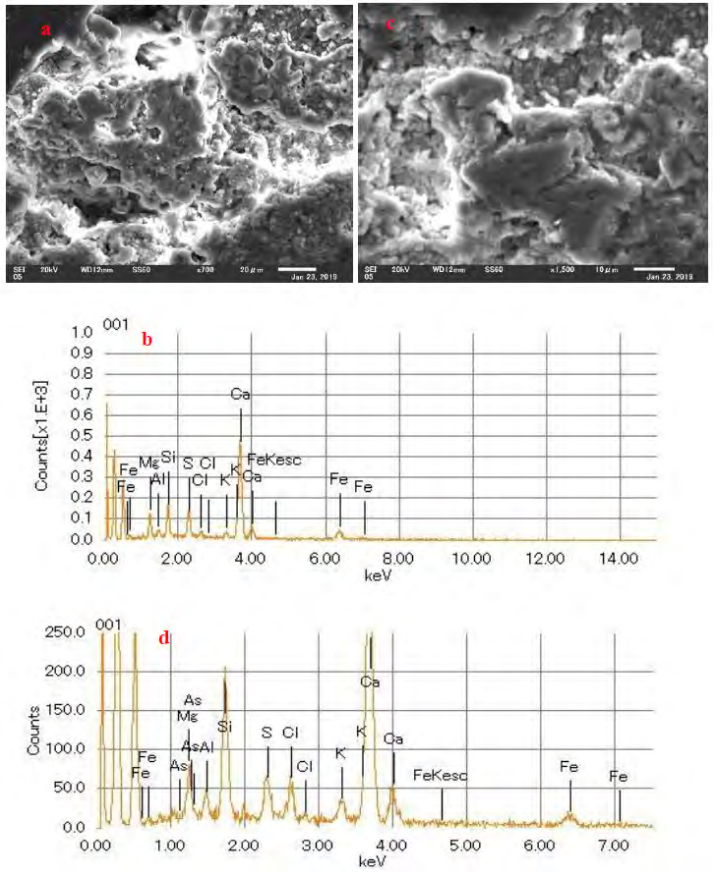


Figure 7. (a) SEM image of the yellow paint layer, (c) high-magnification image of (a) X1500; and (b), (d) EDX analysis of the paint layer indicating the presence of yellow goethite (α -FeOOH) pigment

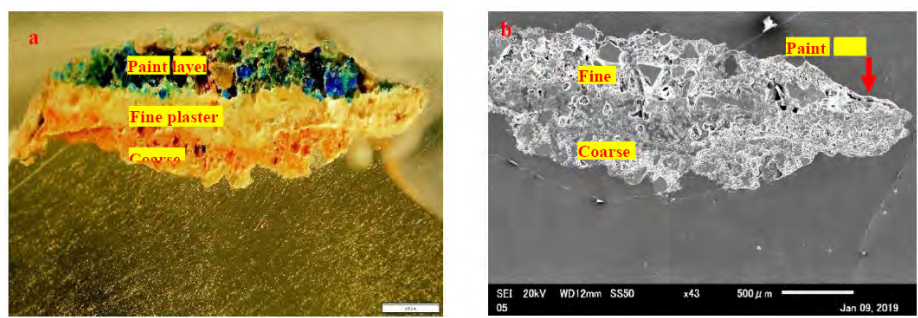


Figure 8. (a) PLM and (b) SEM images of the cross-section of the sample showing the three layers applied over sandstone; the main material of the pharaonic wall in Luxor Temple

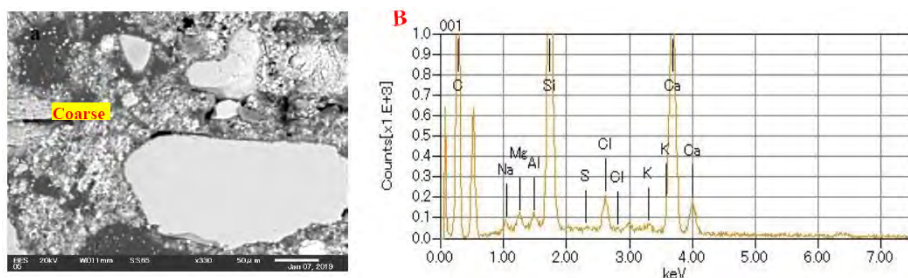


Figure 9. (a) SEM image of the coarse plaster layer captured in the BSE mode, and (b) EDX analysis of the same sample

The cross-section investigation revealed that three layers were applied on the surface of the pharaonic wall in the temple. The bottom most layer, i.e., “arriccio,” was a coarse plaster layer. The quartz content and shape of this layer varied throughout the surface of the samples. The second layer i.e., “intonaco,” was a layer of finer, smoother plaster, which was mainly composed of calcium carbonates. The top most layer was the pigment layer (Sallam et al., 2016; Sallam et al., 2019; Ahmed et al., 2013; Basem et al., 2015), as shown in Figs. 10 and 11.

The coarse plaster layer was mainly composed of quartz, K-feldspar, calcium carbonate, sodium chloride, and gypsum. The matrix was composed of fine, angular-shaped particles (visible) with size ranging from small to very large. Square and round particles were present at the bottom of the layer. Moreover, large particles with various shapes and sizes were diffused in the entire layer (Basem et al., 2015).

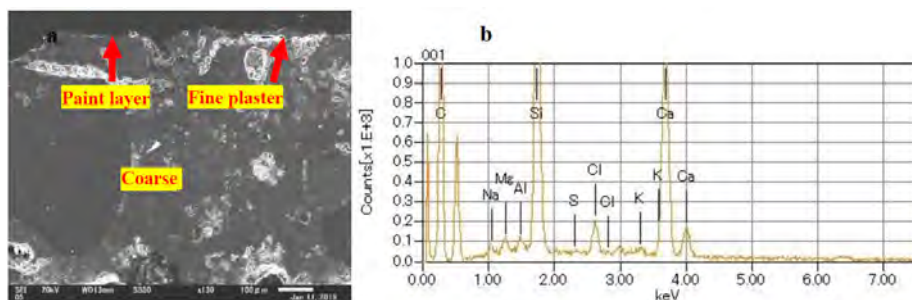


Figure 10. (a) SEM image of the cross-section of the sample indicating the presence of three different layers of Roman over-painting (from the bottom to the top): the coarse plaster, fine plaster of the intonaco, based mainly on calcium carbonates, and pigment layers; (b) EDX analysis of the same sample

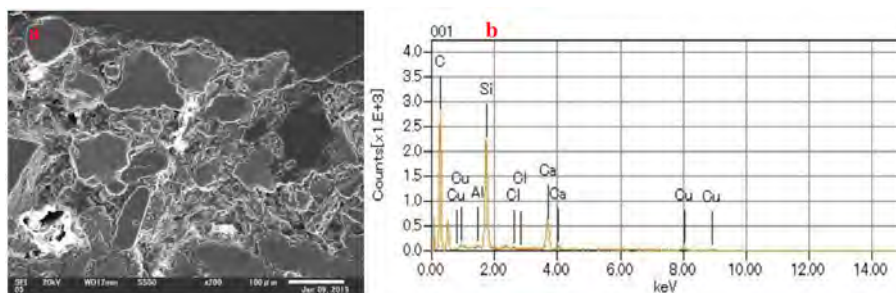


Figure 11. (a) SEM image of the paint layer indicating the blue pigment of the fine plaster; (b) EDX analysis indicating the presence of Si, Cu, Ca, and Cl as the major ions in this layer. This composition is in agreement with that of cuprorivaite ($\text{CuCaSi}_4\text{O}_{10}$). The blue pigment is an artificial pigment (Egyptian blue)

3.1.4. Observation by CT scanning

The mural paintings were investigated using the advanced features of CT scanning to study their cross-section porosity, structure, and composition. CT scanning is a powerful nondestructive technique for characterizing mural paintings made up of different materials (Sallam et al., 2016 and Sallam et al., 2019) (Figure 12).

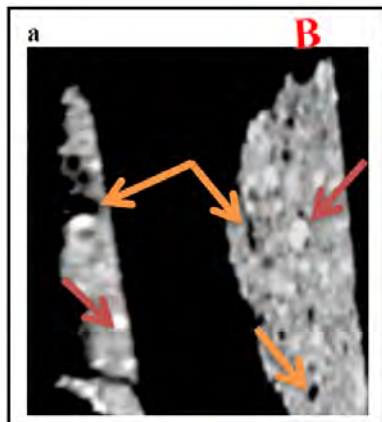


Figure 12. (a, b) CT scan image of the sample showing porous black areas formed because of mineral loss. White areas indicate gypsum and calcite.

4. Conclusion

In this study, the stratigraphic structure and porosity of the paint layer were investigated using PLM, SEM–EDX, and CT scanning. The CT scan of the paint layer showed the presence of black areas, which were formed because of mineral loss. These black areas caused temperature fluctuations throughout the layer, thereby leading to variations in mechanical

properties, such as stress and seasonal changes. The cross-section investigations revealed that three different layers were applied on the surface of the pharaonic wall in the temple. The bottom most coarse plaster layer, “arriccio,” was composed mainly of quartz particles of different sizes and shapes (from small to large and from angular to round, respectively). Traces of gypsum, calcium carbonate, aluminosilicate, and feldspar were also observed in this layer. Furthermore, the fine plaster layer, “intonaco,” was composed of calcite, quartz, and traces of gypsum. The paint layer comprised mainly calcium carbonate (Lime) and traces of gypsum. The thin yellow pigment layer contained calcite, quartz, and iron oxide. The EDX analysis results showed a Fe peak, indicating the presence of yellow pigment, i.e., goethite ($\alpha\text{-FeOOH}$). The blue pigment in the fine plaster layer was attributed to the Egyptian blue pigment. The EDX results showed that Si, Cu, Ca, and Cl were the major ions present in this layer. The composition of the sample was in agreement with that of cuprorivaite ($\text{CuCaSi}_4\text{O}_{10}$). The structural and EDX analyses of the cross-sections of the paint layers of the samples described that these layers were comprised of calcium carbonates and traces of gypsum, indicating that the Coptic artists applied their pigments on dry plaster (lime and gypsum), “secco fresco” and not fresh plaster, “buon fresco” (Lime). The results obtained in this study will be of great importance in the future for the conservation and restoration of Roman fresco over-paintings. The next step of this research is to design appropriate strengthening and retrofitting intervention plans and strategies for these unique mural paintings.

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References

- Jill, K., 1976. “Luxor A Guide to Ancient Thebes”, Second edition, London.
- Dilruba, S., and Fumio, O., 2011. “Surface Coating Technique of Northern Black Polished Ware by the Microscopic Analysis”, *Ancient Asia Volume*, P.58.
- Sallam, A., Ying, H. Moustaph, T. Muhammet, M. Mamoun, and U. Abdusalam (2016), “Studies on the Deterioration of Coptic Mural Paintings in the Monastery of Martyrs and the Luxor Temple”, *International Journal of Conservation Science*, Volume 7, Issue 2, 2016. 493-500.
- Sallam, A., Hemeda, S., Moustaph, H., Muhammet, T, Mamoun, M., Abdusalam, U (2019), “CT Scanning and MATLAB Calculations for Preservation of Coptic Mural Paintings in Historic Egyptian Monasteries “ *Scientific Reports* 9 (1): 2019, 3903.

- Sallam, A., Thanaa.A., (2019). Innovative Technique for Measurement Fingerprint of Cracks and Strain on the Surfaces of the Archaeological Painting, Aswan Case Study. *International Journal of Advanced Science and Technology* Vol. 28, No. 16, (2019), pp. 1034 - 1044
- Ahmed, A., Hussein, M., and Atef, B. 2013. "Analytical study of Coptic wall paintings in Egypt, El- Bagawat necropolis, Kharga Oasis: a case study" *Periodico di Mineralogia*, 82, 1, 25-40.
- Basem, G., Mona, A., and Hussein, M. 2015. "Identification of the Byzantine Encaustic Mural Painting in Egypt " *Mediterranean Archaeology and Archaeometry*, Volume 15, No 2, pp. 243-256.

CHAPTER 14

EVALUATION OF DETACHMENT BETWEEN LAYERS OF ANCIENT PLASTER RENDERINGS: COMPARISON BETWEEN THE TRADITIONAL TECHNIQUE AND A NEW AND INNOVATIVE AUTOMATED PROCEDURE CALLED PICUS

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Abstract

During a diagnostic campaign, most cultural heritage properties can be considered structurally as a multilayered system. The causes and phenomenology of degradation may involve the surface alone or the entire section of an ancient artifact. This includes the support, one or more preparatory layer, and the surface. An important section of diagnostics is dedicated to assessing the presence, position, and extension of separation between these layers. The results of these examinations are translated into graphic documentation of discontinuities to achieve conservative diagnosis and outline a project of maintenance/intervention. From 2018 to the present, research has been underway for the development of an acoustic–electronic procedure for the qualitative analysis of the presence of detachment and debonding in ancient artifacts. This procedure and the probe that was expressly developed in this regard are called the “PICUS” (the Latin word for “woodpecker”) system. PICUS is an automatic system for detecting and measuring detachments and nonvisible defects in general. The experimental apparatus consists of a probe made of an electromechanical percussion element that gently taps the surface producing a sound, a force sensor purposely developed to measure the impact force, and a microphone, all connected to an Arduino-like low-cost board, to record and elaborate sounds and the force sensor signal. The probe XY

position on the scene is recognized using an infrared camera system. The PICUS system has been validated by traditional vibro-acoustic measures. So far, it has been tested on various models and materials and ancient techniques, from glazed tile covers to mosaics to wood panels. This chapter is divided into four paragraphs. First, we describe the phenomenon of detachment of ancient renderings according to the lexicon in the field of conservation, normalized to define the forms of alteration. Here, we narrow the field to the detachments that occur between different layers in rendering plasters or mosaic bedding that employ lime as a binder. Then, we describe, from an acoustic point of view, the nondestructive testing (NDT) procedure in use by conservators and restorers for detachment diagnosis, according to the well-established procedure of tapping and listening. Other NDT techniques that can be successfully conducted in situ are briefly exposed. The complete PICUS system, hardware, software, and models for qualitative analysis of in situ detachments are then presented. Finally, we compare the results of two diagnostic techniques: the tapping technique traditionally used by conservators and restorers and the PICUS cross-correlation data processing algorithm. The maps obtained are compared, providing information on the effectiveness of the treatment and confirming the validity of the proposed method.

Keywords: Automated procedures, detachments, models, NDE, PICUS

1. Adhesion defects between layers of renderings in ancient structures

1.1. Cultural heritage renderings as multilayered structures

The varied expressions of creativity and talent of the artisans of the past that we consider here, such as mosaics, wall paintings, stucco reliefs, graffiti, slab coverings, and decorated pavements, are heritage items usually admired mainly because of their aesthetic value. These heritage items hold multilayered structures, that go beyond their outward appearance, like portrayed in Fig.1. Thus, understanding the stratified structures of mortar-based heritage techniques allows us to appreciate the intricate knowledge and skill that went into their creation. It reminds us of the delicate interplay between craftsmanship, environmental factors, and the need to preserve our cultural heritage for future generations.



Figure 1. Tomb of the Veteran, 2nd century AD. This rock-cut tomb showcases two layers of rendering mortar, with the top layer featuring decorative elements. Som, H.K. of Jordan.



Figure 2. Mosaic fragment showcasing its layered structure, consisting of the following components: tessellatum, bedding layer, nucleus, and rudus.

Mortar-based heritage techniques have a stratified structure, showcasing the careful layering of materials (Fig.2). In certain cases, the rendering of structures may be reduced to a single layer of mortar that covers the underlying support. However, traditional and classic plastering techniques involve covering the substrate with several layers that overlap each other. This type of stratification is essential to ensure the desired mechanical qualities of the plaster once it dries, considering many environmental factors. The method described, which has a strong association with a longstanding tradition of historical texts and technical manuals, can be observed in several construction examples¹. This technique has been used from classical antiquity to modern construction until the introduction of new industrial binding agents.

Lime mortars are composed of calcium hydroxide and mineral aggregates. These ingredients are carefully combined to create a cohesive mixture that provides strength, durability, and workability for all cultural heritage applications (Pappalardo, 2008).

Lime mortars have two essential elements: (1) calcium hydroxide, also known as hydrated lime, which acts as a binding matrix and is obtained through the hydration of quicklime (calcium oxide) with water; and (2) mineral aggregates used to improve the mechanical and chemical properties of the mortar, providing strength and stability. These include sand, crushed stone, *pozzolana*, crushed bricks, or other granular substances (Jackson et al., 2010). They also contribute to the workability and texture of the mixture, allowing for prolonged application and shaping.

Mortars obtained by mixing slaked lime or *grassello* with calcareous or siliceous aggregates, in proportions ranging from approximately 1:2 to 1:4, achieve a consistent, hardened state. The setting process of these mortars, which includes the phenomena that occur after their application, depends on factors such as ventilation and thus on the availability of carbon dioxide, humidity, and the presence of other components generally used as retardants. Mortar setting is thus a dynamic process that continues even after the initial hardening. Over time, the mortar undergoes further chemical reactions and gains strength through a process known as curing. Curing involves the continued carbonation and hydration of lime, contributing to the long-term durability and stability of the mortar.

The above mixture initially undergoes contraction due to the loss of the water it contains through evaporation and partial absorption by the substrate. At the same time, carbon dioxide reacts with calcium hydroxide; in the course of carbonation, a supersaturated solution of calci-

¹ The direct sources and bibliography on the art of plastering are extensive, encompassing various historical periods. Alongside the references to Book VII, Chapter 3 of “*De Architectura*” by Marcus Vitruvius Pollio and Book XXXV, Chapters 47–50, Book XXXVI Chapters 24 and 53–64 of “*Historia Naturalis*” by Pliny the Elder, recent articles on interventions and studies were consulted. However, it should be noted that the majority of these sources primarily provide specific information on local variations of the technique.

um carbonate is formed, a poorly soluble salt that precipitates as a crystalline felt. The crystals bond to the aggregates, forming a strong, porous lattice with good compressive strength and elastic modulus, which, given the same constituent material, depends on the physical conditions under which the mortar set. Favorable to the formation of an intact crystal lattice are the right amount of water in the mix, the percentage between aggregates with fine, medium, and coarse grain sizes, and exposure to carbon dioxide (Malathy et al., 2023).

Intonaco (plaster) is the masonry rendering obtained through the insitu application of mortar. The operation of plastering originates with the primary purpose of protecting the underlying architectural structures from the external environment. In addition, to the function of artistic expression, they regularize, reinforce, and insulate the masonry vertical or horizontal structures on which they have been laboriously applied thanks to technical expedients whose knowledge has been handed down through the centuries.

A distinction is then made between the lower, coarser layers (called *arriccio* for wall paintings or *nucleus* for mosaics) whose main function is to level the surface of the substrate and to provide a reserve of moisture for subsequent layers, and the progressively thinner ones, intended to remain exposed or to receive decoration (Petretto, 2007).

Finally, *support* is defined as the supporting structure (whether natural rock, artificially prepared rock, or masonry equipment) that bears the layers of mortar applied on the surface.

The processes involved in manufacturing lime and achieving proper mortar adherence to the masonry substrate require several labor-intensive steps, including material selection, aggregate sieving and mixing, binder curing, extensive mixing, compacting layers to ensure adhesion, leveling, stitching and trimming of overlapping areas, and decorative finishing (Mora et al., 1986; Capponi et al., 1999).

A better state of preservation is often found in artifacts built according to strict technical rules and, of course, with first-hand materials. Work derived from age-old tradition is characteristic of executors working for wealthy patrons. Conversely, conservation problems are often detected in artifacts in a less-selected environment, of executors working in spontaneous modes, at times when both the material factory and the transmission of knowledge for proper execution are lacking (Mora et al., 1983).

1.2. Detachment and adhesion defects between layers of renderings

The term “detachment” in the context of conservation and restoration refers to a situation with a discontinuity or separation between the superficial layers of materials, both among

themselves and in relation to the underlying substrate. It often indicates a potential risk of the material eventually falling off. This term is commonly used when discussing plasters and mortars, which are artificial stone materials. In the case of natural stone materials, detached parts can take different forms depending on their structural and textural characteristics, and terms such as crusting, spalling, or exfoliation are often preferred. The definition provided is based on the UNI 11182:2006 standard, which outlines terminologies related to conservation and restoration practices.

The solution of continuity between layers has always been an undesirable phenomenon, which can lead to a progressive process of decay. The causes leading to the separation between originally adjacent and adherent rendering layers are several and synergistic (Figure 3-6). Sometimes, the presence of adhesion defects between layers can be attributed to intrinsic causes. Faults in execution can occur at the origin: too dry support or underlay, excessive ventilation during the setting and curing phases, and curing under conditions of poor carbon dioxide availability can all predispose to subsequent conservation problems. These conditions can cause the so-called *shrinkage* phenomenon: a sudden decrease in the volume of the mass, resulting in localized stresses that form cracks and detachments in all directions. This type of phenomenon often takes the form of delamination between different layers of renderings or separation from the support. It can follow the texture of the support underneath, e.g., lacking of adhesion in correspondence with mural joints or wooden or stone elements (Quagliarini et al., 2011).



Figure 3. Concattedrale of Santa Maria Assunta in Venafrò (IS) displaying a palimpsest of fresco paintings from the 5th, 13th, and 15th centuries. The noticeable lack of adhesion between the renderings has resulted in significant loss and lacunae.



Figure 4. In situ detachment of the tessellatum and its bedding layer from the nucleus.



Figure 5. In situ delamination and detachment between preparatory layers due to shrinkage. Museo delle Arti e Tradizioni Popolari, EUR, Rome.



Figure 6. Bulges and rise of the tessellatum due to environmental causes. Archaeological site of Carsulae, Terni, Italy.

Meanwhile, the presence of detachment between layers is also attributable to external causes, such as environmental, climatic, and anthropogenic factors to which the artifacts have been exposed over the centuries. These types of alteration can take different forms: lack of adhesion of one layer to another (e.g., by the action of moisture), deformation and bulging, and detachment of whole sections of layers from the support (e.g., by the growth of weeds, vibration, weathering, and seismic events) (Alberti et al., 2013; Giuliani, 1990).

These phenomena, appropriately represented in graphical documentation, are compared with other information, such as crack patterns, capillary rise fronts, lacunae, and gaps. This comparison aims to understand deterioration causes, attempt possible countermeasures, and strike a balance between conservative actions that maintain the status quo with minimal intervention.

2. Nondestructive evaluation techniques for in situ detachment detection

Modern conservation intervention projects fall under the responsibility of professionals known as conservator-restorers, who adhere to a comprehensive professional and ethical code.

One essential skill of conservator-restorers is the ability to conduct a qualified analysis of heritage objects, enabling them to perform independent and scientifically rigorous work. This analysis involves assessing the conservation status of an object by identifying indicators of its conservation history, evaluating environmental conditions (microclimate and ecosystem), examining the nature of the constituent materials, and identifying signs of aging, damage, and their causes. The conservator-restorer collaborates with a diagnostic team to determine which nondestructive tests or destructive analyses are necessary to enhance the overall understanding of the object. This includes identifying and characterizing any neoformation products and establishing their correlation with factors of deterioration. Through careful observation and surveys, the conservator-restorer directly investigates the various forms and degrees of alteration present in the work.

In this stage, the conservator-restorer identifies and documents the extent and depth of detachments between layers. These detachments may not be discernible from the outside and sometimes manifest as localized uplifts and deformations of specific areas. In many cases, these detachments remain invisible until an event highlights the defect, at which point the affected portion may crack or detach partially or completely, resulting in the formation of gaps or lacunae.

To detect decay phenomena, such as detachments between layers of renderings in ancient structures and renderings in situ, there are a limited number of nondestructive and noninvasive

evaluation (NDE) methods available. Some of these methods involve controlled contact and some are contactless, and both can be performed on-site, providing effective results.

Tables 1 and 2 present some of the most recent NDE methods.

Table 1. Contactless NDE		
Method of Excitation	Response Detection Method	Method of Data Interpretation
Acoustic	Detection of vibration amplitude and frequency with optical interferometry (Doppler laser scanner vibrometer)	Comparison of different frequency responses and mapping of corresponding areas
Acoustic	Incident and reflected acoustic wave detection by microphones	Extraction of the impulse response of the reflective surface (considered as an indicator of the reflective or absorptive capacities of the point) associated with defects in the structure; mapping of corresponding areas
Natural or acoustic	Detection of surface displacements by speckle interferometry (electronic speckle pattern interferometry)	Displacement reconstruction through interference fringes corresponding to changes in the optical path associated with displacement. Interference patterns are given by the superposition of images obtained by laser illumination
IR Imaging	Remote sensing of the intensity of thermal radiation emitted by a structure, with sensors that transform the radiation of the IR spectrum into an electrical signal	The reconstructed image, in levels of gray to which a conventional color scale can be associated, can give information about the presence of continuity solutions due to different thermal conductivities (and therefore different surface temperatures) caused by air gaps in the structure

Table 2. NDE involving contact with the object under test		
Method of Excitation	Response Detection Method	Method of Data Interpretation
Acoustic	Contact and remote ultrasonic transducers (hybrid ultrasound technique)	Analysis of the received signal amplitude, proportional to attenuation due to the presence of air (defects)
Energetic	Tap testing	It involves the tapping on the surface of the test object whose condition was assumed depending on the type of sound it made. A solid high-pitch sound suggests that the point is in good condition, whereas a “dull” sound suggests a bad condition.
Time domain	Impact time	The techniques used in dynamic tap testing involve tapping the test surface with an impact hammer or tapper, where the contact time (impact duration) is then measured. The contact time can be measured by mounting an accelerometer or a force transducer into the tapping mass. The forcetime pulse received by the accelerometer after each tap is converted into a voltage pulse.

However, the application of NDE techniques in investigating heritage renderings faces certain limitations. Conducting measurements on-site is not always feasible because of various factors. The techniques often require optimal operational conditions, the availability of power

supply for instrumentation, and data interpretation that may need to be done separately from the measurement process. These factors can introduce practical challenges and cost implications, making these survey techniques less commonly used in actual work environments. In such cases, the conservator-restorer often relies on specialized, traditional auscultation techniques to analyze detachments.

2.1. Auscultation by tapping or knocking in use by conservators and restorers

The shape and extent of voids beneath the surface serve as valuable indicators of the underlying causes that resulted in the detachment.

During the analysis of detachments, the conservator-restorer employs the auscultation test, which resembles a physician auscultating a patient's lungs. This method is minimally invasive as the plaster has already withstood centuries of exposure to deteriorating agents and thus can withstand this contact investigation. This test involves lightly tapping the surface with either the fingers (Fig. 7) or knuckles of one hand while the palm of the other hand rests beside it (Fig.8). The tapping is executed with a brief, impulse-like force, and the aim is to maintain a consistent level of force throughout the entire examination. Thanks to the sensitivity of the specialist, the percussion is calibrated according to the possibility of stressing the plaster.

The vibration of the layers within the detachment generates a distinct “hollow” sound within the cavity, which is surrounded by the enclosing walls. The propagation of sound waves occurs through the medium of air outside the cavity. The sound is audibly perceived and subjectively interpreted by the operator, who instinctively analyzes the acoustic signal over time and across its frequency components.

The auscultation test is performed by maintaining contact with the entire rendering surface. The restorer, focusing on categories such as “detachment,” “lack of adhesion from the support,” and “deformation of preparatory layers,” aims to discern the distribution, extent, and sometimes the nature of the defect (including whether it affects superficial or deep layers and whether it involves debris accumulation or voids).

The location, depth, and extent of the detachments are subsequently recorded on the graphic documentation that accompanies each conservation assessment. This graphic documentation of deterioration phenomena is essential for any intervention or maintenance project. It can be presented as a map depicted with a colored overlay, superimposed on the photographic base of the object. Initially, it can be drawn on-site (Fig. 9), and later transferred to computer-aided design software for further analysis and documentation.



Figure 7. Auscultation by tapping with the fingertips.



Figure 8. Auscultation by knocking.

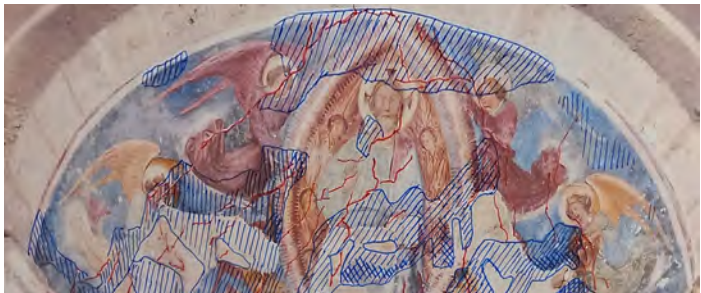


Figure 9. In situ handmade graphic documentation of detached areas.

2.2. Acoustics of detachments

What is a conservator-restorer actually auscultating by subjecting a surface to investigation by tapping or knocking?

The sound phenomenon that occurs when a rendering surface is stressed by an impulse-like impact like tapping is similar to that produced by percussion musical instruments. An approximation to a detachment is that of a small tympanum drum radiating sound waves in a circular plate-like manner from its constrained edges in the fundamental mode (0,0) due to impulsive mechanical stress. A detachment produces sound waves according to its modes of vibration and the compressibility of the air contained in the underlying closed cavity. A solid high-pitch sound suggests that the point is in good condition, whereas a “dull” sound suggests a bad condition.

To illustrate this occurrence, we can compare two oscillograms (plots of acoustic amplitude evolution over time) obtained by tapping. They relate to the condition of different points: adherent or detached. Fig. 10 shows two representations (in the time domain) of signals coming from an intact area (top) and one coming from a hollow, detached area (bottom). The amplitude of the signal corresponding to the detachment is higher compared with that of an intact portion. This is predictable because a detachment behaves like a highly efficient sound source. Conversely, a nondetached point absorbs the transmitted wave within the structure, resulting in lower amplitude. As said before, in the cavity-type mode, the motion is trapped in the cavity, with a relatively longer decay time of the sound with respect to an intact area. The time evolution is different; the decay of the “intact” sound over time has a shorter duration than that of the detachment signal (Mariani et al., 2020).

The acoustical properties of a detachment between layers are also determined by the mechanical properties of the layers from which they are made because the sound is produced by vibrations of the material itself.

The mechanical vibration of the surface (be it a plaster, a finishing layer, or a mosaic) implies that it possesses two fundamental properties. Stiffness is one of the fundamental properties of the surface as it generates a pull-back force opposing displacement. According to Hooke’s Law, the pull-back force is proportional to the displacement from the equilibrium point. This force is determined by the elastic modulus of the mortar and the compressibility of the underlying air. Additionally, the surface possesses inertia, which causes vibrations to dampen until they return to the equilibrium point. In cases of detachment and decohesion, maintaining the precarious equilibrium becomes crucial.

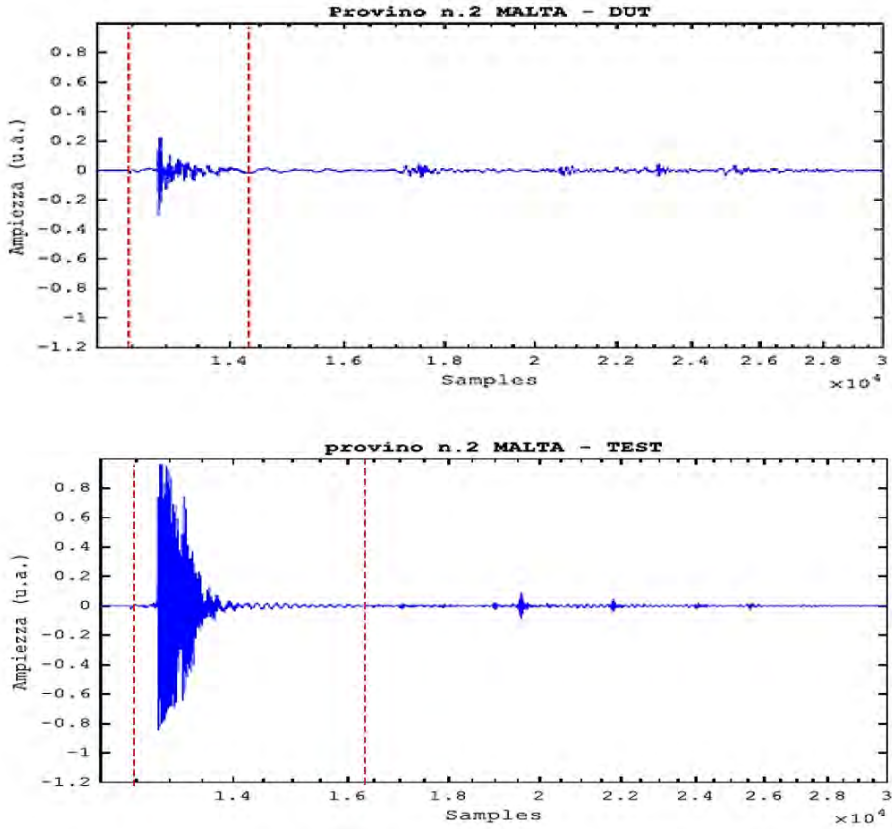


Figure 10. (top) An oscillogram generated by mechanically soliciting a portion of the surface in a good state of conservation. (bottom) An oscillogram generated by mechanically soliciting a hollow portion of the surface. The red lines indicate the start and end of the signals. The tails of the signals can be interpreted as undifferentiated noise.

From another point of view, detachments can store potential energy almost as in the case of a spring because of the presence of air below the vibrating mortar layer. Also, kinetic energy is taken on due to the mass (thus the depth at which detachment is located because a shallower or deeper position implies the presence of one or more vibrating layers above the air cushion). Detachment possesses a damping system due essentially to the material forming the cavity walls. Vibrating frequencies can be estimated through analysis in the frequency domain (Caliano et al., 2022).

The power spectrum PS of a time series $x(t)$, as are the audio signals produced when tapping or knocking on a detached surface, describes the power distribution of the sound signal as a function of its frequencies; therefore, PS is expressed in mV^2/Hz .

Fig. 11 shows an observation through a spectrum analyzer of the power spectrum of a sound emitted from an intact area (left) and one coming from a hollow, detached area (right), both excited by tapping. The intact area produced a vast range of frequencies, whereas the detachment showed its own vibration frequencies due to the geometry of the detachment and the stiffness of the material.

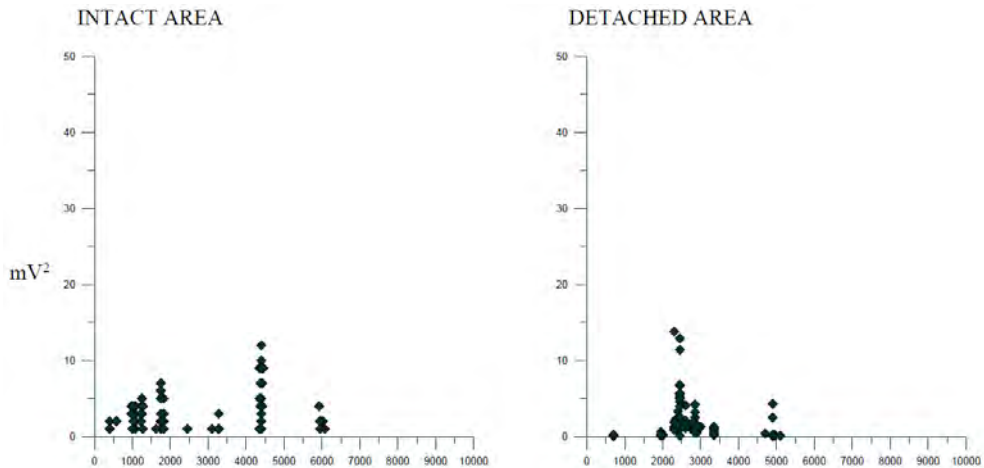


Figure 11. Power spectrum of a sound emitted from an intact area (left) and one coming from a hollow, detached area (right), both excited by tapping.

2.3. Auscultation issues by the technique in use by conservators and restorers

The precise tapping of plaster serves to identify areas that require monitoring or intervention as the condition of the plaster can deteriorate over time. Through the combination of auscultation tests and meticulous observation, a comprehensive assessment of the overall condition of a vulnerable rendering layer can be achieved.

The reliability of information obtained through the auscultation method is subject to various critical factors. Although the results can be deemed accurate and qualitatively representative when compared with tests conducted using specialized instrumentation (Hinsch K. et al., 2009), this holds true only when the auscultation is performed by skilled and trained professionals. The practical experience gained in the field is invaluable as the range of execution techniques and the causes and manifestations of deterioration are extensive. During the investigation process, the restorer's subjectivity comes into play in several ways. It involves applying varying degrees of force while striking the surface with the instrument

(hand), perceiving the surface's motion through the palm of the other hand, and interpreting the perceived sound through hearing.

Thus, the analysis of these events and the interpretation of the collected data heavily rely on the sensitivity and perception of the practitioners. Notably, they may not consistently be in the same operating condition over time, and their application of force during the examination may vary. These factors introduce a level of subjectivity that can influence the results and interpretations of the investigation.

Another specific feature of a specialist is the precision of the information transfer into a map, (Figg. 12 and 13). This graphic documentation is one of the documents at the base of a conservation project. However, it must be emphasized that the level of precision in graphical documentation can indeed vary, and this documentation is thus susceptible to transfer errors that can occur during the communication and drawing stages, providing or receiving misinformation, leading to incorrect or imprecise data being recorded. Additionally, prolonged and repetitive knocking notably can have an impact on the operator's hands. The physical strain and repetitive nature of the action can lead to fatigue or discomfort for the practitioner.

Considering all these factors that involve subjectivity, sensitivity to boundary conditions, and potential physical strain, this assessment method may not be easily repeatable. This lack of repeatability poses limitations on the method's reliability, particularly when it comes to accurately tracking the progression of decay over time.

3. The PICUS system

The PICUS system is an electromechanical auscultation system. It performs an automated analysis similar to that conducted by a professional who routinely examines detachments by hand, as previously described.

So far, three different data processing methods have been implemented on the PICUS system. In this paper, we illustrate the method involving a cross-correlation algorithm. The result tells if the points under examination are similar to one point taken as a reference REF or if they are definitely dissimilar from it. The choice of the REF is a delicate step that still involves a preliminary investigation conducted by an experienced conservator-restorer based on his or her experience.

The PICUS system has been developed to help conservators and restorers detect and measure detachments and more generally nonvisible defects objectively and repeatably, thus freeing the result from the subjectivity of the operator. This would allow one to repeat measurements (e.g., to monitor a detachment over time).



Figure 12. Auscultation.



Figure 13. Transfer of information to another operator for drawing on the documentation.

3.1. Procedure of the PICUS system

The hardware apparatus of the PICUS system is composed of a probe equipped with a miniaturized electromechanical percussion element (a solenoid), a microphone, and an infrared (IR) camera, all connected to a low-cost Arduino-like microcontroller, as shown in Figg. 14 and 15. Furthermore, because the probe's position in the measurement scenario is important, a two-dimensional measurement system based on the use of an IR camera that detects the location of an IR-LED placed on the probe is implemented (Caliano et al., 2021).

When the operator performing the procedure presses a button on the probe case, the microcontroller actuates the solenoid core to gently tap the surface under test. The force applied can be regulated according to the need. The microphone allows the capture of the free-vibration audio signal generated by the impact of the solenoid nucleus on the surface. The IR camera sends the X and Y coordinates of the IR-LED on the probe to the microcontroller unit to provide the localization of its position on the plane, (Fig. 16).



Figure 14. PICUS microcontroller and probe.



Figure 15. (top) PICUS probe mounted on a mouse-case; (bottom) PICUS IR camera.

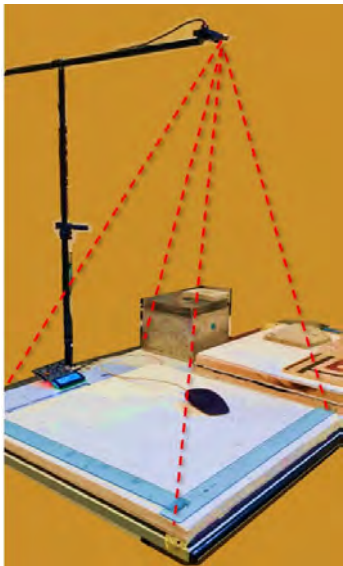


Figure 16. Scheme of the probe positioning.

The audio signal is sampled at a high sampling rate by the microcontroller electronics unit and processed in real time. The value resulting from the process is stored in a local mass memory (an SD card) as the Z coordinate, together with the X and Y coordinates provided by the IR camera, (Fig. 17).

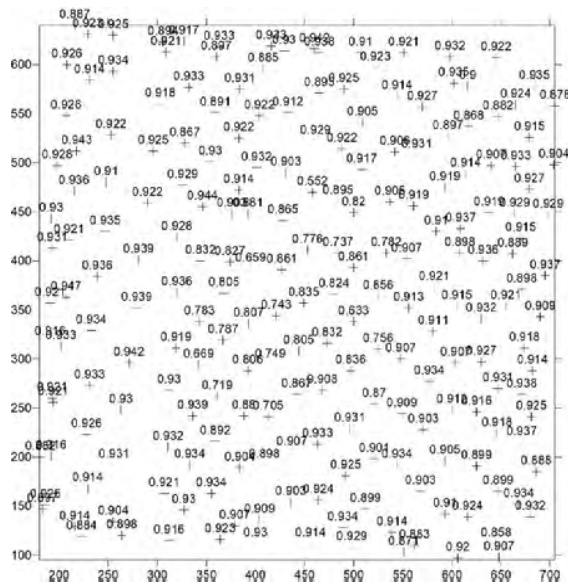


Figure 17. Grid file of the coordinates X , Y , and Z obtained with a surface modeling freeware.

The audio data sampled by the PICUS Probe were processed in real time, and the coordinates X , Y , and Z and other values were stored in an SD memory card to be plotted in the second phase of the process.

The chosen method involves a cross-correlation algorithm (Mariani et al., 2020, Caliano et al., 2021). It performs the cross-correlation in the time domain of two audio signals, similar to that conducted by a professional who routinely examines detachments by hand.

The reference area should be chosen in good conservative condition, possibly without any defects. The audio signal REF is sampled by the PICUS Probe on the reference area. Then, TEST signals can be sampled anywhere on the same surface. All other TEST signals will be cross-correlated with respect to the REF.

The cross-correlation algorithm assigns a numeric index to the similarity between the two signals. The index can vary between 0 and 1. Zero means no similarity at all; that is, the point is hollow. One means complete similarity; that is, the point is in good condition and no detachment is present. As aforementioned, the index value is stored as the Z coordinate, together with the X and Y coordinates of the position.

Postprocessing of the stored data involves the use of a freeware modeling tool that embeds various features, such as gridding, surface analysis, contour mapping, and 3D surface mapping (Caliano et al., 2021). A color scale is assigned to the values of the Z coordinate, resulting in a colored map of similarities or dissimilarities to the REF, (Fig. 18).

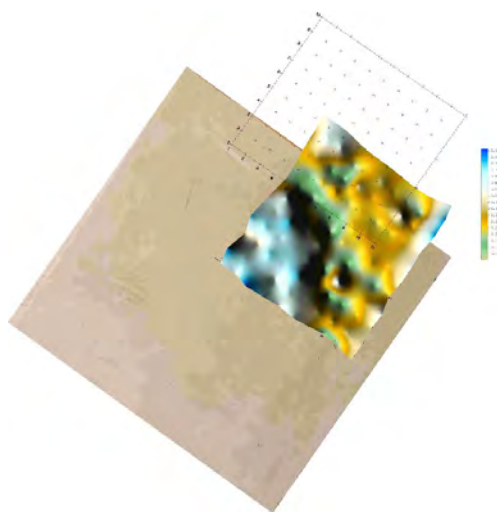


Figure 18. Example of a surface map from the data acquired using the PICUS system.

3.2. Preparation of mock-up specimens of wall paintings for testing with the PICUS system

Some mock-up objects were constructed for testing. For the verisimilitude with some cases most frequently found in conservation and based on experience, the models were reproduced to

1. detect large and small adhesion defects, even those very close together and having irregular shapes;
2. delineate the profile as precisely as possible; and
3. differentiate adhesion defects from each other according to their position in the section, that is, according to the depth at which they are located, whether superficial or closer to the substrate.

Among all the different materials tested with the PICUS system, such as brick, marble, mortar, glass, and wood, it is useful to present here some models that reproduce the mortar-based Vitruvian technique as in Book II, chapters 3–6, and Book VII, chapter 3, characterized by a stratified structure.

The support consisted of a handmade terracotta tile of $50 \times 50 \times 3.5$ cm, (Fig. 19). It was soaked in water for 2 days.

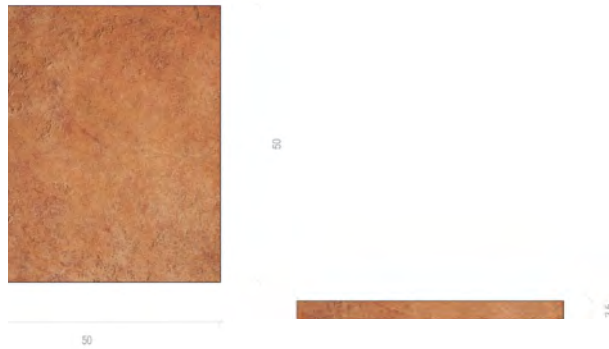


Figure 19. Sample support.

Then, a preparatory layer was applied to the support. The plaster was 3 cm thick, and it consisted of lime, *pozzolana*, and river sand, the latter with a grain size <2.5 mm in a ratio of 1:2:0.5, respectively, (Fig. 20).

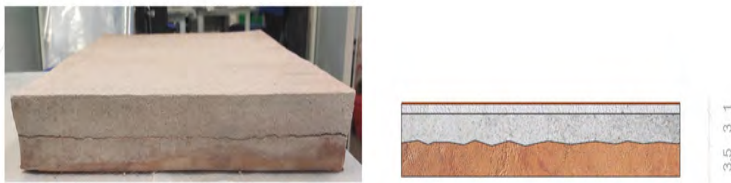


Figure 20. Application of rendering in two layers of mortar.

Air cavities were created on the *arriccio*, which was dome-shaped or with sharp edges. The position and the profile of the cavities were known. Model A was a specimen where defects were present between the substrate and plaster and had a dome shape, with a maximum depth of 1 cm. Model B had four air cavities with sharp edges and known profile, 2–2.5 cm deep, and the cavities involved the whole section of plaster. Model C reproduced the lack of adhesion in correspondence with mural joints, (Fig. 21).

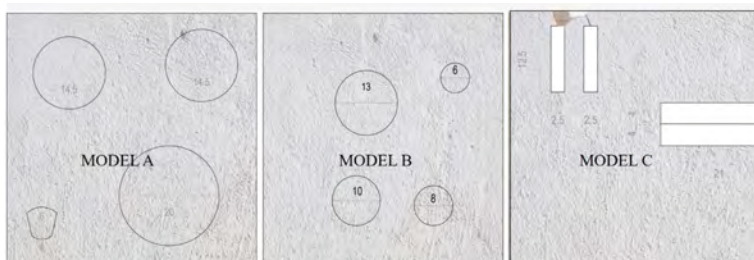


Figure 21. Position and shape of the cavities introduced between the support and preparation and between preparation and the top layer.

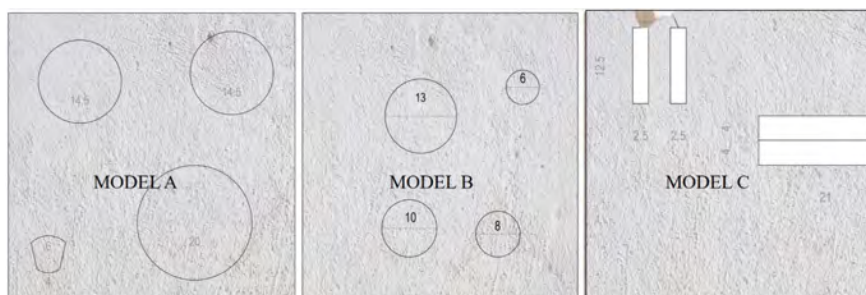


Figure 21. Position and shape of the cavities introduced between the support and preparation and between preparation and the top layer.

Finally, a previously prepared 1-cm-thick *intonachino* was applied when still fresh to cover the defects, (Fig. 22).

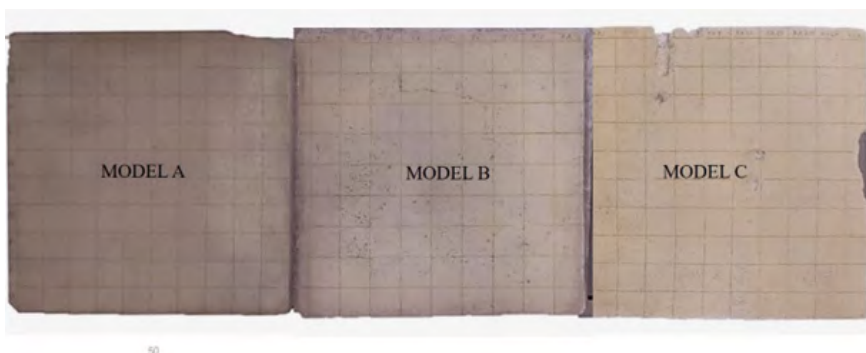


Figure 22. Surface of the models, lacking any decoration, marked with a grid to help the expert in assessing the location of detachments and transferring this information onto a map. The grid serves as a reference framework for accurately documenting the detected detachments and their spatial distribution.

4. Different techniques compared: traditional auscultation and cross-correlation with the PICUS Ssystem

The distribution of detachments was initially mapped using the traditional hand-knock method. Three conservator-restorers participated in the process, employing their expertise, hand knuckles, and ears to auscultate the surfaces of the models. The models were arranged side by side to simulate a wall covering with interrupted joints. The auscultation results, reflecting the different sensitivities of the three individuals, were then transferred onto separate maps labeled A1, A2, and A3. The maps illustrating these different results are shown in Fig. 23 below.

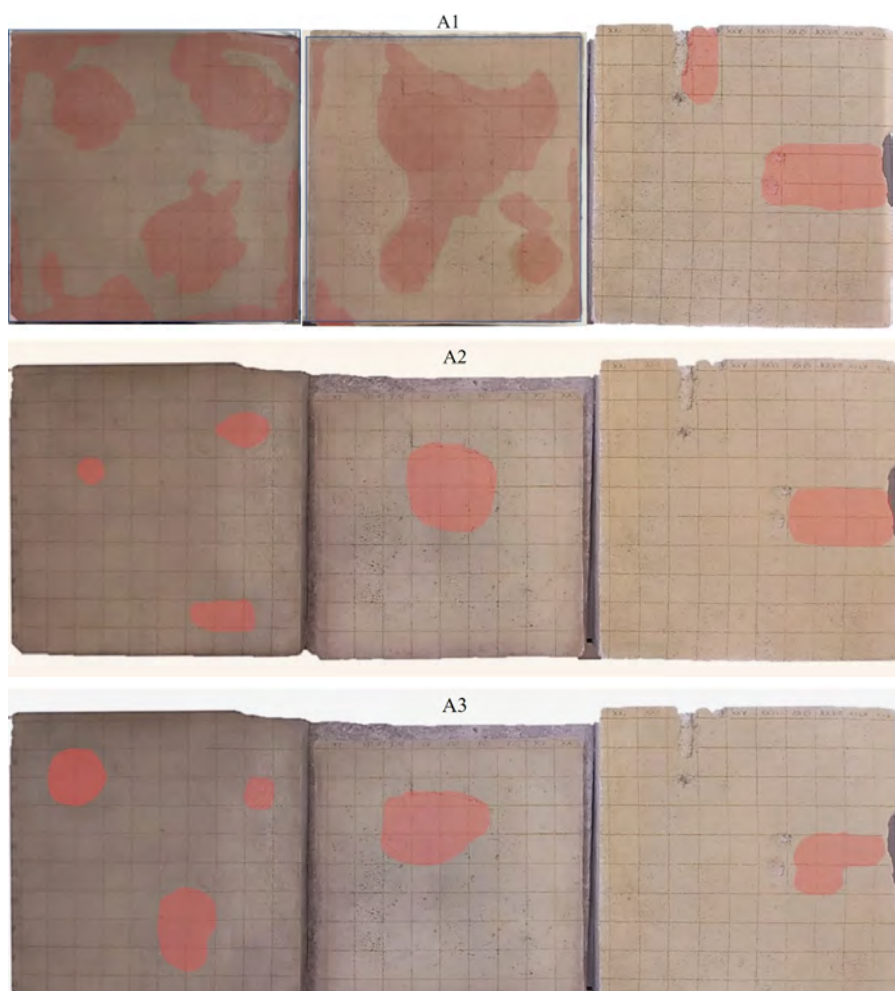


Figure 23. Maps of detachments obtained through auscultation using the traditional technique, filled in by three senior conservator-restorers.

Discrepancies among the three results were noticeable, indicating different perspectives on what should be highlighted in a detachment map. According to the operators, each map represented a distinct approach. In Map A1, every variation in sound was documented to provide a comprehensive overview of adhesion defects. Map A2 emphasized both sound and surface vibration, aiming to capture a more holistic understanding of the condition. Map A3 focused specifically on adherence defects that require immediate attention and action.

These different approaches reflect the individual priorities and interpretations of the operators regarding the significance of various aspects of the detachment mapping process.

The analysis technique using cross-correlation, as described earlier, generated a map that closely resembled the manually obtained A1 map. This promising outcome was enhanced by the implementation of color-scale thresholds in terms of the clarity of the representation, facilitating the identification of detachment areas. In Fig. 24, the color scale stopped when the cross-correlation index Z exceeded 0.9. Beyond this threshold, the substrate remained intact.

The data obtained using the PICUS system can be regarded as qualitative yet repeatable. The cross-correlation analysis between the reference signal and the test signal can always be performed on a section with an unknown condition. The repeatability of the measurement serves as a crucial benchmark for long-term maintenance or intervention programs and does not seem to be affected by boundary conditions, such as the presence of an intact or cracked surface or the perimeter of a detachment. Moreover, the data can be represented in various formats and require minimal storage space. The measurement setup is straightforward, and the equipment can be easily transported to the site for in situ analysis.

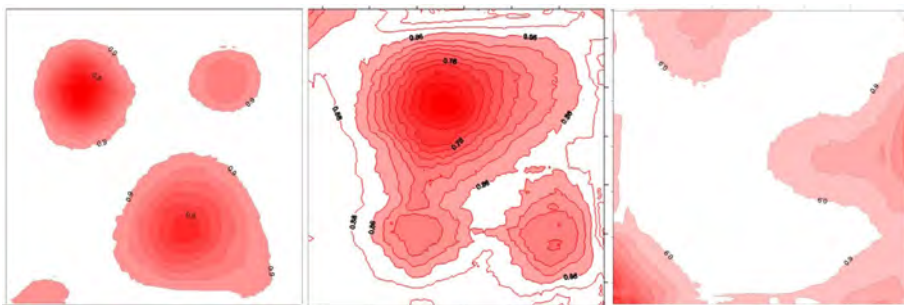


Figure 24. The same models' maps obtained by auscultation with the PICUS probe and processed with the cross-correlation algorithm.

The selection of the reference REF is always possible, allowing a conservator/restorer to assess the most suitable part for optimal operating conditions. The in situ application of the PICUS system is planned for the current year, ensuring that it can be used on-site to conduct necessary analyses.

References

- Marco Vitruvio Pollione, published by Carlo Amati (1829), vol. 1, Dell'architettura, Book II, Italian ed. Books I-XII. www.archive.org.
- Pliny the Elder, *Historia Naturalis*, transl. Eichholz D.E. (1949-54), Harvard University Press
<http://www.masseiana.org/pliny.htm>
- Pappalardo U. (2008), *The Splendor of Roman Wall Painting*, J. Paul Getty Museum
- Jackson M., Deocampo D., Marra F., Scheetz B. (2010), Mid-Pleistocene Pozzolan Ash in Ancient Roman Concretes, in "Geoarchaeology. An International Journal", Vol. 25, Issue 1

- Malathy R., (2023), Lime based concrete and mortar enhanced with pozzolanic materials –State of art, in “Construction and Building Materials”, Vol. 390
- Petretto M. A., (2007), Le indagini endoscopiche: contributo agli studi sulla cupola e sulle strutture murarie della chiesa, p.199-208; in “La Fabbrica di San Carlino alle Quattro Fontane: gli anni del restauro”, Volume speciale, Bollettino d’Arte, Poligrafico e Zecca dello Stato.
- Mora L., Mora P., Zander G., 1986, Coloriture e intonaci nel mondo antico, pp. 11-16; in “Intonaci colore e coloriture nell’edilizia storica, conference proceedings”, Roma
- Capponi G., D’Angelo C., Sabatelli M., 1999, I recenti interventi, restauri e manutenzioni, pp. 85-110; in “Restauro al Quirinale”, Volume speciale, Bollettino d’Arte, Poligrafico e Zecca dello Stato
- Mora P., Mora L., Philippot P. (1983), Conservation of Wall Paintings, Bologna, Ed. Compositori UNI 11182 (2006) - Cultural heritage, Natural and artificial stone materials. Description of the form of alteration - Terms and definitions.
- Quagliarini E., Lenci S., Seri E. (2012), On the damage of frescoes and stuccoes on the lower surface of historical flat suspended light vaults, *Journal of Cultural Heritage* 13, 293–303. <http://doi.org/10.1016/j.culher.2011.11.008>
- Alberti L., Bourguignon E., Carbonara E., Roby T., Escobar J.S., (2013). Illustrated Glossary: Technician Training for the Maintenance of In Situ Mosaics. Los Angeles; Tunis: Getty Conservation Institute; Institut National du Patrimoine de Tunisie. http://hdl.handle.net/10020/gci_pubs/glossaire_english
- Giuliani, Cairoli F. (1990), *Edilizia nell’antichità*, Roma INS Hinsch K., Zehnder K., Joost H., Gülker G., (2009), Monitoring detaching murals in the Convent of Münstair (Switzerland) by optical metrology, *Journal of Cultural Heritage* 10, 94e105, <https://doi.org/10.1016/j.culher.2008.06.011>
- Mariani F., Savoia A.S., Caliano G. (2020), An innovative method for in situ monitoring of the detachments in architectural coverings of ancient structures, *J. Cult. Herit.*, n. 42, pp. 139–146. <https://doi.org/10.1016/j.culher.2019.07.013>
- Caliano G., Mariani F., Calicchia P. (2021), PICUS: A Pocket-Sized System for Simple and Fast Nondestructive Evaluation of the Detachments in Ancient Artifacts, *Appl. Sci.*, 11, 3382. <https://doi.org/10.3390/app11083382>
- Caliano G., Mariani F., Vitali F., Pogliani P. (2022), The PICUS system in the detection of defects on panel paintings and wooden boards, presented in 2022 IEEE IUS Intern. Ultrasonic Symp., Venice, IT, Oct. 10-13, https://epapers.org/ius2022/ESR/paper_details.php?PHPSESSID=q6ips8hvj6qkr6im82t3jq4ub3&paper_id=2037.

On plastering, see also:

- NORMAL 23/86. Technical Terminology: Definition and Description of Mortars. Describes mortars used for decoration; offers definitions of mortars based on features, functions and properties. The scope of the booklet is to unify the technical terminology of mortars for decorations. Techniques for carrying out and applying the mortars are also discussed.
- NORMAL 23/87 Technical Terminology: Definition and Description of Mortars. Contains definitions related to Decorative Mortars. The two documents address the subject of mortars, from the purely terminological aspect (definition of the term mortar, differentiation of mortars according to their function, nature of the binder, and the setting process). Now replaced in UNI Recommendation 10924:2001.
- DIMOS Corso sulla manutenzione di dipinti murali, mosaici, stucchi. Tecniche di esecuzione e materiali costitutivi, parte 1 – modulo 1. http://www.iscr.beniculturali.it/documenti/allegati/DIMOS_parte_I-modulo_1.pdf
- Biscontin, G. (1985). *L’intonaco: Storia, cultura e tecnologia*. Atti del convegno di studi, Bressanone. Padova, Libreria Progetto editore.

- Allag, C., & Barbet, A. (1972). Techniques de préparation des parois dans la peinture murale romaine. *Melanges de l'Ecole Française de Rome*, 84(2), 935-1070.
- Hansen E. F., van Balen K., Rodriguez-Navarro C. (2005) Variations in High-Calcium Lime Putty and Mortar Properties Resulting from the Use of Freshly-Slaked Quicklime and Commercial Dry Hydrated Lime, in the Proceedings of the International Building Lime Symposium, Orlando Florida, National Lime Association
This work was carried out at the Getty Conservation Institute

CHAPTER 15

SCIENTIFIC METHODOLOGY FOR THE STUDY OF CORROSION MECHANISMS, MORPHOLOGIES AND CRACKING IN ARCHAEOLOGICAL COPPER-BASE OBJECTS

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Abstract

Understanding the corrosion processes of archaeological metals, corrosion mechanisms and morphologies, including cracking, are essential for conservation scientists; and also important for conservators, curators and archaeologists. Knowledge of particular aspects of corrosion in ancient metals and alloys is required for deciding how best to preserve heritage artefacts. In addition, the corrosion products themselves are interesting. There may be only a thin noble patina or corrosion crust, combinations of thick corrosion layers with metallic remnants, or completely corroded and mineralized objects that yet retain their original shape. Also, corrosion layers may retain some historical and even technological aspects of metalworking of interest for conservation scientists, archaeometallurgists and archaeologists. In this Chapter, we discuss three aspects of the study and analysis of corrosion in archaeological copper alloys, especially tin bronzes:

- The types of corrosion found on (and in) archaeological copper alloy artefacts recovered from aerobic soil burial environments. Examples are given of internal corrosion damage and the corrosion layers and morphologies, which can be complex.
- The more usual and available analytical methods for the study and analysis of corrosion in these artefacts. Most of the information about the corrosion phenomena and damage has been obtained via invasive sampling, using a variety of techniques. This is sometimes not allowed, notably for high-status artefacts. Recourse must then be made to non-invasive methods, such as visual analyses and surface (or near-surface) chemical composition measurements of corrosion products; and also the refurbished alloy surfaces, assuming that corrosion patinas may be removed.
- Cracking and fracture mechanisms in moderately to severely damaged (fragmented) artefacts. This is a specialist topic requiring fractographic expertise in addition to the more usual examination methods. Examples of fracture surface analyses, in combination with metallography, are included to illustrate the contributions of fracture surface studies.

Keywords: Archaeological Copper Alloys; Corrosion Mechanisms; Analytical Methods

Acronyms and Nomenclature

AAS:	Atomic Absorption Spectrometry
EBS:	Electron Backscatter Diffraction
EDS:	Energy Dispersive Spectrometry (of X-Rays)
FTIR:	Fourier Transform Infrared (spectroscopy)
ICP–OES:	Inductively Coupled Plasma – Optical Emission Spectrometry
IRS:	Infrared Spectroscopy
NAA:	Neutron Activation Analysis
OM:	Optical Microscopy
PIXE:	Particle-Induced X-Ray Emission
RAMAN:	Raman Spectroscopy
SCC:	Stress Corrosion Cracking
SEM:	Scanning Electron Microscope
SEM–BSE:	Back-Scattered Electron (mode)
SEM–SE:	Secondary Electron (mode)
WDS:	Wavelength Dispersive Spectrometry (of X -Rays)
XRD:	X-Ray Diffraction
XRF:	X-Ray Fluorescence

1. Introduction

Understanding metal corrosion processes, corrosion morphologies and mechanisms is essential for conservation scientists, and also important – in less detail – for archaeologists and conservators. Knowledge of particular aspects of corrosion in a variety of metallic alloys in burial environments is required for deciding how best to preserve heritage artefacts both during and after excavation.

In addition, the corrosion products themselves are potentially interesting. There may be only thin noble patinas or corrosion crusts, combinations of thick corrosion layers and metallic remnants, or completely corroded objects that yet retain their original uncorroded shape (Scott 2002; Selwyn 2006). Also, corrosion layers may retain some technological and historical aspects of metalworking of interest for archaeologists and especially archaeometallurgists. For example, (i) thin decoration layers and materials, or motifs and carved patterns, may be covered and preserved by corrosion layers; (ii) metallurgical processing details may be retained in partially or even completely corroded objects as “ghost structures” (Piccardo et al., 2007; Oddy and Meeks, 1982; Oudbashi et al., 2013); and (iii) corrosion layers and products can be informative about dating artefacts and their history after abandonment and during their long-term burial (Berthelon 2007).

In this chapter we discuss the types of corrosion found on (and in) archaeological copper alloys recovered from aerobic soil burial environments. Examples are given of internal corrosion damage and the corrosion layers and morphologies, which can be complex. Most of the knowledge about these corrosion phenomena has been obtained via invasive sampling, using a variety of analytical techniques. This is sometimes not allowed, particularly for high-status artefacts. Recourse must then be made to non-invasive methods, such as visual (photographic) analyses and surface, or near-surface, chemical composition measurements of corrosion products and the refurbished alloy surfaces.

2. Corrosion analysis techniques

Owing to the variety of invasive analytical techniques available, each with its advantages and limitations, and because scientists and conservators often use different analysis methods, it is important to provide guidelines for their use. In addition, careful stepwise planning of an investigation is needed to prevent the loss of potentially useful information. In this respect a combination of non-invasive and invasive methods (if permitted) would be optimal. In fact, the complexity of archeometallurgical corrosion very often needs invasive methods to provide more detailed information about the alloys, corrosion processes and damage; and also enable well-founded advice about preserving corroded artefacts.

2.1. Non-invasive techniques

Non-invasive analytical methods to analyze and characterize different aspects of historic and artistic works have been strongly developed during the last decades. This development has been stimulated by the wish to reduce and control the effects of sampling and destructive methods on valuable artefacts (Rousaki et al, 2018; Artioli and Angelini, 2011; Thickett et al, 2017).

An overview of these analysis methods and their purposes is given in Table 1. Considerable information about an artefact may be obtained without taking samples for invasive analyses. However, most of the information is descriptive rather than quantitative (surface chemical analysis). As stated above, if detailed knowledge of the alloys, corrosion and damage is required, then invasive analysis methods will be needed.

Table 1. Non-invasive analysis techniques and purposes	
Analysis Techniques	Purposes
• Visual inspection (unaided eye and hand lens) • Macrophotography and stereo binocular optical microscopy ($\leq 50X$); SEM fractography on small detached pieces • X-Ray radiography (limited enlargement) • Surface chemical analysis: various techniques, e.g. XRF; SEM + EDS or WDS for small objects (coins, ornaments, and small detached pieces)	• Basic identification and provenance • Artefact condition, surface details - nominally intact - damage: deformation, macrocracks, detached pieces - surface corrosion appearance and colouration • ‘Hidden’ damage - macrocrack extents and patterns, ‘hairline’ cracks - corrosion depths and layers - missing pieces and previous restorations (if any) • Corrosion products, including patinas; alloy surface compositions, and fracture surface compositions for small detached pieces

2.1.1. Optical microscopy

Study of surface corrosion products and morphology is a preliminary method useful for characterization of the state of conservation in archaeological copper-based objects. Using a low-magnification portable or bench loupe or microscope shows the surface effects, pits and colours of corrosion crusts. In many cases, these observations help conservators to recognize the type of corrosion (active or passive).

2.1.2. Radiography

For many years, radiographic methods (X-Ray radiography in particular) have been used to study the manufacturing methods and deterioration of archaeological metals (Fell et al, 2006). These methods show some aspects that are not visible from unaided eye observations. The thickness of corrosion layers, presence or absence of internal metallic remnants, internal fractures and cracks covered with corrosion, and hidden decorations and patterns are some of the features distinguishable by using X-Ray (and other) radiography techniques.

2.1.3. Surface chemical analysis

Characterization of the chemistry of corrosion layers is a very important aspect in corrosion studies. There are numerous different analytical methods for chemical analysis, but only some can be used as non-invasive tools for the characterization of corrosion phases. Most of these methods are used as micro-scale analyses that help scientists and conservators to analyze very small phases in multi-phase corrosion products. Nowadays, micro-Raman spectroscopy, micro-XRD, micro-XRF and micro-FTIR are used for this purpose (Artioli, 2010; Varela, 2013; Stuart, 2007). Note that X-Ray based ‘surface’ analyses are *effectively* near-surface, owing to a (very) limited penetration of X-Rays.

2.2. Invasive techniques

An overview of these such analysis methods is given in Table 2. Much more quantitative information can be obtained from sample analyses. Most of the information can be obtained from chemical composition analyses and metallography. However, fractography can be a useful addition to metallography, particularly for damage assessment. Detailed fractographic analysis can benefit restoration and conservation procedures by helping to identify the types of damage and an artefact’s susceptibility to further damage.

2.2.1. Chemical compositional analysis

Although elemental analysis is not essentially useful to characterize corrosion products, it may allow understanding the nature of the base metal/alloy and reveal changes in the chemistry of the metal/alloy and corrosion layers, especially in the case of de-alloying (leaching of an alloying element or elements). Different methods are used for detecting metal/alloy compositions by (i) taking small samples for ICP, AAS, or NAA analyses, and (ii) the study of cross-sections taken from metal/corrosion interfaces using micro-XRF or EDS and WDS (Artioli, 2010; Pollard et al, 2007).

Table 2. Invasive analysis techniques and purposes

<i>Analysis Techniques</i>	<i>Purposes</i>
• Chemical compositional analysis (quantitative and semi-quantitative methods) • Optical and SEM metallography on cross-sections, low to mid-high magnification ($\leq 5000\times$) • Phase analysis • Fractography, mainly SEM	• Identification of alloy/metal composition and type • Manufacturing processes, decorations and corrosion layers • Corrosion products and corrosion layers • Damage: deformation, macrocracks, detached pieces

2.2.2. Metallography

Optical and SEM Metallography of cross-sections have been used extensively to study and characterize corrosion processes in archaeological metals (Scott and Schwab, 2019). These methods lead to observations of the sequences and thicknesses of corrosion layers; internal and external corrosion crusts; the boundaries representing the original surfaces; and other features not observable from surface analyses. Combinations of optical and SEM metallographic observations are strongly recommended, whereby SEM contributes not only to higher magnifications (details) but also the ability to conduct local chemical analyses of selected phases and layers using EDS or WDS.

2.2.3. Phase analysis

Multi-phase corrosion layers may be detected by analyzing small samples taken from the surfaces of corroded objects. These phases and mineral products can be analyzed by methods such as XRD, Raman or FTIR (Artioli, 2010). These allow the finding of all the different compounds formed as corrosion layers. Of course, it is also possible to use these methods on metallographic cross-sections.

2.2.4. Fractography

Fractography of archaeological metals is uncommon owing to its specialist nature (Wanhill and Oudbashi, 2023) and the difficulty of obtaining suitable samples. Interpretive fractography is possible only if an artefact is severely cracked and broken and the fracture surfaces are well-preserved. This latter condition is seldom met, mainly due to post-fracture corrosion. Furthermore, curators and conservators may be disinclined to allow fractographic analysis because of concerns about an artefact's fragility, the need for invasive sampling, and general unfamiliarity with the potential benefits of fractography. SEM fractography is by far the most useful technique, since conventional optical microscopes have very limited depths of focus for proper fracture surface examinations at magnifications above about 100–200X.

3. Copper alloys surface and bulk corrosion

Copper was used as the first metal for producing different types of artefacts. In addition, various copper alloys were produced by adding metallic elements such as arsenic, tin, lead, and zinc (France-Lanord, 1980; Scott, 2002), to improve the castability, mechanical working, and final properties, notably strength and hardness for tools and weapons. In fact, hoards of copper alloys have been discovered at archaeological sites in many areas around the world. The alloying elements vary in their presence and amounts, depending on the mineral resources (ores) and

local pyrometallurgical developments over time. In turn, the alloy compositions, including minor elements, have influenced the corrosion behaviour in long-term burial environments.

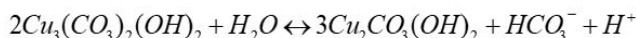
3.1. Copper or impure copper

Corrosion of copper or impure copper in archaeological soil environments has been well studied and is a complex phenomenon. The corrosion severity and types of products and layers strongly depend on the chemical properties of the burial environments. The first corrosion layer formed at the surface of a buried copper artefact is cuprous oxide: cuprite (Cu_2O). This thin oxide layer then may be covered with Cu(II) corrosion products such as basic copper carbonates or copper trihydroxychlorides. The chemical composition of this second layer depends on the presence of soluble anions in the burial environment. Also, contextually rare corrosion products are sometimes observed, such as copper sulphates. These are more usual for copper corrosion in urban atmospheres.

As noted in the introduction to this chapter, corrosion of copper may vary from a very thin patina to completely corroded and mineralized objects. In low- or moderately-corrosive soils with high amounts of carbonate and bicarbonate anions, a thin layer of cuprite covered with green malachite ($\text{Cu}_2(\text{CO}_3)(\text{OH})_2$) and sometimes blue azurite ($\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$) are the main corrosion layers.

In more detail, malachite and azurite are formed in the presence of soil water (moisture) containing CO_2 . Malachite is more stable than azurite, with the latter becoming malachite in the presence of increasing moisture and decreasing CO_2 (Selwyn, 2004; Fernandes, 2009; Luo et al, 2010). Regular growth of malachite on the surface of copper objects leads to formation of a green patina. Azurite forms in environments rich in bicarbonate anions (HCO_3^-). This means that the presence of azurite in corrosion products shows that carbonate activities in the soil environments are important; and also signifies that the pH is neutral or slightly acidic (McNeil and Little, 1992; Vink, 1986).

All the foregoing possible changes in soil conditions imply that azurite could have transformed into malachite and vice versa:



Summarising so far, if *both* copper carbonate corrosion products are present they may indicate (i) changes in the soil water contents, e.g. during seasonal changes, and (ii) variations in bicarbonate contents. Furthermore, these latter variations are linked to corrosion dissolution events when calcite (CaCO_3) is contained in the soils (Franke and Mircea, 2005).

Adding to the complexity, the presence of chloride ions in soils, together with water and oxygen, may lead to formation of nantokite (CuCl) (Scott, 1990; McNeil and Little, 1999). During burial or after excavation, nantokite will form copper trihydroxychlorides (atacamite or paratacamite). This is called “active corrosion” or “Bronze Disease”, which penetrates into the metal and is a cyclic (continuously recurring) reaction, without the need for more oxygen or chlorine ions. The reaction continues until all the metal (or alloy) transforms into copper corrosion products, namely the copper trihydroxychlorides atacamite and/or paratacamite (Selwyn, 2006; Scott, 2002; Scott, 1990; Casaletto et al, 2006; Scott, 2000, Quaranta, 2010). A schematic of the Bronze Disease process is shown in Figure 1. This process is sometimes used to explain the occurrence of pale green powdery patches and pits after excavation of archaeological copper alloys (Selwyn, 2006).

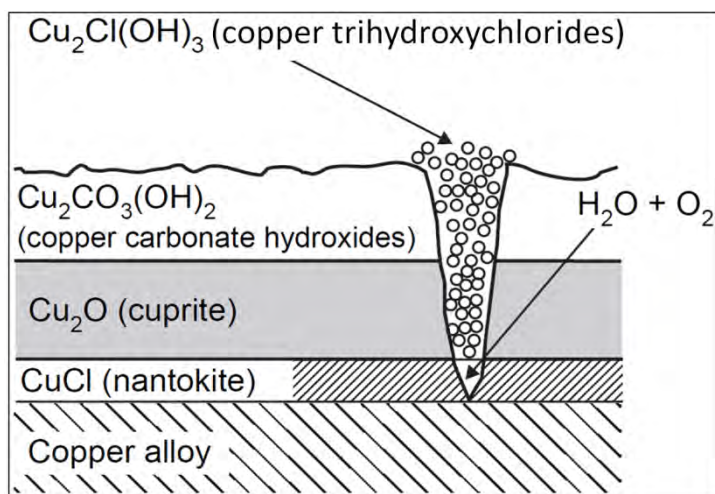
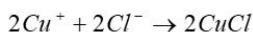


Figure 1. Schematic of the Bronze Disease process: see the main text also.

The cyclic reaction is demonstrated by the following equations (Scott, 2002; Quaranta, 2010):



N.B. There are well-defined measures for stopping and preventing Bronze Disease in individual artefacts and collections. (Scott, 1990; Papapelekanos, 2010; Oudbashi, 2016).

Figure 2 provides two images of the same area of a cross-section of a copper coin (*folus*) from the Iranian Safavid period (16th-18th centuries AD). ICP-OES analysis showed that the

coin was made of impure 99.5 wt.% copper. Furthermore, XRD analysis of corrosion products on the coin surface revealed that the main corrosion compounds were malachite and cuprite, with paratacamite and some soil minerals as minor components (Hajjari et al 2021). Corrosion layers observed by dark field OM, Figure 2a, are a combination of external grey-green and internal purple (green and red in bright field OM) layers bracketing the original surface. The external grey-green layer is relatively thick (ca. 150-250 microns) while the internal layer includes a narrow regular layer (ca. 50 microns) above deeper intergranular attack. This latter aspect is better visible in Figure 2b, which is an SEM-BSE image.

The main corrosion mechanism for this coin was near-surface dissolution and oxidation of copper that formed and deposited cuprite and malachite over the original surface, with some effects of chloride ions in the burial soil leading to formation of minor amounts of copper trihydroxychlorides. The internal corrosion was also cuprite, with low concentrations of chlorine ions. (Hajjari et al, 2021).

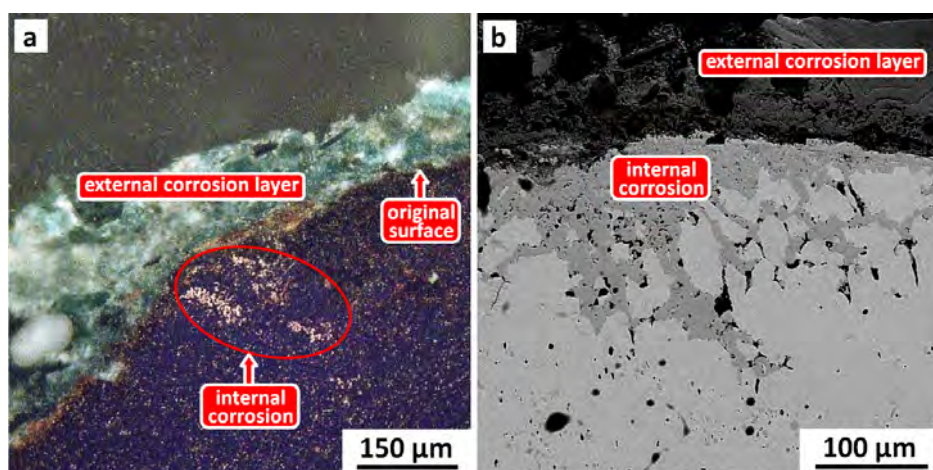


Figure 2. (a) Dark field OM and (b) SEM-BSE metallographic cross-section images from an Iranian Safavid copper coin (16th-18th centuries AD). Both images show a basically two-layered corrosion attack. The thick external layer consisted of basic copper carbonate (malachite) with some copper trihydroxychlorides. The internal layer was copper oxide (cuprite). Images source: Omid Oudbashi.

Figure 3 provides two images of the same area of a cross-section of a rectangular copper rod from the South-western Iran Haft Tappeh archaeological site, dated back to the 14th century BCE. Chemical analysis by EDS and micro-PIXE revealed that the rod was made of impure copper with about 99 wt.% Cu (Oudbashi and Davami, 2014a; Oudbashi et al, 2019). It was buried in a severely corrosive soil with a high concentration of soluble chloride, and had suffered from Bronze Disease (Oudbashi, 2018).

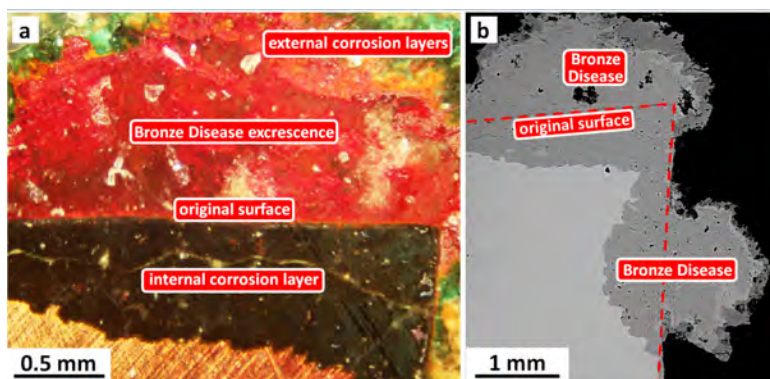


Figure 3. (a) Bright field OM and (b) SEM-BSE metallographic cross-section images from a rectangular copper rod from Haft Tappeh and dated to the 14th century BCE. Both images show a three-layered corrosion attack, including (i) two-layered external corrosion consisting of a thin green layer of copper trihydroxychlorides (atacamite and paratacamite) and a thicker red layer of cuprite: (ii) a single thick layer of internal corrosion consisting of copper oxide (tenorite) Figure 3b shows how the external layers formed excrescences typical of Bronze Disease. Images Source: Omid Oudbashi.

XRD and micro-Raman analyses revealed that the external green and red corrosion layers shown in Figure 3a were copper trihydroxychlorides (atacamite and paratacamite) and cuprite (Cu_2O), respectively, while the internal brown corrosion layer was also a copper oxide (tenorite: CuO) (Oudbashi, 2015). Figure 3b shows the external corrosion layers forming excrescences typical of Bronze Disease. Figure 3b also has sufficient contrast (enhanced by the BSE mode) to show the thin outside layer of copper trihydroxychlorides. On the other hand, the similar contrast for the external cuprite and internal tenorite demonstrates their chemical similarity: both are copper oxides, as mentioned above.

3.2. Single-phase tin bronzes

Most of the available information and analysis comes from decades of studies of archaeological single phase (α) tin bronze (Cu-Sn) artefacts, revealing much complexity. Extensive optical and SEM metallographic analyses on samples have shown that there are two basic types of tin bronze corrosion in burial environments (Chase, 1994; Robbiola et al., 1993; 1994; 1998). This knowledge has been obtained primarily by invasive sampling, which also established the bulk alloy compositions using several techniques, one of the main ones being SEM + EDS. Non-invasive chemical analyses have been obtained from allowed patina ‘scrapings’, using XRD and IRS (Robbiola et al, 1998, Robbiola and Portier, 2006; Ingo et al, 2019), and small object surfaces using SEM + EDS (Ingo et al, 2019). In particular, Robbiola et al, (1998) combined non-invasive and invasive techniques to obtain a correlation between the tin contents in the patina and bulk metal for nominally single-phase Cu-Sn alloys.

3.2.1. Type I corrosion

This type has a basically two-layered limited-depth corrosion morphology, and is characteristic for alkaline soil burial environments. This type retains the original shape (or original surface) of the artefact, and macroscopic traces of polishing or use may survive. The top layer consists usually of powdery malachite resulting in a commonplace green patina (Chase 1994; Scott 2002; Selwyn 2004), as mentioned near the beginning of subsection 3.1. Another possibility is azurite: this, however, has seldom been reported for ancient copper alloys (Selwyn 2004).

The second layer consists of a thin deposit of cuprite (Cu_2O) rich in tin oxide (SnO_2), and forms a smooth patina adjacent to the metal surface. The patina colour can be green, blue, grey or black and is often highly prized for its aesthetic appearance. The chemical composition indicates that the main corrosion process is decuprification (selective copper leaching) from the metal surface combined with local oxidation of tin. This second-layer patina is noble and strongly rate-limiting for further corrosion, even stopping it entirely. This is why the patina is thin and further corrosion (if any) is limited, even after burial for millennia.

Figure 4 shows example metallographic cross-sections and analyses schematics for a corroded tin bronze vessel (one of a series) recovered in Luristan, Western Iran. The vessels had been buried in a partially corrosive soil environment and were studied to determine the corrosion mechanisms (Oudbashi et al. 2016, Oudbashi, 2018). The OM cross-section in Figure 4a show a basically two-layered corrosion crust consisting of a green-blue thick layer above the original surface and a compact darker green layer beneath it. In some samples this layer may sometimes retain evidence of the alloy microstructure. However, in Figure 4a there is also some thicker orange-brown intergranular attack disrupting the continuity of the thin dark green layer: see Robbiola et al. (1998). Figure 4b illustrates that SEM-BSE enabled finer detail to be observed at the same magnification (although losing the valuable colour information provided by OM). Also a narrow intergranular crack was captured by this cross-section. SEM-EDS measurements showed the alloy to be a binary tin bronze with 9.6 wt.%Sn (Oudbashi et al. 2014b). XRD analysis of the corrosion layers revealed that the external corrosion layer was composed of malachite and some azurite, and therefore formed by decuprification, i.e. selective leaching of copper from the alloy (Oudbashi et al. 2016).

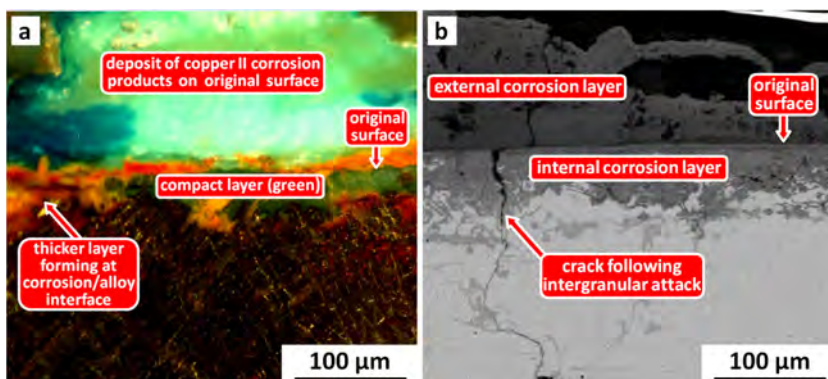


Figure 4. Bright field OM and SEM-BSE metallographic cross-section images from a tin bronze vessel from Western Iran (after Oudbashi et al. 2016). The corrosion has a basically two-layered stratigraphy, corresponding to Type I corrosion (Robbiola et al. 1998).

3.2.2. Type II corrosion

This type has a basically three-layered corrosion morphology and is characteristic of chloride-containing soil burial environments. The corrosion crust is coarse (rough) and much thicker than for Type I, and can transform an artefact into a multi-layered bulk material without any remaining metal (Scott 2002; Selwyn 2006).

The three-layered crust consists of (i) a variable-thickness powdery external layer that includes basic copper chlorides; (ii) a thick red layer of copper oxide that contains the original metal surface, though this is not visually detectable; (iii) an internal layer tin-rich with respect to the bulk metal, formed as in Type I by selective copper leaching, and also local oxidation of tin (Taube et al. 1996; Robbiola et al. 1998; Mabilie et al. 2003).

We note here that Type II is also associated with post-excavation Bronze Disease, which has been described already in subsection 3.1. Figure 5 shows OM metallographic cross-section images and analysis information for two tin bronze objects recovered from Haft Tappeh. These were from a series of copper-based objects that had been buried in a corrosive soil with high amounts of soluble chloride (Oudbashi 2015; Oudbashi 2018). These example artefacts had undergone severe corrosion attack, as had all the other objects (some were completely corroded). XRD, SEM-EDS and Raman spectroscopy analyses confirmed that the severe attack was due to three-layered Type II corrosion. Note, however, that such comparative metallographs as in Figure 5 reveal variations in the appearances of the basically three-layered structures, from which it may be concluded that detailed analysis is required or should be done to support the OM observations, see the next subsection.

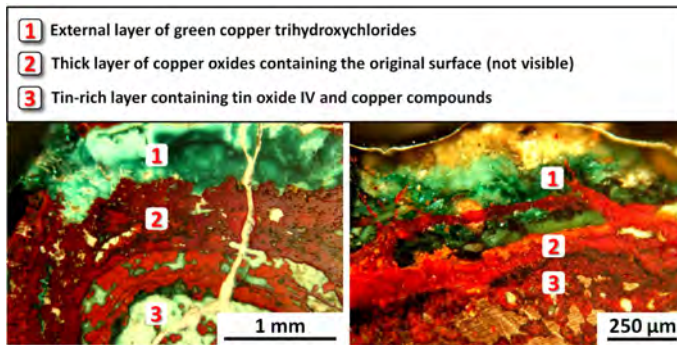


Figure 5. Bright field OM metallographic cross-section images for two tin bronze objects from Haft Tappeh (after Oudbashi 2015). The corrosion has a basically three-layered stratigraphy, corresponding to Type II corrosion. The examples illustrate the variable appearances of Type II, thus requiring detailed analyses for locating these layers.

3.2.3. Variable appearances of Type I and Type II corrosion

Besides illustrating the layered appearances of Types I and II corrosion, Figures 4 and 5 show that details of these corrosion layers can vary within the basic classification. Further illustrations of this are given by other Iranian tin bronze examples in Figure 6. The type I example in Figure 6a shows a two-layered structure of malachite (external) and a very thin tin-rich noble patina bounding the well-defined original surface of a tin bronze vessel from South-western Iran (Oudbashi et al. 2019). The Type II example in Figure 6b is more or less typical of completely corroded tin bronze objects, in this case a plate from Northern Iran. The structure comprises a thin layer of copper trihydroxychlorides; a thick banded layer of copper oxides, whereby the banding is known as the Liesegang phenomenon (Scott 1985); and a banded bluish-grey internal phase rich in tin. Banded copper oxide layers have also been observed in other fully corroded Iranian tin bronze objects (Oudbashi and Emami, 2010; Oudbashi et al, 2013). As concluded in subsection 3.2.2, detailed analyses are required or should be done to support the OM observations.

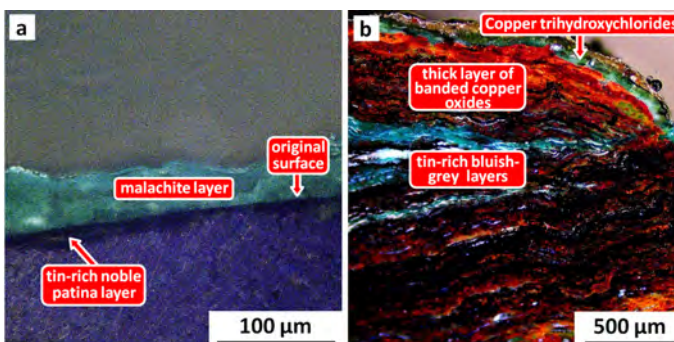


Figure 6. (a) Dark field and (b) bright field OM metallographic cross-section images for two tin bronze objects from Iran. Figure 6a is for a vessel from South-western Iran. Figure 6b is for an almost completely corroded plate from Northern Iran. Images source: Omid Oudbashi.

3.3. Two-phase (high-tin) bronzes

The corrosion morphology and stratigraphy in archaeological high-tin bronzes (more than about 15-17 wt.% Sn) has been less investigated. Nevertheless, some studies have revealed interesting aspects of corrosion in these alloys. Their microstructures consist of a low-tin (α) phase and a high-tin phase, intermetallic β or ($\alpha + \delta$) eutectoid. The main corrosion mechanism is preferential selective leaching of copper from one of the phases, without changes to the second phase. This mechanism also leads to formation of a tin-rich surface layer with very low thickness (Ingo et al 2002; Ingo et al 2004; Ingo et al 2019; Saraiva et al 2020). The overall result is a two-layered corrosion structure.

Figure 7 is a bright field OM metallographic cross-section from a corroded high tin bronze vessel recovered in Western Iran and dated to the Sasanian period (3rd to 7th centuries AD). The microstructure is comprised of islands of α in a martensitic β matrix. The corrosion attack resulted in a thin tin-rich external layer and a thick internal layer. Semi-quantitative SEM-EDS analysis indicated a bulk alloy composition of 50 wt.% Cu-37 wt.% Sn, with minor amounts of lead, nickel and sulphur. Phase analyses gave 85.90 wt.% Cu-12.46 wt.% Sn for the α islands and 74.42 wt.% Cu-22.80 wt.% Sn for the matrix (Oudbashi et al. 2017). This type of microstructure is called a β bronze and is formed by a peritectic transformation in bronzes containing more than 20 wt.% Sn (Park et al. 2009). The thick corrosion layer confirms the main corrosion mechanism mentioned above: in this case the β phase was completely converted to corrosion products, while the α islands were unaffected. However, it is noteworthy that an intergranular crack along α/β interfaces and possibly due to stress corrosion cracking (SCC) was also present in the sample. See subsection 3.6 for much more on SCC, but there for single-phase tin bronzes.

Figure 8 is an SEM-BSE metallographic cross-section from another high-tin β bronze vessel recovered in Sagzabad, North-central Iran, and dated imprecisely to the Iron Age. Although this vessel is not well recorded and documented, it is significant because the corrosion attack is macroscopically and microscopically different from that in Figure 7. The most remarkable difference shown by Figure 8 is the almost uncorroded surface. There was some local attack and minor cracking normal to the surface, but then this resulted in severe internal cracking parallel to the surface and mainly through the β phase but also along α/β interfaces. The internal cracking is highly directional, suggesting SCC.

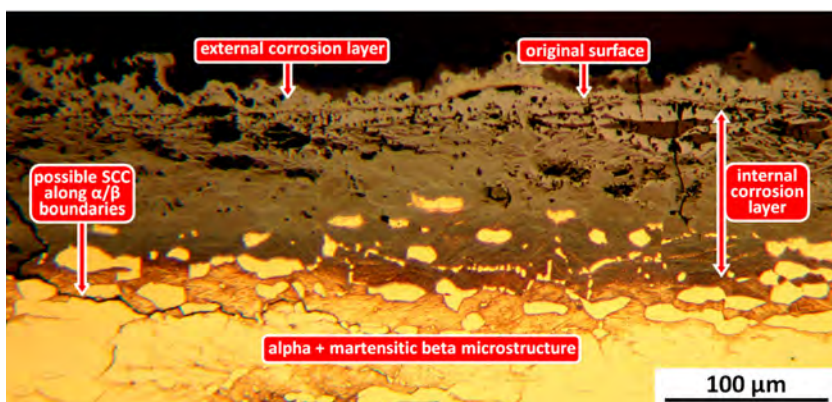


Figure 7. OM bright field metallographic cross-section image for a fragment of a Sasanian vessel from Western Iran. The main corrosion mechanism is preferential selective leaching of copper from the beta phase without changes to the alpha, which is preserved as islands in the internal corrosion layer. Note that possible stress corrosion cracking (SCC) has occurred along alpha/beta grain boundaries also. Image source: Omid Oudbashi.

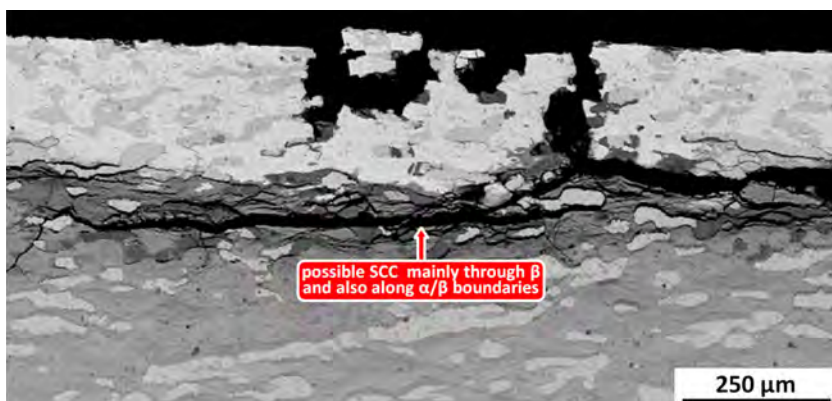


Figure 8. SEM-BSE metallographic cross-section image for a fragment of a high-tin bronze vessel from North-central Iran. The corrosion attack is very different from that in Figure 7. The surface in Figure 8 was largely uncorroded, with only occasional cracking normal to it. However, this cracking resulted in severe internal cracking parallel to the surface and mainly through the beta phase, but also along alpha/beta grain boundaries. Image source: Omid Oudbashi.

Possible reasons for the differences between the damage shown by Figures 7 and 8 are compositional and microstructural variations, different burial environments, and different combinations of burial loads and any retained residual stresses. An alternative possibility for the cracking, namely intrinsic brittleness (Park et al, 2009) is most unlikely, since (i) the vessels would have been susceptible to cracking and fracture immediately after manufacture; and (ii) intrinsic brittleness results in many branching microcracks throughout an artefact, not just locally. Clearly there is more forensic research to be done on archaeological high-tin bronzes.

3.4. Arsenical copper (Cu–As)

The corrosion of arsenical copper (arsenical bronze) objects has not been investigated sufficiently in detail to obtain definitive conclusions about the mechanisms of corrosion and morphologies of the corrosion products. However, the presence of arsenic as an alloying element may lead to some resistance against corrosion during long-term burial, and also decrease the corrosion rate (Scott, 2002). It is worth noting that a specific corrosion morphology due to arsenic has not been reported. N.B: A silvery appearance is observed in some ancient Cu-As objects, and this has been attributed to different causes: Inverse segregation, cementation, or corrosion (probably artificially initiated corrosion) (Constantinides et al. 2002; Meeks 1993; Mödler 2016). This phenomenon is not well understood and is under investigation.

Optical and SEM-EDS metallography and FTIR (Fourier transform infrared spectroscopy) have been used by Constantinides et al. (2002) to analyse artificial patinas on arsenical copper samples. They observed a very thin three-layered structure enriched with arsenic. The layers were as follows: an outer layer of basic copper carbonates, a middle layer of sandwich-like cuprite, and an inner layer of nanokite enriched with arsenic. This structure resembled Type II ‘rough’ corrosion in tin bronzes.

Optical metallography, SEM-EDS, micro-XRF and XRD methods have recently been used to study completely corroded arsenical copper objects recovered from corrosive soils in Eastern Iran (Mortazavi et al. 2022). The study also found a three-layered corrosion structure, but in this case, it comprised two external layers over the original surface and a corroded core (internal ‘layer’). The outermost layer consisted of basic copper carbonates and copper trihydroxychlorides; the second layer comprised cuprite, copper trihydroxychlorides, and some corrosion products of arsenic and lead; and the internal corrosion was a mixture of cuprite and copper trihydroxychlorides. The overall structure was attributed to selective leaching of copper from the alloy, accompanied by outward migration of arsenic and lead ions that enriched the second external layer (Constantinides et al. 2002).

3.5. Brasses (Cu–Zn)

A wide-range of studies on archaeological brasses has revealed a corrosion mechanism by which a multi-layered corrosion structure forms. Like tin bronzes, archaeological brass artefacts in a soil burial environment undergo a de-alloying process. In fact, there are two corrosion processes (Papadopoulou et al. 2016; Liang et al. 2021; Di Fazio et al, 2022):

- Dissolution of zinc and copper in the brass, followed by re-deposition of copper above the original surface.

- Selective dissolution of the zinc leaving a copper-rich layer under the original surface.

The second process, called dezincification, is observed more frequently in Cu-Zn alloys with zinc contents more than 15 wt.% Zn (Scott, 2002). In these alloys the copper and zinc corrosion products are visible above the original surface, while copper oxides are the main corrosion layers under it. The compositions of the external copper and zinc corrosion products are strongly related to the soluble salts available in the burial soil (Papadopoulou et al. 2016).

3.6. Copper alloys stress corrosion cracking (SCC)

Types I and II tin bronze corrosion may show localised thin intergranular or transgranular layers at and close to the metal–corrosion interfaces. These thin layers are red-coloured and caused by a corrosive solution penetrating into the metal. There is no overall preference for the direction of penetration, but extensive corrosion may result in local cracking.

The ‘normal’ corrosion process mentioned in the previous paragraph is distinct from stress corrosion cracking (SCC). This is because SCC results in much more severe cracking that progresses deep into the metal, developing into networks of long cracks that become wider as they grow. Eventually the cracking can result in broken-off pieces and fragmentation of artefacts. SCC is a complex problem that occurs in many metals and alloys owing to the simultaneous presence and interaction of three factors: (i) metal or alloy susceptibility to SCC; (ii) the presence of an aggressive environment; (iii) sustained (constant) stresses/loads. There is a general consensus that different SCC mechanisms occur in different materials in different environments, but little or no agreement about which mechanisms act in specific combinations. For archaeological copper alloys (and other ancient metals) the environments are usually aerobic soils containing moisture and chlorides; the stresses result from soil-burial loads and any retained cold-work in the artefact.

Only a limited amount of literature has *positively* identified SCC in ancient copper alloys, (Oudbashi and Wanhill, 2021; Wanhill and Oudbashi, 2023). Most of the evidence is for Iranian single-phase tin bronzes, but possible SCC in high-tin bronzes has been mentioned in subsection 3.3. The SCC cracking is mainly intergranular, but also transgranular along slip planes, i.e. promoted by retained deformation in the microstructure. Limited evidence of SCC along annealing twin boundaries has also been observed. Figure 9 illustrates intergranular cracking and fracture in two Iranian bronze vessels. Figure 9a shows an almost fully annealed microstructure with many annealing twins. In Figure 9b the arrows point to cracking and spalling of a thin corrosion layer overlying the fracture surface. The bulk chemical compositions were (a) 91.15 wt.% Cu, 8.71 wt.% Sn, 0.12 wt.% Zn, 0.02 wt.% As; and (b) 89 wt.% Cu, 10.71 wt.% Sn, 0.42 wt.% P.

Transgranular SCC in tin bronzes is difficult to observe owing to subsequent local corrosion. However, Figure 10 illustrates two clear instances of its crystallographic nature, namely cracking and fracture along *multiply-orientated* slip planes. These give the fracture surfaces a jagged microscale appearance. The bulk chemical compositions were (a) 89 wt.% Cu, 10.71 wt.% Sn, 0.42 wt.% P; and (b) 88.58 wt.% Cu-10.97Sn-0.45Zn.

Comparison of the cracking and fracture in Figures 9 and 10, and especially the direct comparison of intergranular and transgranular cracking in Figure 10a, shows the much larger scale of intergranular SCC. Consequently it is the main threat to the integrity of single-phase tin bronze artefacts.

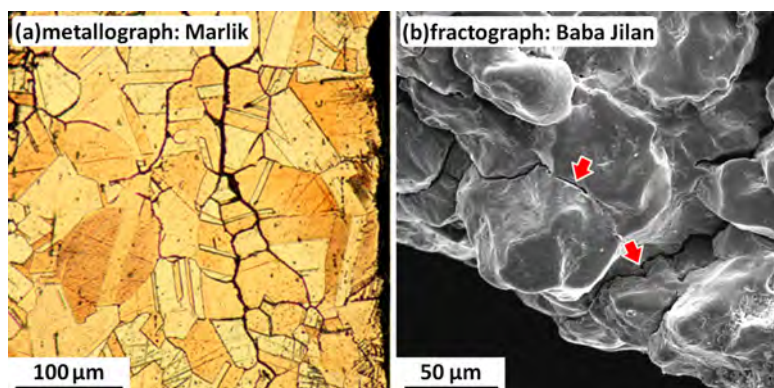


Figure 9. OM metallographic and SEM-SE fractographic images of intergranular SCC in two Iranian bronze vessel fragments: **(a)** Marlik, 14th–10th century BCE. **(b)** Baba Jilan, 8th century BCE; the arrows point to broken thin corrosion films. Original images source: Omid Oudbashi.

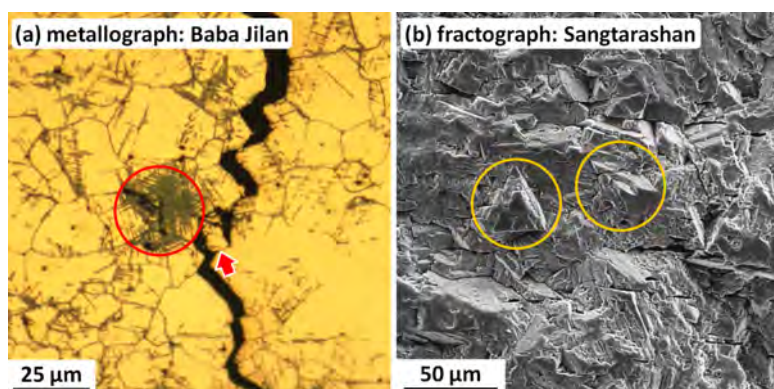


Figure 10. OM metallographic and SEM-SE fractographic images of SCC in two Iranian bronze samples. **(a)** Button, Baba Jilan, 8th century BCE, showing (i) a region of intense slip plane attack and later general corrosion (ringed grey area); (ii) a block of transgranular fracture (arrowed) inside the main intergranular crack. **(b)** Vessel, Sangtarashan, 8th–7th century BCE, illustrating transgranular SCC; the triangular features (ringed) were caused by intersecting cracks on different $\{111\}$ slip planes. Original images source: Omid Oudbashi.

4. Concluding remarks

Corrosion of archaeological copper alloy artefacts has been important for many years in conservation and archaeological science. In recent years, numerous analysis methods have been used by scientists to understand corrosion mechanisms and morphologies in different types of copper-base artefacts, including invasive and non-invasive investigations. Valuable information has been obtained from different methods, with OM and SEM microscopy and microanalysis widely employed to obtain corrosion stratification and chemistry data. These data are obtainable mainly by invasive sampling and combinations of analysis methods, since (i) non-invasive methods are limited to surface and (very) near-surface measurements; and (ii) archaeological copper alloy corrosion is an exceedingly complex phenomenon, as has been illustrated in this chapter.

A combination of OM and SEM metallography, SEM + EDS, micro-Raman spectroscopy and XRD has proven – in the authors' experience – most useful for corrosion studies of archaeological copper alloys. These enable:

- OM metallographic observations of corrosion layers and metallic microstructures *in colour* at low to medium magnifications, up to about 1000X.
- SEM metallographic observations of corrosion layers and metallic microstructures in B&W contrast at low- to medium-high magnifications, up to about 5000X. Higher magnifications are possible, but the most useful information is usually obtained in the range quoted here, including the combination of SEM metallography and EDS.
- Characterization of whole corrosion products via a molecular or phase analysis, for example XRD, Raman (or micro-Raman) or FTIR.

A seldom used technique is fractography, usually SEM fractography, owing particularly to the greater depth of focus compared to conventional OM fractography. Fractography can provide valuable additional information compared to metallography, and examples have been included in this chapter. These examples have helped to show that SCC had occurred in some archaeological artefacts from different periods.

References

- Artioli, G. (2010). *Scientific Methods and Cultural Heritage: An Introduction to the Application of Materials Science to Archaeometry and Conservation Science*, Oxford University Press, Oxford.
- Artioli, G., Angelini, I. (2011). Mineralogy and archaeometry: fatal attraction. *European Journal of Mineralogy*, 23(6), 849–855.

- Berthelon, R. (2007). Archaeological metal artefacts and conservation issues: long-term corrosion studies. In *Corrosion of Metallic Heritage Artefacts: Investigation, Conservation and Prediction for Long-Term Behaviour*, Dillmann, P., Béranger, G., Piccardo, P., Matthiesen, H., Eds.; European Federation of Corrosion Publication 48; Woodhead Publishing: Cambridge, UK, pp. 31-40.
- Casaletto M.P., De Caro, T., Ingo, G. M., Riccucci, C. (2006). Production of reference “ancient” Cu-based alloys and their accelerated degradation methods. *Appl. Phys. A*, 83, 617-622.
- Chase, W.T. (1994). Chinese bronzes: casting, finishing, patination and corrosion. In *Ancient and Historic Metals: Conservation and Scientific Research (Part 2)*. Scott, D.A., Podany, J., Considine, B.B., Eds.; The Getty Conservation Institute, Los Angeles, CA, USA, pp. 85-118.
- Constantinides, I., Adriaens, A., Adams, F. (2002). Surface characterization of artificial corrosion layers on copper alloy reference materials. *Appl. Surf. Sci.*, 189 (1-2), pp. 90–101.
- Di Fazio, M., Felici, A.C., Catalli, F., Medeghini, L., De Vito, C. (2022). Micro and Nanoscale Structures and Corrosion Patterns in Brass: The Case Study of Ancient Roman Orichalcum Coins. *Minerals*, 12, 827. <https://doi.org/10.3390/min12070827>
- Fell, V., Mould, Q., White, R. (2006). Guidelines on the X-radiography of Archeological Metalwork. Swindon: English Heritage.
- Fernandes, R. (2009). Study on Roman and Merovingian copper alloyed artefacts-In soil corrosion processes and recycling practices. MSc Thesis, Vrije Universiteit Amsterdam.
- France-Lanord, A. Ancient Metals, Structure and Characteristics: Technical Cards. Rome, ICCROM, 1980.
- Franke, W.A., Mircea, M. (2005). Plutarch’s Report on the Blue Patina of Bronze Statues at Delphi: A Scientific Explanation. *JAIC*, 44, 103-116.
- Hajjari, E., Oudbashi, O., Hemati Azandaryani, E. (2021). Technical studies on the mechanisms of corrosion and state of conservation of two hoards of Persian copper coins (folus) from the Safavid period in Iran, *Journal of the Institute of Conservation*, 44(2), 86-98.
- Ingo, G.M., Angelini, E., Bultrini, G., Calliari, I., Dabala, M., De Caro, T. (2002). Study of long-term corrosion layers grown on high-tin leaded bronzes by means of the combined use of GDOES and SEM + EDS, *Surf. Interf. Anal.*, 34, 337-342.
- Ingo, G., Angelini, E., de Caro, T., Bultrini, G., Calliari, I. (2004). Combined use of GDOES, SEM + EDS, XRD and OM for the microchemical study of the corrosion products on archaeological bronzes. *Appl. Phys., A* 79, 199–203.
- Ingo, G.M., Balbi, S., De Caro, T., Fragala, I., Angelini, E., Bultrini, G. (2006). Combined use of SEM-EDS, OM and XRD for the characterization of corrosion products grown on silver roman coins. *Appl. Phys.*, A83, pp. 493-497.
- Ingo, G.M., Riccucci, C., Guida, G., Albin, M., Giuliani C., Di Carlo, G. (2019). Rebuilding of the burial environment from the chemical biography of archaeological copper-based artifacts. *ACS Omega*, 4, pp. 11103-11111.
- Lehmann, E.H., Vontobel, P., Deschler-Erb, E., Soares, M. (2005). Non-invasive studies of objects from cultural heritage, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 542, 1–3, pp. 68-75.
- Liang, Z., Jiang, K., Zhang, T., Lin, S., Corrosion behavior of brass from the Western Zhou Dynasty in an archaeological-corrosive medium. *J. Alloys Comp.* 865 (5), 2021,158579.
- Luo, W., Jin, R., Qin, Y., Huang, F., Wang, C. (2010). Analysis of the Corrosion Products of the Ancient Bronzes Excavated from Qiaojia Yuan Tombs. *Applied Physics Research*, 2, 156-169.
- Mabille, I., Bertrand, A., Sutter, E.M.M., Fiaud, C. (2003). Mechanism of dissolution of a Cu–13Sn alloy in low aggressive conditions. *Corros. Sci.*, 45 (5), pp. 855-866.
- McNeil, M.B., Little, B.J., (1999). The Use of Mineralogical Data in Interpretation of Long-Term Microbiological Corrosion Processes: Sulfiding Reactions. *JAIC*, 38, 186-199.

- McNeil, M.B., Little, B.J. (1992). Corrosion Mechanisms for Copper and Silver Objects in Near-Surface Environments. *JAIC*, 31, 355-366.
- Meeks, N. (1993). Surface characterization of tinned bronze, high-tin bronze, tinned iron and arsenical bronze. In *Metal Plating and Patination: Cultural, Technical and Historical Developments*; La Niece, S., Craddock, P., Eds., Butterworth-Heinemann Ltd.: Oxford, UK, pp. 247-275.
- Mödlinger, M., Sabatini, B. A. (2016). Re-evaluation of inverse segregation in prehistoric As-Cu objects. *J. Archaeol. Sci.*, 74, pp. 60-74.
- Mortazavi, M., Kavosh, H., Naghavi, S., Khanjari, R. (2022). Microstructural and analytical study of uncommon corrosion features on archaeological Cu-As alloys from Tappeh Graziani in Southeastern Iran. *Microsc. Microanal.*, 28(2), pp. 302-316.
- Oddy, W.A., Meeks, N.D. (1982). Unusual phenomena in the corrosion of ancient bronzes. in *Science and Technology in the Service of Conservation*; Brommelle, N.S., Thomson, G., Eds.; International Institute for Conservation of Historic and Artistic Works; IIC Washington Congress, pp. 119-124.
- Oudbashi, O. A. (2018). methodological approach to estimate soil corrosivity for archaeological copper alloy artefacts. *Herit. Sci.*, 6 (2), (15 pages): DOI: 10.1186/s40494-018-0167-4
- Oudbashi, O. (2016). Corrosion risk assessment approach in archaeological bronze collections: From burial to long-term preservation environments. In *Metal 2016: Proceedings of the Interim Meeting of the ICOM-CC Metals Working Group*, September, 26-30, 2016, New Delhi, Menon, R., Chemello, C., Pandya, A., Eds., International Council of Museums - Committee for Conservation (ICOM-CC), pp: 188-194.
- Oudbashi, O. (2015). Multianalytical study of corrosion layers in some archaeological copper alloy artefacts. *Surf. Interface Anal.*, 47 (13), pp. 1133-1147.
- Oudbashi, O., Bahadori, S., Aliyari, A. (2022). "Corrosion Analysis and Assessment of a Collection of Archaeological Copper Alloy Objects from Sagzabad, Northern Iran," *Proceedings of the Interim Meeting of the ICOM-CC Metals Working Group*, September, 5-9, 2022, Helsinki, 2022, 231-239.
- Oudbashi, O., Wanhill, R.J.H. (2021). Long-term embrittlement of ancient copper and silver alloys. *Heritage* 2021, 4, pp. 2287-2319. DOI.ORG/10.3390/heritage4030130
- Oudbashi, O., Agha-Aligol, D., Mishmastnehi, M., Barnoos, V. (2019). The Elamite metalworkers: multianalytical study on copper objects and ingots from second millennium BC of southwestern Iran, *Archaeological and Anthropological Sciences*, 11, 2059-2072
- Oudbashi, O., Naseri, R., Heidarpour, B., Ahmadi, A. (2019). Study on the corrosion mechanisms and morphology of archaeological bronze objects from a Bronze Age graveyard in Southwestern Iran. In *Metal 2019, Proceedings of the Interim Meeting of the ICOM-CC Metals Working Group*, Chemello, C., Brambilla, L., Joseph, E. (Eds.), International Council of Museums – Committee for Conservation (ICOM-CC) and Haute École Arc Conservation-restauration (HE-Arc CR), 2019, pp. 150-157.
- Oudbashi, O., Hasanpour, A., Jahanpoor, A., Rahjoo, Z. (2017). Microscopic and microanalytical study on Sasanian metal objects from Western Iran: A case study. *STAR: Science & Technology of Archaeological Research*, 3, pp. 194-205.
- Oudbashi, O., Hasanpour, A., Davami, P. (2016). Investigation on corrosion stratigraphy and morphology in some Iron Age bronze alloys vessels by OM, XRD and SEM-EDS methods. *Appl. Phys. A.*, 122:262. (11 pages): DOI: 10.1007/s00339-016-9793-4
- Oudbashi, O., Davami, P. (2014a). Investigation on Manufacturing Process in Some Elamite Copper Alloy Artefacts from Haft Tappeh, South-west Iran. *Microscopy and Microanalysis*, 20 (Suppl 3), pp. 2034-2035.
- Oudbashi, O. Davami, P. (2014b). Metallography and microstructure interpretation of some archaeological tin bronze vessels from Iran. *Mater. Character.*, 97, pp. 74-82.
- Oudbashi, O., Emami, S.M., Ahmadi, H., Davami, P. (2013). Micro-stratigraphical investigation on corrosion layers in ancient Bronze artefacts by scanning electron microscopy energy dispersive spectrometry and optical microscopy. *Herit. Sci.*, 1: 21. (10 pages). DOI: 10.1186/2050-7445-1-21

- Oudbashi, O., Emami, S.M. A. (2010). note on the corrosion morphology of some Middle Elamite copper alloy artefacts from Haft Tappeh, South-West Iran. *Stud. Conserv.*, 55 (1), pp. 20-25.
- Papadopoulou, O., Vassiliou, P., Grassini, S., Angelini, E., Gouda, V. (2016). Soil-induced corrosion of ancient Roman brass – A case study. *Mater. Corros.*, 67 (2), pp. 160-169.
- Papapelekanos, A. (2010). The critical R.H. for the appearance of “Bronze Disease” in chloride contaminated copper and copper alloy artefacts. *E-Conserv. Mag.*, 13, pp. 43-52.
- Park, J.S., Park, C.W., Lee, K.J. (2009). Implication of peritectic composition in historical high-tin bronze metallurgy. *Mater. Character.*, 60 (11), pp. 1268-1275.
- Piccardo, P., Mille B., Robbiola, L. (2007). Tin and copper oxides in corroded archaeological bronzes. In Corrosion of Metallic Heritage Artefacts, Investigation, Conservation and Prediction for Long-Term Behaviour; Dillmann, P., Béranger, G., Piccardo, P., Matthiesen, H., Eds.; European Federation of Corrosion Publication 48; Woodhead Publishing: Cambridge, UK, pp. 239-262.
- Pollard, A.M., Batt, C.M., Stern, B., Young, S.M.M. (2007). *Analytical Chemistry in Archaeology*, Cambridge university Press, Cambridge.
- Quaranta, M., Sandu, I. (2010). On the Degradation Mechanism under the Influence of pedological Factors Through the Study of Archaeological Bronze Patina, “Alexandru Ioan Cuza” University of Iași Publishing House, Iași.
- Robbiola, L., Portier, R., A. (2006). Global approach to the authentication of ancient bronzes based on the characterization of the alloy-patina-environment system. *J. Cult. Herit.*, 7 (1), pp. 1-12.
- Robbiola, L., Blengino, J.-M., Fiaud, C. (1998). Morphology and mechanisms of formation of natural patinas on archaeological Cu–Sn alloys. *Corros. Sci.*, 40 (12), pp. 2083-2111.
- Robbiola, L., Fiaud, C., Harch, A. (1994). Characterisation of passive layers of bronze patinas (Cu–Sn Alloys) in relation with the tin content of the alloy. In European Federation Corrosion Publication, No 12, Marcus, P., Baroux, B., Keddad, M., Eds.; The Institute of Materials, London, UK, pp. 150-154.
- Robbiola, L., Fiaud, C. (1993). Corrosion structures of long-term burial Cu–Sn alloys: Influence of the selective dissolution of copper. *Ed. de la Revue de Métallurgie*, 6, 157-162.
- Rousaki, A., Moens, L., Vandenaabee, P. (2018). Archaeological investigations (archaeometry), *Physical Sciences Reviews*, 3, pp. 20170048.
- Saraiva, A.S., Figueiredo, E., Águas, H., Silva, R.J.C. (2020). Characterisation of archaeological high-tin bronze corrosion structures, *Stud. Conserv.* DOI: 10.1080/00393630.2020.1857523
- Scott, D.A. (2002). *Copper and Bronze in Art: Corrosion, Colorants and Conservation*; The Getty Conservation Institute, Los Angeles.
- Scott, D.A. (2000). A review of copper chlorides and related salts in Bronze corrosion and as painting pigments. *Stud Conserv.*, 45, 39-53.
- Scott, D.A. (1990). Bronze disease, a review of some chemical problems and the role of relative humidity. *J. Am. Inst. Conserv.*, 29, pp. 193-206.
- Scott, D.A. (1985). Periodic corrosion phenomena in bronze antiquities. *Stud. Conserv.*, 30 (2), pp. 49-57.
- Scott, D. A., & Schwab, R. (2019). *Metallography in Archaeology and Art*, Cham, Switzerland: Springer Nature.
- Selwyn, L.S. (2006). Corrosion of metal artifacts in buried environments. In *ASM Handbook Volume 13C, Corrosion: Environments and Industries*; ASM International, Materials Park, OH, USA, pp. 306-322.
- Selwyn, L.S. (2004). *Metals and Corrosion: A Handbook for the Conservation Professional*. Canadian Conservation Institute, Ottawa.
- Stuart, B.H. (2007). *Analytical Techniques in Materials Conservation*, Wiley.
- Taube, M., Davenport, A.J., King, A.H., Chase, W. (1996). Selective dissolution in copper-tin alloys: Formation of corrosion-resistant patina on ancient Chinese bronze mirrors. *MRS Proc.*, (432), pp. 283-288.

- Thickett, D., Cheung, C.S., Liang, H., Twyde, J., Maev, R.G., Gavrilov, D. (2017). Using non-invasive non-destructive techniques to monitor cultural heritage objects. *Insight - Non-Destructive Testing and Condition Monitoring*, 59(5), pp. 230-234.
- Varella, E.A. (2013). Conservation Science for the Cultural Heritage: Applications of Instrumental Analysis, Springer.
- Vink, B.W. (1986). Stability Relations of Malachite and Azurite. *Mineralogical Magazine*, 50, 41-47.
- Wanhill, R.J.H., Oudbashi, O. (2023). Fractography of ancient metallic artifacts: archaeometallurgical fracture analysis and restoration and conservation aspects. In ASM Handbook Volume 12, Fractography, Second Edition; Schroeder, C.J., Parrington, R.J., Maciejewski, J.O., Lane, J., Eds; ASM International, Materials Park, Novelty, OH, USA.

CHAPTER 16

PHOTOGRAMMETRY DATA PROCESSING FOR THE DETECTION AND CONSERVATION OF THE MAYA HERITAGE IN THE TROPICAL ENVIRONMENT OF EL PETÉN, GUATEMALA

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Abstract

A survey using a vertical take-off and landing (VTOL) unmanned aerial vehicle (UAV) equipped with a light detection and ranging (LiDAR) sensor and a red, green and blue (RGB) oblique camera was carried out in April 2022 by the University of Jaén in Spain and the University of San Carlos de Guatemala in the tropical forest of El Petén, Guatemala, in the Yaxhá-Nakum-Naranjo National Park, with the participation and expertise of a German company from Munich. This chapter illustrates the various stages of the expedition and the results of the high-resolution data acquired, processed and interpreted. This highly advanced technology allows direct georeferencing of the two data sets, LiDAR and RGB, facilitating data processing. The aim of the expedition was to detect ancient settlements of archaeological importance in a park of 38,000 ha, largely inaccessible, to validate and compare the results already obtained by other archaeologists, even without the use of LiDAR. We also tested the hypothesis of the importance of LiDAR in a tropical environment, where vegetation covers the pyramids and hides archaeological remains and the caliza stone benches used to build the monumental acropolises of the three parks. The spatial scale connects large, monumental pyramids with small settlements covered by earth and tropical vegetation to form a continuous landscape, like a palimpsest, where we can also detect vegetation biodiversity and significant remains. The high-resolution data also gives us hope for the development of virtual restoration and remote 3D models for local and global tourists. The chapter highlights the challenges of using this competitive technology and its relative benefits in an environment with many anthropogenic and environmental threats.

Keywords: LiDAR, Maya Archaeology, VTOL drone, Photogrammetry, conservation

1. Introduction: what was previously known

Light detection and ranging (LiDAR) technologies are creating a paradigm shift in conservation sciences. Nowadays we can observe our earth's surface continuously at spatial resolutions that enables our measurement surveys to transition from samples, like monuments and pyramids to continuums, like landscapes. Archaeologists have so far mainly used LiDAR sensors carried on aircraft and not remotely piloted (Canuto et. al., 2018) as happens instead with the unmanned aerial vehicle (UAV) and specifically with vertical take-off and landing (VTOL) drones beyond the pilote's line of sight. What does this type of detection involve? In our experience, the VTOL marks a small revolution in survey methods, which are traditionally linked above all to airborne scanning, in addition to terrestrial laser scanning or satellite data. The VTOL involves observing processes, patterns, and changes in large areas of the landscape, much faster and with a higher spatial resolution because the height from which the sensor looks at the landscape is reduced. Therefore, the resolution is also better. For the conventional airborne model, the resolution is of the order of 30 cm, while for VTOL drones, it is of the order of 2 cm. With the airborne method, archaeologists can cover entire regions, however, using a VTOL drone is cheaper and easier. Thus, by balancing the ease of detection and the time to cover a given area, the VTOL drone is more advantageous than the airborne method, because of its simplicity to fly and resulting less expensive in terms of human resources. That is how our expedition to Guatemala was organized, in April 2022, thanks to the expertise of the German company Quantum Systems of Munich and the Universities of Jaén, Spain, and the University of San Carlos de Guatemala. The area under investigation was the archaeological park "El Triangulo Cultural," including the Mayan sites of Yaxhá, Nakum, and Naranjo (Fig. 1).

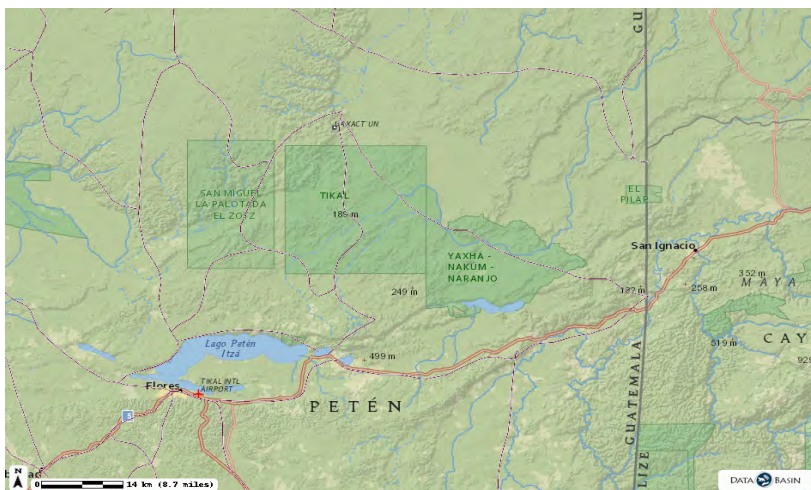


Figure 1. Geographic boundaries of the park "El Triangulo Cultural," Guatemala.

1.1. Area mission with VTOL

All three sites are monumental, even if from different historical periods, and include hundreds of minor sites scattered throughout the landscape and poorly surveyed. The area is located in the north of the El Petén region, on the border with Belize and not far from the monumental site of the more famous Tikal. The whole area is part of a national park and the UNESCO Mayan Biosphere and is a Ramsar site due to the numerous wetlands recognized as internationally significant. The objective of the mission was to identify transects to fly over (Fig. 2).

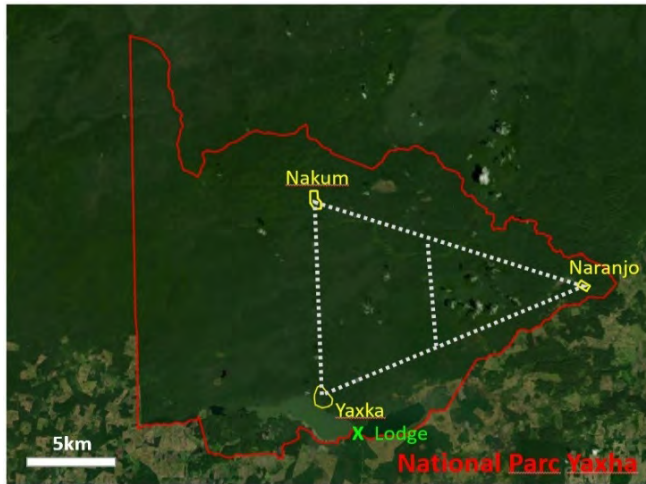


Figure 2. Survey areas.

Given the time constraints (i.e., only 5 days were available), covering the entire 38,000 square metre park area was impossible. The chosen technology was LiDAR, mounted on the Trinity +90 fixed-wing drone (Fig. 3).



Figure 3. VTOL Trinity+90 ready for the survey.

Additionally, we employed an oblique chamber equipped with red, green, and blue (RGB) sensors. We intended to gain a better understanding of the places, almost inaccessible on foot and covered by dense tropical vegetation. More specifically the objectives of our study can be summarised as follows:

- to detect new potential archaeological heritage through canopy vegetation, to better understand the human–environment relationship.
- to quantify, through LiDAR data, possible measures of conservation and to assess the challenges to preserving Mayan architecture.
- to apply our results to educational content.
- to evaluate virtual reality and remote applications with the obtained RGB real models.

Table 1. Mission Parameters	
Survey Size	1900 Ha
Duration	5 days
Number of Flights	12
Flight Speed	20 m/s
Altitude	90 m
Equipment	Trinity+90 Qube 240
Survey Targets	Yaxhá area 93,17 Ha Nakum area 49,52 Ha Naranjo area 22,37 Ha 3 transects 15 km* 300 m width

Table 1 displays the parameters for the mission while Fig. 4 demonstrates the correlation amongst primary parameters, including the ground level altitude and the examined points’ velocity and concentration. The study necessitates the pre-determination of these parameters, as the mission’s triumph and primitive data accuracy hinges upon them. Moreover, the application of suitable classification algorithms will be executed for exhaustive post-processing of the data at the end of the mission.

2. LiDAR for archaeology

LiDAR technology has been used successfully in archaeology for at least 25 years, especially where vegetation, as in our case in the tropics, constitutes a serious obstacle to detection. Indeed, the advantage of the laser beam is that it penetrates deeply through the foliage of the canopy. Lidar reports the spatial coordinates of targets at different heights in a 3D cloud of points: at ground level, at the height of shrubs and low vegetation, and up to that of the canopy

Point density by ground speed and altitude.

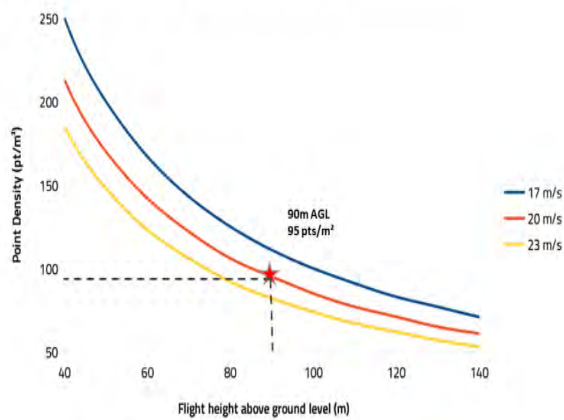


Figure 4. Parameters of flight and relationship.

and monuments. From the difference between the canopy height target and the ground elevations, we can obtain the vegetation profile in the form of both 3D and 2D data. In the case of the Maya biosphere, there is a long literature illustrating the successes of local archaeologists, often associated with university missions (Chase A. et al. 2013; Chase A. et al. 2020). They have used LiDAR to fly over large areas and map archaeological remains; that would take months to map using other instruments, such as the total station. Extensive causeways and settlements have been found between the monumental pyramids, leading to the conclusion that the population of these sites was far greater than previously thought. Many of these missions are still ongoing and welcome enthusiastic staff and student researchers from all over the world. In our case, instead of airborne LiDAR, we used a particular type of UAV, the VTOL, which allowed us to collect useful results both in a short time and with a considerable saving of economic resources. Therefore, we can affirm that the remarkable result of our LiDAR survey was to obtain high-resolution topography of large landscapes in a few days and with precise georeferencing. Our survey with the LIDAR adds to the many that already exist in El Petén, even if not in El Triangulo Cultural. Conferences, publications, and workshops provide opportunities for comparison, but, to date, there is no public LiDAR database for archaeology in Mesoamerica that provides inter-regional samples.

Figure 5 presents a mapping of all LiDAR surveys (Canuto M. 2022) conducted in the El Petén region over a decade-long period from 2009 to 2019, even if they did not strictly cover the cultural triangle area; however, these data are still private.

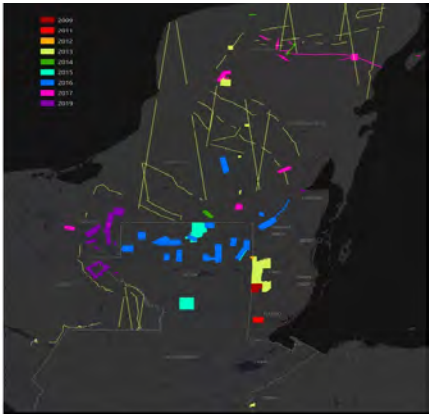


Figure 5. LiDAR airborne flights between 2009 and 2019.



Figure 6. Specifications of the survey with the Trinity +90.

In Figure 6, the results of our flights are reported. Previously, to prepare for our scientific mission to Mayan land, we also analyzed numerous satellite images obtained from passive sensors (Landsat, Sentinel, Pleiades). Undoubtedly, we obtained an excellent preliminary environmental framework, however, we could not explore the archaeological remains’ landscape in greater depth. In this part of the world, where vegetation prevails, the satellite image aided our comprehension of the importance and relationship of some natural resources, such as the Holmul River (Fig.7), in relation to monumental archaeology. Nevertheless, we discerned that to attain a profound understanding that surpasses even minor archaeology’s spatial scope, we necessitated the assistance of active sensors, such as LiDAR.

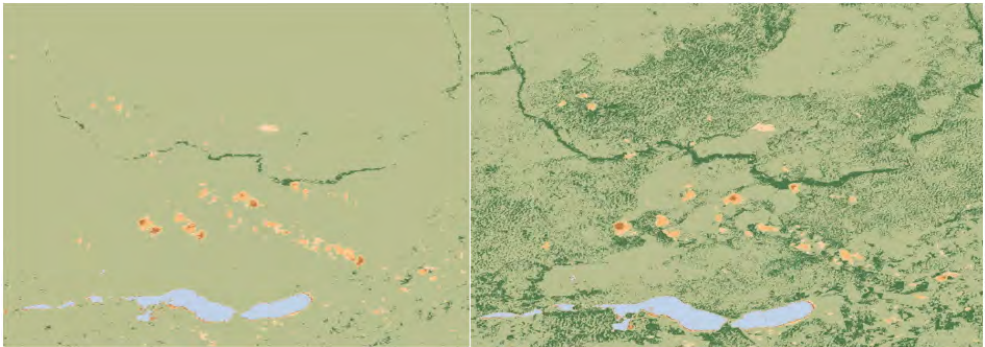


Figure 7. Two satellite images of the Holmul River which borders the ancient Nakum.

Our aim was to comprehend the spatial connection between the monumental structures and the minor ones, which are still covered by tons of vegetation and earth (Fig. 8), in terms of a deep human–environment relationship. Many of these sites are in a precarious state of conservation,

and we also wanted to deepen this aspect, in order to be able to dialogue with the park managers and establish conservation priorities. Moreover, digitising cartography for a significant portion of the park will enhance our ability to define the term “archaeological site” in this area of the world, where looting, human neglect and abandonment, and widespread environmental threats deprive the local populations of even their intangible heritage which, in contrast, UNESCO (Consejo Nacional de Areas Protegidas, CONAP) would like to protect and hand down to future generations.



Figure 8. Unexcavated archaeology.

The master plan for the “El Triangulo Cultural” park is a document prepared by CONAP that must be renewed at least every five years. It outlines not only proposals, recommendations and goals, but also aspirations to be pursued, providing motivation toward local communities, several of which have substantial tropical forest areas under concession (Bocci C. et al., 2018). However, the plan has an inadequate understanding of what is meant by an “archaeological site.” It reports extensive descriptions of the best-known monumental sites and some minor sites too. However, numerous geographical coordinates require rectification, conflicting with those from other sources. The local archaeologists have reported many drawings for some more minor settlements, based on intuitive volumetric arrangements discovered on-site. The master plan is, therefore, more a list of the present archaeology than a plan for managing and using archaeological sites. Indeed, the term “fruition” (from researchers and tourists’ side) is inappropriate, as even some major areas, such as Nakum, connected with a carretera of about 15 km to Yaxhá, are unreachable for most of the year. Despite the increase in tourists in recent years, supervision is still insufficient, and making use of the park’s archaeology is entrusted to courageous tourists’ free and impromptu initiative. The master plan indicates the main anthropogenic and environmental dangers that threaten these sites’ integrity and represent a

tool for comparison and dialogue for researchers who, like us, have the ambition to analyze these places (Table 2).

Table 2. Plan Maestro de la Reserva de la Biosfera Maya (CONAP)	
Anthropogenic threats	Environmental threats
Looting or predation	Forest fires
Poorly planned infrastructure	Weathering
Frontier advancement and agricultural practices and livestock	Uncontrolled growth of vegetation
Exploration and exploitation of petroleum	
Uncontrolled public use	
Inadequate interventions	
Illegal taking of materials and wood	

If the Maya thrived in the rainforest and mastered the use of all available resources in a hostile environment, we, the people of the 21st century, cannot claim the same adaptation. Precisely the inaccessibility due to the forest and the floods of the Holmul River, also due to anthropogenic causes, has favored the exploitation still not sufficiently controlled by the vigilantes. On the contrary, we direct our interest not only to individual monumental architectures but also to numerous interstitial settlements, which, once mapped, will reveal to us this civilization’s way of life (Fig. 9).

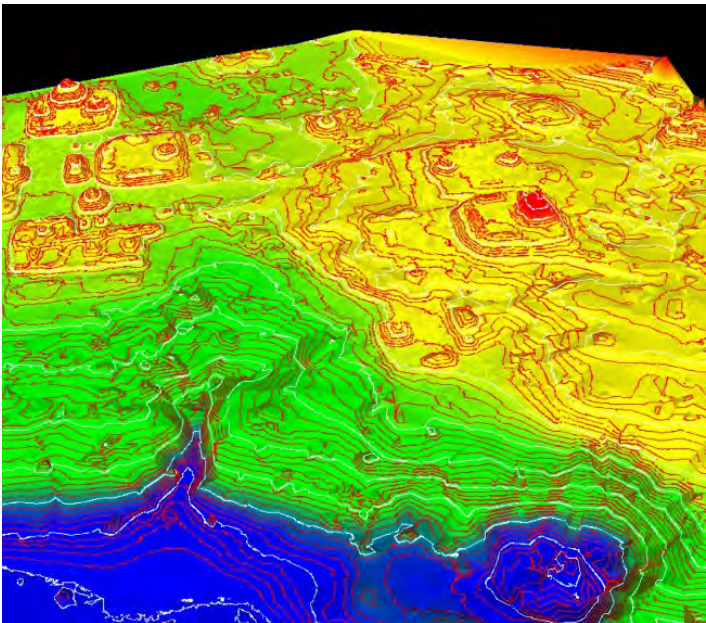


Figure 9. Yaxhá LiDAR map extrapolation.

2.1. History and description of the main sites and survey

With the purpose of advanced knowledge of the site and as a preliminary to our survey, we summarize the main historical news of the investigated monumental sites in Table 3. This research will be used for the stratigraphic characterization that we will insert in the 3D models drawn up on the results of the RGB photogrammetric data.

One of the questions we asked ourselves while addressing this survey was the purpose of the cartography we intended to acquire; what we risked losing by leaving out and by omitting, and whether this was a project that would be well served by LiDAR or photogrammetry alone, or whether the ground survey could achieve the proposed objective just as well, but at a lower cost (Fig. 10).

Indeed, the architecture is static but the nature around it is very dynamic and what we lose with a map, even in 3D, is greatly understandable with video representations, not excluding the soundscape of nature, which gives us a better understanding of the importance of preserving the forest; we acknowledge that conservation, maintenance, and restoration of architectural heritage require a multidisciplinary approach, even with a digital virtual representation (Fig. 11)

Table 3. Description and history of the main sites				
	Main Features	Archaeological and Ecological Features.	Date of site occupation	Restored Buildings
Yaxhá lagoon	Extension of about 7 square kilometers, maximum depth of 17 m. Vegetation of the dry savannah, with some species of acacias, brambles, and thorny weeds.	An important site for the reproduction and nesting of fish and birds. Cenotes and karst landscape.	back to 700 BC.	
Yaxhá	Located on the north shore of the homonymous lagoon	Ten architectural ensembles comprising more than 500 structures and covering an area of 3 km ² . Many acropolizes are connected by roads. The tallest is Structure 216, and the two solar observatories (Plaza B and Plaza F).	The occupation of the site dates back to 700 BC. and more than 30 stone monuments have been recorded, covering a period between AD 357 and 796.	Known since 1904. Nowadays the site has 14 restored buildings. the main studies have been conducted by the Yaxhá, Nakum, Naranjo/ PROSIAPETEN Triangle Project since 1989.

Topoxé	Located on an island in the southwest sector of the Yaxhá lagoon, surrounded by the islands of Paxté, Canté, and Jacalté, which also contain pre-Hispanic settlements.	Topoxte counts about 100 structures, among which building C, the main temple of the central plaza stands out. Although the main occupation of Topoxte is Postclassical, there is evidence from the Preclassical and an important Late Classical tomb (Site 49) where important jade, bone, and shell offerings were discovered.	The occupation of these islands is mostly of the Postclassical period.	This site has been known since 1831 and has been excavated since 1970.
Nakum	Nakum is located on the banks of the Holmul River and its epicenter, covering 0.5 km ² , comprises some 200 structures arranged in two large main clusters joined by a roadway, on a north–south axis. The South Group is the most important, composed of an acropolis-type ensemble and several squares around it, which include the Central Square. The site is located about 15 km from Yaxhá, to which it is connected by a dirt road that is not always easily passable.	In the Central Square, building A stands out, with a crest with three towers and false round arched vaults. It and building C formed a solar observatory. In the acropolis, building D stands out, with 44 rooms, and building E and building G are the tallest on the site. Nakum was first reported in 1905 and has been formally investigated since 1994. Currently, 15 buildings have been restored and a Middle Preclassical to ninth-century AD occupation has been defined.	The site contains three inscribed stelae (AD 771 and 849) indicating that this site was probably independent of other larger centers such as Naranjo or Yaxhá at the end of the Late Classical period.	Nakum was first reported in 1905 and has been formally investigated since 1994. Currently, 15 buildings have been restored and a Middle Preclassical to ninth-century AD occupation has been identified.
Naranjo (Sa'al)	One of the largest archaeological sites in the entire Maya Biosphere Reserve, and one with a great history inscribed in stelae and other monuments. Strategically located between the Holmul and Mopán rivers, its settlement comprises a large residential area of 5 km ² with more than 2,000 mounds.	Its epicenter covers 3 km ² and has about 350 larger structures mainly distributed in 6 acropolis-type clusters and several squares, where there are temples, palaces, ball courts, astronomical complexes, and a road. In the Main Square, the structures B-15 (Palace), B-18, and B-20 (Group E) and the triadic acropolizes D1, B5, C9, and C10 stand out. Pyramid C9 is the tallest on the site, rising to 34 m. 49 stelae, altars, and inscribed panels were also recorded, as were a hieroglyphic stairway and a ball game marker. Naranjo produced a distinctive style of polychrome vases.	Studies have revealed occupation between 600 BC and 830 AD, and their inscriptions show its prominent political role in the classical period.	Known since 1905, it is a heavily looted site. Formal investigations began in 2002. The site suffers from a strong history of predation, especially the large-scale theft of its stone monuments in the 1970s and 1980s. Recently, the site has been restored, especially the palace complex B-15 and the pyramid B-18.

Holmul River	It originates from the mountains north of Lake Macanché, and runs for 120 km to the border of Guatemala and Belize, where it takes the name of Río Bravo; flows into the Caribbean Sea, passing through Yaxhá, Nakum, Naranjo National Park.	Composed of many seasonal pools and shallow sectors, because its slopes are sedimented due to inadequate road planning for the extraction of wood, known locally as trocopás, which altered the bed, producing numerous annual floods.	It was formerly the port of the city-state of Nakum.	



Figure 10. RGB Camera survey.

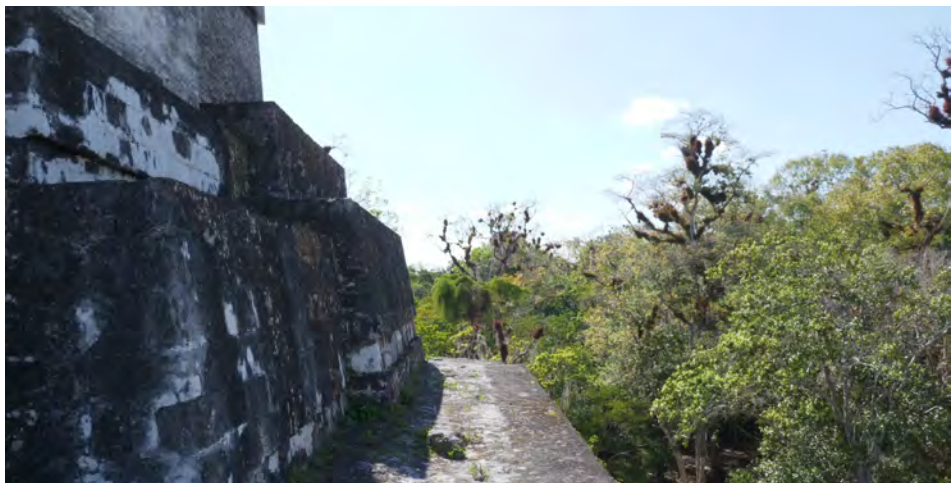


Figure 11. Architecture and sacred natural environment.

2.2. Conservation issues

Integral and multidisciplinary 3D models, faithful to reality, are advantageous and indispensable for the conservation and management of heritage to be understood in this way. The photogrammetric technique, used for the three main acropoleis complements that of LiDAR.

The disappearance of the natural environment has a direct effect on the loss of traditions, gastronomy, medicinal knowledge, and agricultural systems. It is not only a question of deforestation (albeit undoubtedly relevant on a global scale as well), it is a question of the loss of relationship with the wood, which was the main cause of the disappearance of a large part of the traditional culture that lived there, as well as its roots in the Mayan culture and the cosmovision which developed and lived together with the forest.

At the end of the mission, we proceed with the post-processing of our LiDAR data, to classify and validate the mapping of the main acropolis with the aim also to produce “transformative information” (Fig. 12).

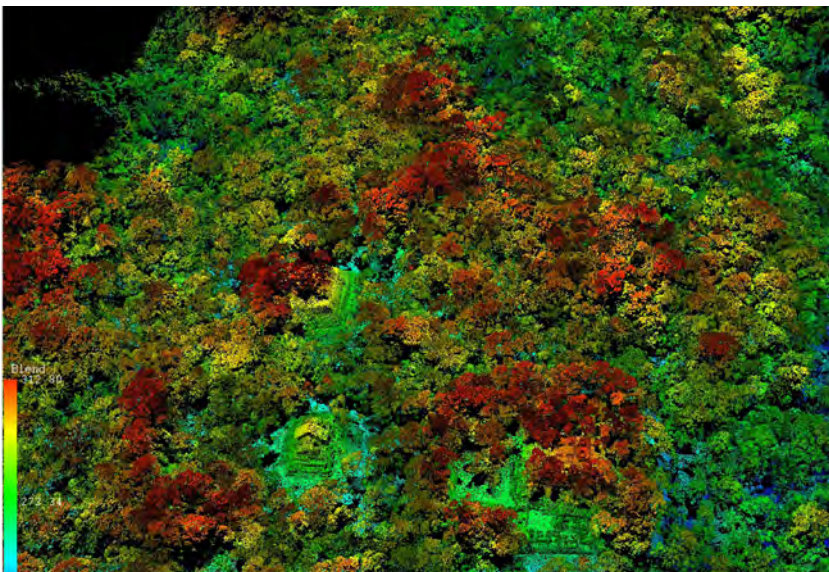


Figure 12. Post-processing of the LiDAR data for Naranjo.

With the classification of the cultural and ecological context of the samples, our data may provide an opportunity to evaluate different approaches to archaeological sampling and transformative information about previously undocumented archaeological sites and regions (Fig.13).



Figure 13. Mounds to be excavated.

What does the term “transformative information” mean? In general, we could argue that transformative information refers to knowledge or data that have the potential to bring about significant changes or transformations in the lives, perspectives, and behaviors of people, in this case, the viewers of our case study. It is information that has the power to influence decision-making, change opinions and inspire action. LiDAR has enabled us to research both monumental and minor sites, detecting ground anomalies and aiding in the understanding of Mayan civilization’s organization. In a next phase, we will further examine the significance of the spatial distribution of mounds and alignments, as well as shifts in alignments from the monumental core, to establish links between monuments and the wider settlements. This can be achieved through the precise microtopography facilitated by LiDAR VTOL (Figs.14, 15).

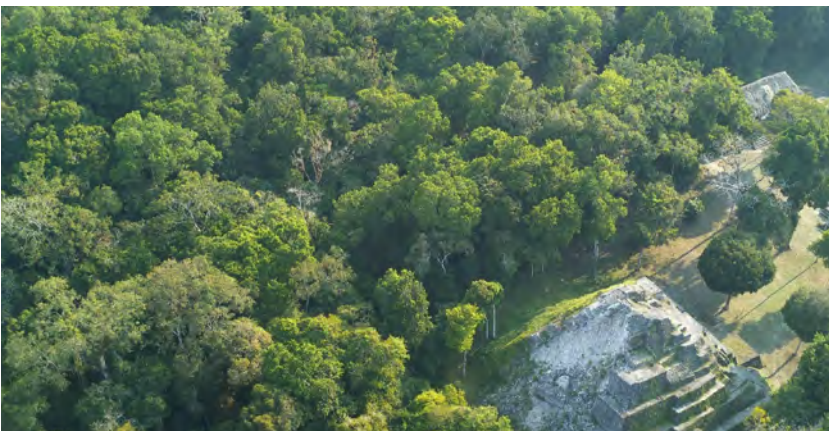


Figure 14. Mapping and calculation of volumes of the mounds for management and vegetation control.

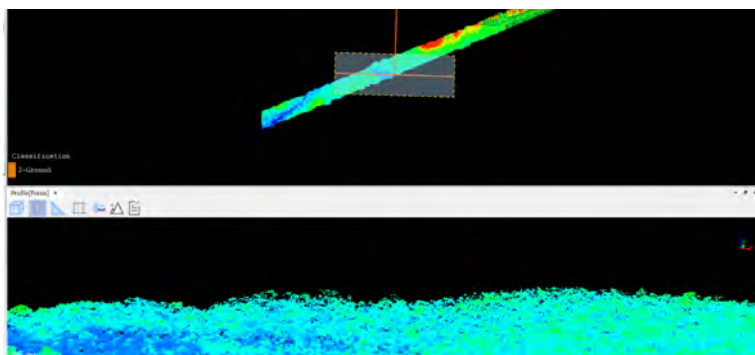


Figure 15. Water canals are hidden by the tropical vegetation but revealed by LiDAR.

Once the point cloud was classified, the next step was to create Digital Elevation Models (DEMs) and search for ‘anomalies’, possible areas of archaeological potential that had previously been hidden by vegetation. Digital Elevation Models (DEMs) show the elevation of the terrain at each point, allowing a detailed representation of the area and the distribution of archaeological sites. LiDAR DEM analysis may also contain possible ‘false positives’, i.e. survey anomalies that only appear to be of archaeological interest. Therefore, the data must be validated in the field; after classifying the point cloud, the next step was to create DEMs in order to locate “anomalies,” potential areas of archaeological interest that were previously obscured by vegetation. DEMs provide detailed representations of the terrain’s elevation at every point, thereby facilitating accurate depiction of the area and identification and distribution of archaeological sites. The LiDAR-derived DEM analysis may contain “false positives,” which are survey anomalies that may appear to have an archaeological significance. Validation of false positive data must be validated on the ground, and this stage can only be partially bypassed, even with future technological advances in LiDAR (Fig. 16).

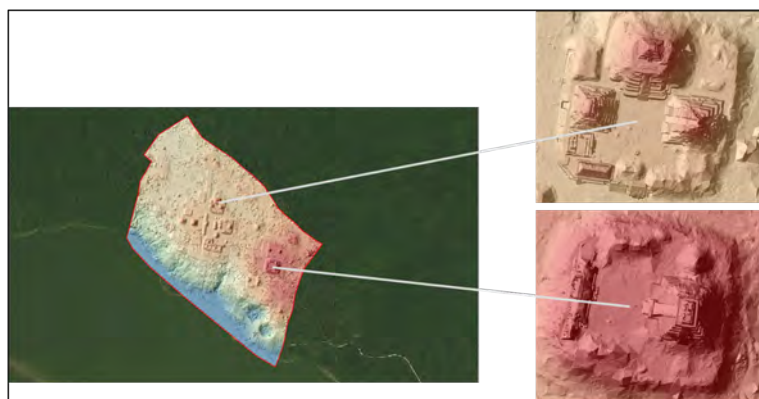


Figure 16. DEM elaboration and enhanced visualization.

3. What do our achievements signify and where and how can further progress be made in the field?

By comparing the cartographies that derive from the results achieved, with those of local archaeologists who have been on-site in the past and have published their results (Fig. 17), we report how our topography is accurate and precise, just as the georeferencing is precise, notably in contrast to the sources analyzed before the survey. This is a practical result from which the scientific community will undoubtedly benefit, as a more rigorous and higher-quality basis for study. Returning to the work, from an individual point of view, the study of the micro-topographies, the tumuli between one pyramid and another, is noteworthy and helps us to configure the spaces better, also giving proposals and suggestions for different kinds of users. What do these tumuli consist of? Can they constitute valid additional research for spatial pattern analysis? If applicable, do these spatial patterns indicate planning activities beyond the monumental core of the Pyramids? Otherwise, in what areas of archaeology can they demonstrate progress? How might these sites be properly investigated in the future? (Fig. 18).

With these data, we can establish the relevance of the spatial distribution of mounds and alignments and shifts. The alignments from the monumental core establish the link between monuments and wider settlements and give meaning to the archaeological site definition. LiDAR and photogrammetry help the conservation of archaeology through the monitoring of vegetation and improving relative control and management. For possible further analysis, we propose the application of segmentation and deep learning techniques with or as an alternative to predictive models (Carleton W.C. et al. 2017).



Figure 17. Nakum cartography by previous archaeologists and by LiDAR survey.



Figure 18. Interstitial spaces between monumental pyramids.

3.1. LiDAR and deep learning

Deep learning is a machine learning technique with appropriate algorithms that analyze large amounts of data, the so-called big data, to find common patterns in very large cartography on a regional scale, such as our landscape. Establishing relationships between these patterns can then be seamlessly combined with the LiDAR point cloud for a greater understanding and analysis of archaeology. Especially if we are dealing with complex sites, such as that of the Selva Maya, LiDAR can create high-resolution 3D models, and deep learning with appropriate software can be applied both onto 2D data, obtained from DEMs and, also, as with the e-cognition software, directly to 3D data. It is possible to train the deep learning neural network to find in the vast landscape we wish to consider, the prearranged shapes that are supposed to be repeated with a certain frequency. Thus, from the noisy and shapeless 3D cloud that comes from the LiDAR data, we arrive at a recognition and a classification of the objects in a completely automatic way, greatly facilitating and speeding up the work. Therefore, we will find helpful information on the presence or absence of structures that have an archaeological value; for example, in the case of mounds, once classified the types of mounds with deep learning algorithms, we can order the program to find the objects so classified, in the broader landscape's content. Deep learning is certainly a very useful technique because it can indicate, as in our case, the presence or absence of same similar mounds and distinguish in the context what may interest us and what then deserves validation. The specialist knowledge of both the software and the scientist who writes the neural network algorithm is indispensable.

4. Discussion

LiDAR technology is increasingly being used in archaeology to produce high-resolution 3D maps of archaeological sites and cultural landscapes. This type of data can provide critical information for reconstructing the history and evolution of archaeological sites, shedding new light on the history of places. Certainly, an archaeological heritage such as the Maya, located in one of the few intact tropical forests on the planet, poses many conservation problems, also from the point of view of sustainability. In order to try to achieve adequate levels of resilience, continuous monitoring and spatial technology, as we have proposed, are required, which is a good starting point for reconstructing ancient landscapes such as those revealed through archaeology. Looking at the maps of the local archaeologists, we can see that the “reconstruction of the landscape” only concerns the monumental pyramids and, at most, a few small hills around them. Even the so-called minor sites that have been explored so far have been explored by foot, using a total station. We can therefore see that there is a certain topographical approximation to these maps (Fig. 17). However, even if they give us a fairly accurate picture of the layout of the pyramids, they do not provide a true reconstruction at a regional scale, especially at the scale of the park of this entirely cultural context. LiDAR allows us to complete these surveys, which have not yet been validated with accuracy, even if they give us the volumetric dimension. In fact, even the geographical coordinates are often imprecise, especially in the case of the so-called minor interstitial sites. LiDAR also allows us to reconstruct the landscape in its entirety, which is a remarkable result considering that one of the objectives of the master plan is not only to preserve the archaeology, but also to do so in relation to the landscape. Possible future scenarios for the use of these high-resolution models are models for virtual cultural tourism, the search for remote virtual restorations, digital products for education and park management. The scale can range from that of the object (decorations, inscriptions, stelae) to that of the landscape as a whole. The statistics included in CONAP’s master plan show that the number of tourists visiting the Cultural Triangle has undoubtedly increased significantly in recent years; the statistics show that this increase is mainly linked to the number of locals who visit the park more frequently. Tourism could stabilise or increase in the coming years if these trends are confirmed, but then tourism could become a kind of threat to the very fragile archaeology of these sites, adding to those already known (Table 2).

Therefore, it becomes essential to establish preventive conservation and protection measures also for those hidden archaeological sites that tourists could reach; it is not only mass tourism that holds our attention but also tourism made up of scholars and small groups, which could, however, create damage to poorly protected sites.

Some archaeologists use predictive models of the archaeological potential of sites (Carleton W.C. et al. ,2017), but the deep learning techniques we have mentioned are also very promising. Furthermore, often, when we talk about archaeology, we talk about sites that are protected by international treaties such as the World Heritage Convention. The protection of World Heritage requires knowledge of potential conflicts and their avoidance and appropriate implementation strategies (Hernández M. et al, 2022) Concerning the potential UNESCO World Heritage status, the candidacy was advanced for both Naranjo and Yaxhá (CONAP). However, the outstanding universal value, (OUV), was not recognized for Yaxhá, which local archaeologists restored without considering the UNESCO conservation principles. We hope that the same does not happen for Naranjo, which, despite being a smaller site, has the peculiarity of being more widespread in the land and equally important. Naranjo, like Yaxhá, enjoys the presence of water, the management of which is of specific interest for the past, as it is in all Maya sites where water management had a particular development; water was a resource considered sacred by the Maya as the anthropologist Lisa Lucero (Lucero L., 2018) acknowledges talking about Conservation Cosmology about the landscape in which the Maya lived, turning the rainforest by being a hindering factor a resource for their civilization. These fundamental cultural values, also intangible, of the past to be transmitted to future generations require the conservation not only of the archaeology but also of the surrounding landscape and, therefore, we must not only preserve the OUV but also pose the questions of how to build resilience from an environmental point of view and how to ensure that this conservation concerns the monuments and the landscape in their environmental and cultural entirety. Until now, these two types of conservation have marched on separate tracks. Just as the Maya lived by adapting to the environment that hosted them, all these so-called intangible values must be recovered and offered to tourists and scholars to build participation responsibly, and only in this way conservation become sustainable.

5. Conclusion: LiDAR and ethical considerations

Often in the critical reflections of archaeologists it has been said that publishing LiDAR detection data in open-source format can be compromising for ethical reasons (Cohen, A., Klassen, S., Evans, D., 2020.). In some countries, especially in Latin America, where the incidence of looting is high, giving excessive space to LiDAR data and publishing it in open source could increase rather than decrease these looting phenomena. It is essentially a threat arising from the misuse of the technology; in our perspective, LiDAR as an innovative spatial technology is instead an opportunity for heritage management. The implementation of management projects under the aegis of international organisations (Hernández M. et al. 2022)

means for us to strengthening vigilance through continuous monitoring and surveying with LiDAR, thus overcoming the ethical challenge and ensuring greater vigilance and, consequently, greater preservation and conservation of sites. One of them is undoubtedly the identification of research topics to encourage the development of master's and doctoral programmes, or to obtain 3D models from the point cloud for local park managers, who, with the help of the university, can carry out useful web services, even with the use of remote services. A whole series of conservation measures on the monuments, in collaboration with networks of conservators and restorers, means a higher quality of restoration and preventive conservation of monuments. The possibility to produce models, on which the results of monitoring can be reported, enable simulation tests to implement conservation measures. Concerning the preservation of the OUV, many archaeological remains are so inaccessible that it is difficult for park managers to go into the field and monitor them continuously. Thus, UAVs monitoring can undoubtedly help the management. However, we still need to start with a digital database like ours and, through a series of models, establish a dialogue with park managers to make them understand the benefits of similar digital data analysis and monitoring with UAVs. At the same time, there are changes not entirely due to human carelessness, but unfortunately due to the changing environment. There is a need to address the potential loss of heritage, which means loss of tourists and funding. Using LiDAR technology, it is easier and cheaper to reconstruct the heritage of a landscape, especially when it is vast, as in our case of Guatemala. In our view, this case study is a valid contribution to the utility of LiDAR technology in mapping whole landscapes and reconstructing archaeological and heritage assets. LiDAR is particularly useful for the discipline of spatial archaeology. This discipline interprets archaeology from a temporal perspective by analyzing space and the relationship between the components of the archaeological landscape. LiDAR allows a series of analyses that we have tried to illustrate, which can also be combined with the data that the park managers already have, such as the distribution of the different finds, discovered over the years in the different main sites, or even data about the morphology of the land. We can then link LiDAR data, at very high spatial resolution, to the soils characteristics or to climatic variations over time, or, if we link the data to historical research, we could produce maps in the geographic information system of the Maya's routes networks, establishing relationships of the various trades over the years and a better understanding of the exchanges that took place. For example, the vast territory of Yaxhá had various contacts not only with nearby Nakum and Naranjo, but also with Tikal and more distant places.

The challenge that digital archaeology presents is gaining a deeper comprehension of the archaeological context in which we operate. Innovative technologies such as the LiDAR

sensor on the UAV, as well as high-resolution photogrammetry with RGB sensors transported by UAV, offer high topographic resolution and efficient monitoring, facilitating understanding of the underlying dynamics at a cultural level. Ultimately, this leads to more effective analysis of the culture and history of this territory. Furthermore, the 3D models of the architecture and DEMs of the landscape, which are generated, will enable researchers and the wider public to share experiences and projects. Considering the significant challenges of 21st-century archaeology, the challenges resulting from new spatial technologies and the emergent research methodologies are forthcoming.

References

- Bocci C., Fortmann L., Sohngen B., Milian B.(2018) The impact of community forest concessions on income: an analysis of communities in the Maya Biosphere Reserve, *World Development*, Volume 107, Pages 10-21, ISSN 0305-750X, <https://doi.org/10.1016/j.worlddev.2018.02.011>.
- Campana S., Dabas M., Sarris A. (2018) Mapping the Past From sampling sites and landscapes to exploring the ‘archaeological continuum’ Proceedings of the XVIII UISPP World Congress (4-9 June 2018, Paris, France) Volume 8
- Carleton W.C. et al. (2017), A comprehensive test of the Locally-Adaptive Model of Archaeological Potential (LAMAP), *Journal of Archaeological Science: Reports*, Volume 11, Pages 59-68.
- Canuto M.A. et al. Ancient lowland Maya complexity as revealed by airborne laser scanning of northern Guatemala. *Science* 28 Sep 2018: Vol. 361, Issue 6409, eaau0137
- Canuto M.A. (2022) LiDAR coverage in the Maya area, <https://ancientmayasettlement.com/2022/02/12/206/> last accessed 27 Feb.2023
- Chase, A., Chase, D., Awe, J., Weishampel, J., Iannone, G., Moyes, H., Yaeger, J., Brown, M., Shrestha, R., Carter, W., & Fernandez Diaz, J. (2014). Ancient Maya Regional Settlement and Inter-Site Analysis: The 2013 West-Central Belize LiDAR Survey. *Remote Sensing*, 6(9), 8671–8695.
- Chase, A.S.Z., Chase, D. and Chase, A., 2020. Ethics, New Colonialism, and Lidar Data: A Decade of Lidar in Maya Archaeology. *Journal of Computer Applications in Archaeology*, 3(1), pp.51–62.
- Cohen, A., Klassen, S. e Evans, D., 2020. Etica nel Lidar archeologico. *Journal of Computer Applications in Archaeology* , 3(1), pp.76–91.
- Consejo Nacional de Áreas Protegidas –CONAP, <https://conap.gob.gt/> last accessed 27 Feb.2023
- Hernández M. et al (2022), Geoheritage to Support Heritage Authorities: Research Case Studies on Maya Archaeological Sites in M.-T. Albert et al. (eds.), *50 Years World Heritage Convention: Shared Responsibility – Conflict & Reconciliation*, Heritage Studies, https://doi.org/10.1007/978-3-031-05660-4_27
- Lucero L. (2018) A Cosmology of Conservation in the Ancient Maya World, *Journal of Anthropological Research* 74:3 327-359
- <https://quantum-systems.com/use-case/guatemala/>
- <https://www.ramsar.org/> last access 28 February 2023
- https://whc.unesco.org last access 28 February 2023
- <https://angkorlidar.org/bibliography/> last access 28 February 2023

SOLUTIONS AND PRACTICES

CHAPTER 17

INNOVATIVE, MULTIDISCIPLINARY APPROACH FOR RESTORING PAINTINGS IN HYPOGEAL ENVIRONMENT: ETRUSCAN *TOMBA DEGLI SCUDI* (4TH CENTURY BC) IN TARQUINIA

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Abstract

The *Tomba degli Scudi*, an important Etruscan hypogeum from the 4th-century BC, is situated in the Monterozzi necropolis of Tarquinia, Italy, and it is acknowledged as a UNESCO heritage site since 2004. The restoration of its mural paintings epitomizes an exemplary interdisciplinary collaboration, encompassing restorers, archaeologists, and scientists. As we embarked upon the restoration, collaborative discussions precipitated significant revelations in conservation, archaeology, and biology. This collaboration elucidated the conservation history, the unique execution technique, and thorough examinations of environmental parameters. The inaugural phase of this initiative was generously financed by *Fondo per l'Ambiente Italiano*, the Italian Environment Fund, and the *Soprintendenza Archeologia, Belle Arti e Paesaggio per l'Area metropolitana di Roma, la provincia di Viterbo e l'Etruria meridionale*, focusing on the atrium murals. Subsequently, murals in the sepulchral chamber were rehabilitated. Given the distinct nature of the hypogeal environment, the methodologies and material selection demand meticulous consideration, ensuring alignment with pre-Roman mural traditions in the Italic region. Simultaneously, an exhaustive historiographic assessment furnished comprehensive insights into the conservation history of the hypogeum. Rigorous analysis and restoration accuracy led to a groundbreaking revelation—depictions of human entities used modular templates for individual body components, most potentially crafted from sturdy materials. These templates, which manifested in four scales, corresponded to the hierarchical status of the depicted characters. Historically, the employment of such modular templates, termed *patroni* and *antibola*, was recognized exclusively from the early Middle Ages onward in the western and eastern art traditions, because no prior evidence of this painting modality existed. Consequently, this discovery infers that the inception of this technique predates prior assumptions by approximately a millennium, thereby refining our understanding of technological transitions from Classical Antiquity to the Middle Ages. An important and innovative aspect of this project resides in the exhaustive microbiological examination. Although the Tarquin hypogea had been intermittently probed during preceding restoration efforts, the bacterial and fungal communities, which sustain a nuanced and fragile equilibrium within these environments, had not been rigorously and holistically studied. In this endeavor, a microbiological assessment was executed before, during, and post the restoration stages. The outcomes were compared against data from other hypogea, transforming the Necropolis tombs into genuine scientific research hubs. Notably, the biological examination of the white biological deposit in the paintings was identified as moonmilk, which is an exceptional microbial-derived calcite that conserved the murals instead of impairing them. However, several preservation challenges emerged, especially regarding post-restoration disinfestation practices. Thus, a targeted study of bacterial communities yielded novel insights, heralding a new conservation approach. Concurrently, a pioneering method integrating ultraviolet fluorescence with 3D techniques was deployed. An essential dimension of the project was investigating the interplay between the preparatory strata of the paintings and the pictorial film. This discourse precipitated intriguing procedural decisions, proffering a foundation for subsequent deliberations on pictorial integration in archaeological settings.

Keywords: Restoration, Tomb, Hypogea, Etruscan, Mural Painting, Preparatory Drawing, Biodegradation, Diagnostics, 3D model, Karst phenomena

1. Introduction

The outcomes of the extensive restoration work that recovered the precious Etruscan murals from the 4th-century B.C. are discussed in this section. Rigorous experimental undertakings yielded revelations that recalibrated the conservation strategies for hypogeal settings and changed our understanding of the Etruscan mural techniques applied during its creation in the 4th century BC. The tomb under study is a distinguished Etruscan hypogeum within Tarquinia's Monterozzi necropolis, recognized as a UNESCO heritage site since 2004. As of March 2022, the site has transitioned under the aegis of the nascent Archaeological Park of Cerveteri e Tarquinia (Fig. 1a–d). Geographically, these cities align with the ancient Etruscan territories of *Caere* and *Tarchna*, nestled north of Rome, proximate to the western coastline of central Italy. Tarquinia's vast necropolis houses 6,000 rock-hewn graves, among which 200 contain painted depictions, reflecting a temporal expanse of six centuries from the 7th to the 2nd Century BC (Steingraber, 1984; 2006; Marzullo, 2017).



Figure 1. a. Necropolis of Cerveteri; b. Necropolis of Tarquinia; c. Cerveteri, *Tomba dei Rilievi*; d. Tarquinia, *Tomba della Caccia e della Pesca*.

Since the late 1980s, these painted tombs have been hermetically sealed and equipped with thermally insulating portals to maintain the requisite thermohygrometric conditions crucial for their preservation (Fig. 2 a, b). Additionally, these doors feature an antifog mechanism, enabling visitors to observe the paintings unobstructed.



Figure 2. Examples of thermally insulating doors: earliest prototypes installed (a) most recent type (b): equipped with full glass.

Temperature fluctuations—along with alterations in humidity—pose considerable threats, which are attributed to surface dehydration and internal crystallization of soluble salts. This pertains to the foundational layer, preparatory sections, and the mural facets of rock. Restricting visitor access further safeguards against inadvertent microbial introductions. Maintenance activities, executed at regular intervals, involve minimal personnel donned in protective Tyvek® attire, minimizing their duration within the hypogeum.

The restoration endeavor was initiated in June 2016. Spearheaded by the *Soprintendenza Archeologia, Belle Arti e Paesaggio per l'Area metropolitana di Roma, la provincia di Viterbo e l'Etruria meridionale* (the Office of the Ministry of Culture in charge for the protection and management of the site before the creation of the Archaeological Park) with a valuable contribution from the FAI (*Fondo Ambiente Italiano*), promoted the restoration of the walls in the *atrium* of the tomb (Fig. 3).



Figure 3. *Tomba degli Scudi*. South-east walls: before restoration (left) and after restoration (right).

2. Execution technique

The *Tomba degli Scudi*, attributed to the late Classic era (circa 340 BC), was unearthed in 1870. Notably, it remains inaccessible to the public, given its location beyond the designated visitor area of the Monterozzi necropolis. The tomb entrance is facilitated *via* an elongated dromos that converges at the central *atrium*. Positioned 10 m subterranean, the architectural design of the tomb is similar to that of a typical Etruscan domicile. A central *atrium*, equipped with a dual-incline roof and supported by a *columen*, serves as an ingress to three additional chambers of irregular quadrangular configurations. These burial chambers communicate with the *atrium* through a primary doorway flanked by twin windows (Fig. 4). Among these chambers, both the *atrium* and the primary burial section are adorned with plaster and are further embellished with mural depictions, with the ceiling of the *atrium* being ornate as well.

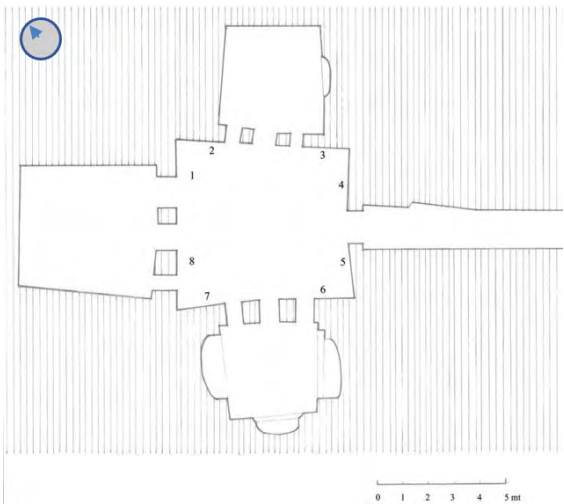


Figure 4. Plan of the tomb.

These illustrative renderings display significant exemplars of the figurative motifs characteristic of grand aristocratic tombs of that epoch. These artworks extol the stature and virtues of the *Velcha* lineage, encapsulating the pivotal moment when the departed embarks on their ethereal voyage to the netherworld, epitomized by a symbolic funeral banquet encompassing the entire familial clan (Maggiani, 2015). The art conservation endeavor within the *Tomba degli Scudi* transpired in dual stages. The inaugural phase coincided with interventions in the *atrium*, elucidating the foundational artistic methodology and the pivotal technique of transcribing preparatory sketches onto walls. The subsequent stage accentuated correlations with the concurrent milieu of pre-Roman Italic mural artistry.

2.1. Preparatory layers

The hypogeum was excavated by ancient Etruscans in a type of hybrid sandstone, termed *sabbione*. This material is devoid of adhesive cement and is solidified only through water and compression (Cirigliano *et al.*, 2021), which renders it friable and thereby simplifying excavation. Within the *atrium* and the primary burial chamber, the plaster was applied onto the rock surfaces, both on walls and ceilings, to render them uniform. The density of the plaster oscillated between 0.5 and 3 cm, with the ceiling of the burial chamber exhibiting a less refined finish. This plaster was composed of lime and *macco*, which is a porous and brittle, coarsely milled, pale-yellow calcarenite. Macco's prevalence in Tarquinia's tombs underscores its recognition and preference among artisans. It apparently supplanted sand, which is the byproduct of hypogeum excavation. This plaster façade received an overlay of white lime, discernible against the background of the murals and in the portrayal of female forms (Fig. 5).



Figure 5. Couple Velthur Velcha and Ravnthu Aprtnai, detail of the North-west wall in the *atrium*. Lime covering plaster is used as the color of background and female complexion.

In various chambers, the layers exhibited divergent thicknesses—more robust and applied with expansive brush strokes in the *atrium*, yet more slender within the Burial chamber. Despite its consistency and the lack of visible fine cracks, subsequent analysis on certain samples (utilizing gas chromatography–mass spectrometry; GC–MS) disclosed an absence of organic additives (refer to Chapter 5). Microscopic evaluations on the TSP8 sample from the *atrium* (Fig. 6 a and b) revealed the stratified coatings, commencing from the plaster—distinguished by its granular texture and the *macco*-induced yellow hue—succeeded by a streamlined, cohesive layer of white wash and the overlying paint film.

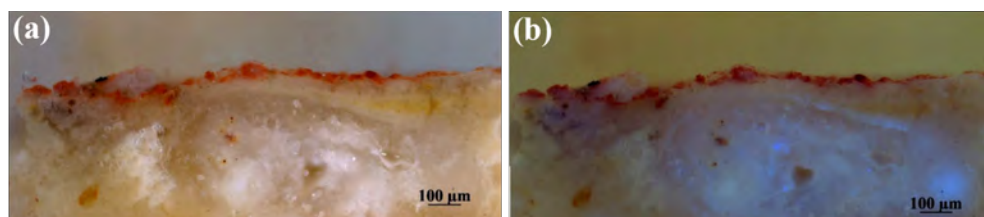


Figure 6. Microphotographs of cross-sections at 100× magnification under (a) visible and (b) UV radiation; *atrium*, north-west wall, flesh tone of the arm of *Vel Velcha*.

Historically, Etruscan mural renditions predominantly employed the *secco* method until the mid-4th century BC when the *fresco* technique was introduced. Herein, pigments, devoid of mediums or binders, were dissolved in water and layered atop a base composed of varied clays, occasionally integrated with a distinct limestone (Cecchini, 2012; pp. 159–183). The advent of lime in painting is traced back to the 5th century BC, serving primarily for crafting plasters of fluctuating thickness to standardize the foundational rock. However, during the latter half of the 5th century, lime facilitated the creation of a plaster substrate whereupon color was still applied using the *secco* method. The preservation state of these artworks attests to the rudimentary nature of this technique, perhaps representing an initial, albeit subpar, and endeavor to mimic Greek *fresco* painting technique. Since the 4th century, a preliminary layer, now forged from lime, re-emerged.

The *Tomba degli Scudi* belongs to this category; it diverges from the traditional *fresco* classification, given that the pigment adorns an already desiccated and superficially carbonated lime layer.

Although certain examples of Apulian and Lucan rock painting exhibit an earlier comprehension of Greek artistic methodologies—potentially due to their direct interactions with Greek settlements in Taranto and Paestum—in Etruria, there appears to be a more tenacious adherence to age-old techniques (Brécoulaki, 2001; Porcelli, 2021). Moreover, the

methodology employed in the tombs of the 3rd century BC, including the *Tomba dell'Orco II* (latter half of the 4th century BC)—often perceived as *fresco* artistry—warrants reevaluation in light of the presence of a lime layer.

2.2. Preparatory drawing transposition technique

During the restoration of the *atrium* walls, spanning from June 2016 to December 2018, investigations delved into the techniques employed by ancient Etruscans to transpose preparatory sketches onto walls. These inquiries sought traces of methodologies previously identified in tombs from the corresponding era, specifically any engraved marks or drawings. However, examination of the decorated surfaces within the Burial Chamber of the Shields unveiled no engraved inscriptions on the plaster. Instead, there existed a faint brush-drawn depiction utilizing a diluted red ochre.

Upon analysis, a consistent pattern among the portrayed forms in the atrium's painting was observed. Detailed examinations exposed a unique method for the transference of the preparatory layer, incorporating repetitive silhouettes or templates across various figures. Such technical augmentations have been extensively documented in Etruscan mural artistry since the 7th century BC, primarily for crafting intricate geometric or naturalistic decorative elements. Illustrative instances of these “lesser images” (Vlad Borrelli, 1991) encompass the ducks depicted in Veio's eponymous tomb, avian figures amidst garlands and ducks in the *Tomb del Cacciatore*, dolphins, and the wave *motif* in both the *Tomba dei Tifoni* and in *Tomba delle Leonesse*, respectively. The motifs discerned in the *Tomba della Scimmia* and *Tomba François* were assembled utilizing entire figures and occasionally inverted silhouettes (Bianchi Bandinelli, 1939).

In case of the *Tomba degli Scudi*, the investigation culminated in a remarkable revelation: the portrayal of human entities was achieved through templates representing individual anatomical sections. The impeccable alignment of extremities, torsos, and crania was demonstrated post the digital rectification of mural images using a prevalent photo-editing software, Photoshop (Fig. 7). Initially, our strategy explored the contours of primary figures onto transparent tracing paper, with the endeavor unfolding directly on the murals on-site. However, owing to the delicate state of the original plaster, this methodology was deemed untenable. As an alternative, digital images were comparatively evaluated on a computer interface. Captured using a full-frame Reflex camera, these high-resolution images were snapped with the camera positioned equidistant from the wall. To simulate an authentic digital workspace, the dimensions

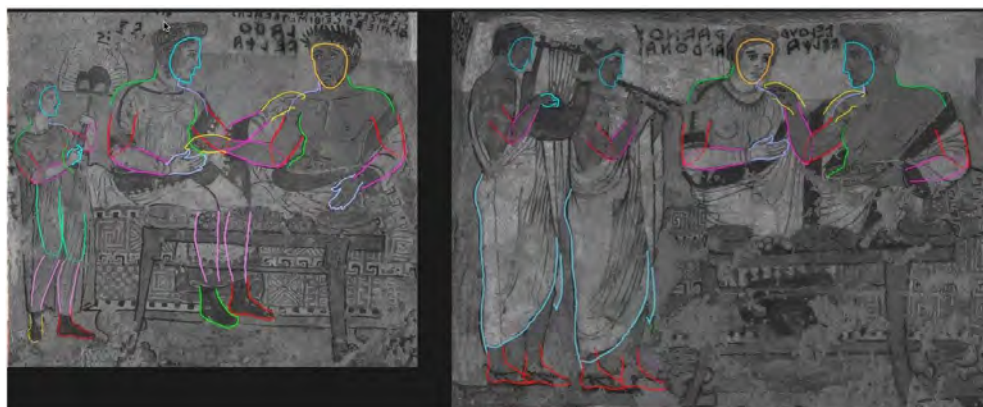


Figure 7. Left: panel 1; right: panel 2 (refer to plan p. 5). Each template of the paintings is visualized in one color.

of the murals were meticulously measured and verified in situ. Subsequent image scaling and rectification were accomplished employing Adobe Photoshop CS6.

The research underscored the likelihood that such templates were crafted from a rigid material, with each template presenting four distinct sizes. These variations reflected the hierarchical exploration of the depicted individuals (Tomassetti, Arrighi, 2019). The concept of templates, compartmentalized into individual anatomical components and tailored to illustrate varied postures, was an unprecedented finding. Historically, the deployment of modular stencils, termed *patroni* and *antibola*, has been attributed exclusively for paintings from the early middle ages onward, evident in both western and eastern artistic traditions. No antecedent instances of such an approach were documented. This revelation propels the inception of modular design techniques back by approximately a millennium, refining our comprehension of artistic methodologies traversing from Classical Antiquity through the Middle Ages (Andaloro, 2002). This discovery subsequently charts a renewed trajectory for understanding the transference techniques of preliminary sketches in Etruscan mural art. Additionally, the findings indicate a correlation with medieval practices, where template dimensions were modulated to dictate hierarchical distinctions among the illustrated subjects. Each anatomical component manifested in four scales: a standard size representing the Velcha lineage; a 65% reduction for servants, winged entities, and the custodian of the *sella curulis*; a 75% diminution for musicians; and an enlargement to 113% for the Velthur–Ravnthu pair (Fig. 8). This rigid hierarchical order was consistently maintained (Table 1).

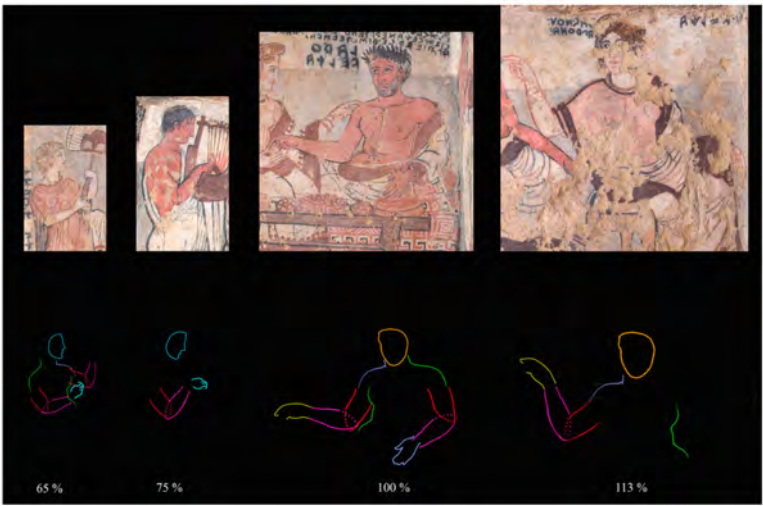


Figure 8. Different percentages scaling in servants, musicians, *Velcha*’s family and ancestors.

Table 1. Template sizes: at 100% for the <i>Velcha</i> family members, reduced to 65% for servants, reduced to 75% for musicians and increased to 113% for ancestors.				
Body Parts	Standard Size 100% (height x width)	Reduced To 65%	Reduced To 75%	Increased To 113%
Three-quarter face	15 × 10 cm	9.75 × 6.5 cm	11.25 × 7.5 cm	16.9 × 11.3 cm
Profile face	15 × 7.5 cm	9.75 × 4.9 cm	11.25 × 5.6 cm	16.9 × 8.5 cm
Shoulder A	10 cm	6.5 cm	7.5 cm	11.3 cm
Shoulder B	15 cm	9.75 cm	11.25 cm	16.9 cm
Chest profile	20 cm	13 cm		×
Forearm	15 × 7.5 cm	9.75 × 4.9 cm	11.25 × 5.6 cm	16.9 × 8.5 cm
Arm	20 × 7.5 cm	13 × 4.9 cm	15 × 5.6 cm	22.6 × 8.5 cm
Frontal hand	12.5 × 7.5 cm			
In profile hand	12.5 × 5 cm			14 × 5.6 cm
Clenched hand	10 × 7.5 cm	6.5 × 4.9 cm	7.5 × 5.6 cm	11.3 × 8.5 cm
Thigh		20 × 7.5 cm		
Calf	24 × 7.5 cm	15 × 4.9 cm		
Frontal foot	10 × 7.5 cm	6.5 × 4.9 cm		11.3 cm × 8.5 cm
Three-quarter foot	12.5 × 7.5 cm			
In profile foot	15 × 10 cm	9.75 × 6.5 cm	11.25 × 7.5 cm	16.95 × 11.3 cm
Players tunic	55 × 25 cm			
<i>Buccina</i>	50 cm (diameter) 4 cm (width)			
<i>Lituus</i>	75 cm			

The strategic utilization of these modular templates, albeit subtly discernible, was efficacious. It facilitated expeditious sketching whilst ensuring consistent imagery. Such a method empowered artisans to meticulously calibrate character proportions, with the varied limb orientations camouflaging this systematic approach. The asymmetrical arrangement of figures within the *Tomba degli Scudi* can be attributed to the artist's intent to preserve the impeccable architectural symmetry of the *atrium* (Maggiani, 2005). Distinctive template sizes also supported the intentional representation of characters based on their societal standing. Thus, servants were portrayed as subordinate to their superiors, whereas the ancestral duo of Velthur–Ravnthu was accentuated, ensuring their immediate recognition as more eminent than their progeny—a result achieved by amplifying their dimensions.

2.3. Pictorial layer

The pictorial layer is characterized by the predominant employment of a select assortment of inorganic mineral pigments, encompassing yellow and red ochre, massicot, smoke black, and lime white. From this palette, a spectrum of red, pink, and purple shades was derived (refer to Chapter 5). In certain regions, the pigment layer is denser and more robust, whereas in others, it manifests in such a fluid manner that it culminates in conspicuous, elongated drips. This disparity is primarily attributed to the frequent amalgamation of pigments with lime, especially evident in the paintings of *atrium* and more pronounced in the depiction of complexions. The integration of lime is not guided by any technical intent linked to a purposeful carbonation process; thus, it does not conform to a deliberate *pittura alla calce* technique. Instead, hydrated lime functions as a pigment additive to soften ochre hues, facilitating the generation of various pink gradations. Similarly, it contributes to crafting the light-blue backdrop behind the figures when blended with vegetable black. One can discern the pigment thickness and the *ductus* of the brush strokes, particularly in the complexions, distinguishing it from the foundational preparatory layer. Conversely, in the Burial Chamber, the pigment appears more diffuse. Examination of the cross-sectional samples (TSP-7 and TSP-2), detailed in the laboratory analysis segment of Chapter 5, highlights a clear demarcation between the paint and lime preparatory layers, demonstrating the application of the *secco* method (Fig. 9). Given the ambient conditions, a prominent re-carbonation layer overlays the paint film, ensuring the preservation of pigments that are only solubilized in water, devoid of any calcium hydroxide mixture.



Figure 9. Left: *Atrium*, the brushstrokes of the whitewash and the pictorial layer are well-visible under raking light. Right: detail of the same wall.

3. State of preservation

The *Tomba degli Scudi* is a hypogeum situated 8 meters beneath the surface, carved into a hybrid sandstone known as *sabbione*. This configuration renders it a nearly isolated, confined system. Preservation conditions within such distinctive environments vary and are highly site-specific. Predominantly, humidity and temperature emerge as critical determinants influencing decay, as they dictate salt migration and karstic processes as well as govern the growth of particular microorganisms. Thermohygrometric readings were captured during the atrium restoration and subsequently during the Burial Chamber's refurbishment. These measurements, taken across varied seasons (*atrium* during spring and summer, Burial Chamber in autumn and winter), consistently indicated environmental stability with readings of 98%–100% RH and temperatures between 17° C and 22° C. Notable deviations were typically associated with instances when the thermally insulating doors were opened. Salt migration presents a significant concern, often resulting in the dislodgement of mural painting fragments. Such deterioration typically ensues in locales susceptible to external environmental fluctuations, encompassing temperature, relative humidity, and air circulation. Another prominent degradation source for the preparatory layers stems from karst processes, intricate chemical reactions propelled by water movement. Owing to its insular nature, stagnant air, and rock foundation, the tomb harbors a highly specialized microorganism community.

Beyond natural deteriorative processes, the tomb exhibits signs of anthropogenic damage. Since its unearthing in 1870, the tomb has experienced varied footfalls, spanning conservation endeavors, multiple graphic documentation initiatives, and military activities. The inaugural documentation campaign of *lucidi* transpired between 1872 and 1873, led by Gregorio Mariani, whose records remain instrumental in mapping degradation trajectories (Capobianco et al. 2019; Porcelli 2021). During World War II, the *Tomba degli Scudi*, similar to other Tarquinian sepulchers, served as a storage facility, safeguarding invaluable ceramics from the local

museum. After the liberation of Rome in 1944, it was first utilized by the Allied forces and subsequently by the Brazilian division as a detention cell. For a comprehensive insight into the preservation status of the tomb, the following chapter will dissect the site based on the stratigraphic layers of its mural art.

3.1. Support

Given the friable and non-cohesive nature of *sabbione*, observed deteriorations predominantly stemmed from the rock inherent geological traits and anthropogenic damages sustained over the years. Several regions displayed erosion marks accompanied by minor fissures. Historically, flooding events have deposited clay-rich soil onto the base of the walls. Notably, specific chasms, penetrating through all preparatory strata, are undeniably of human origin. The distinct morphology of these gaps suggests infliction by an instrument resembling a pickaxe or bayonet.

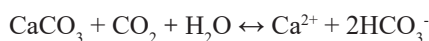
3.2. Plaster

The principal contributor to plaster degradation is the infiltration of water in its liquid form within the substrate. This invasion renders the plaster more susceptible, even making it malleable. Concurrently, a sequence of physicochemical reactions associated with calcium carbonate dissolution manifests a unique degradation phenomenon. This entails a significant depletion of calcium carbonate, inducing a mechanical frailty of the plaster and subsequent cavity formation beneath the pictorial stratum (Fig. 10).



Figure 10. *Atrium*, voids of different sizes are present underneath the pictorial layer.

Although the outermost layers largely remain preserved, the underlying plaster exhibits voids of varying dimensions, ranging from minuscule cavities to expansive hollows, undermining its structural integrity. This condition arises from a complex interplay of chemical and physical reactions, moderated by several factors that balance calcium carbonate solubilization and re-deposition. The cyclical migration of water vapor between the internal atmosphere of the tomb and the exterior of the wall might prompt partial solubilization of calcium carbonate. Additionally, it can lead to the formation of thin calcitic layers, stemming from the evaporation of walls saturated with calcium carbonate. Another distinct, localized issue is the perilous seepage of rainwater, culminating in an accentuated dissolution of CaCO_3 (Dreybrodt, 2012). In karstic contexts, the primary agents of this phenomenon are calcium carbonate (CaCO_3), water (H_2O), and carbon dioxide (CO_2). The inaugural component constitutes the primary ingredient of the plaster, whereas the latter two are omnipresent, both within the rock and the ambient atmosphere:



The outlined reaction demonstrates that CO_2 molecules, upon interaction with water, undergo a transformation into carbonic acid (H_2CO_3). Subsequently, the dissociation of this acid releases HCO_3^- and H^+ ions. These ions react with the dissolved calcium carbonate, yielding bicarbonate and calcium ions. Intriguingly, this reaction is reversible: following the acid-mediated dissolution of calcium carbonate into bicarbonate that is soluble, and therefore, readily removed by infiltrating water, the calcium carbonate may be precipitated from the solution. Nonetheless, this precipitation process is gradual and contingent on specific environmental prerequisites (Lerman & Mackenzie, 2018). Consequently, within the tomb, the plaster acts as the nexus for this chemical dynamic, resulting in a substantial reduction of calcium carbonate within the layer structure, and consequently, the loss of extensive painting sections. Calcite deposition may materialize as either insoluble patinas or dense concretions (Fig. 11).

The patina, characterized by its glassy and pale appearance, served a protective role for the painted layer in the *atrium*. Nevertheless, it induced a slight tonal lightening and, in certain instances, exhibited flaking that compromised part of its depth. Ultraviolet fluorescence (UVF) imaging conducted during the restoration phase indicated that these deposits aligned with regions exhibiting pronounced fluorescence (refer to Chapter 5). Although visually, these zones appeared unaffected, tactile examination revealed pronounced dampness. Hypothetically, these damp zones might harbor water enriched with CaCO_3 or other compounds conducive to surface carbonate precipitation.



Figure 11. *Atrium*, carbonate depositions of different nature and typology are re-deposited on the pictorial layer.

3.3. Pictorial layer

Similar to the prior layer, the pictorial layer exhibited a pronounced loss of material. This depletion originated from the detachment of the pictorial film—often aligning with voids in the layer beneath—and from elements intrinsically associated with the application technique. Specifically, the limited carbonation of the pigment rendered it vulnerable to aforementioned infiltrations and time-induced mechanical and abrasive wear, yielding color loss. Moreover, the tomb walls exhibited a biological patina, termed as moonmilk (refer to Chapter 4). Its whitish, powdery appearance is attributed to its composition: a delicate layer of calcium carbonate nanofibers (Fig. 12). Contrary to potential assumptions, this biogenic layer does not harm the paintings; rather, it apparently shielded them. Notably, a direct correlation emerged: a thicker moonmilk layer corresponds to greater conservation of the underlying pictorial layer (Fig. 13).

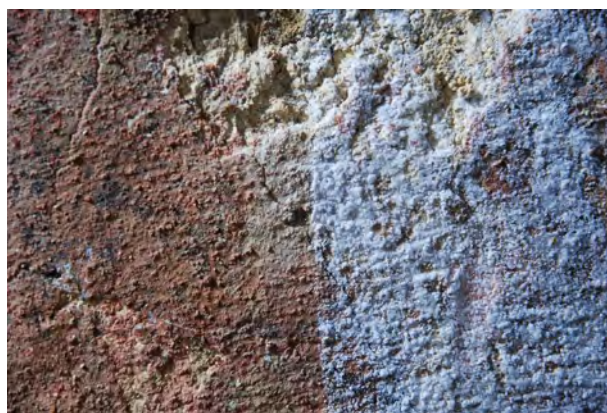


Figure 12. Detail of the wall where the biological white and powdery patina of moonmilk has been removed on the left side.



Figure 13. Detail of the biological patina of moonmilk, where it is thicker and harder, thereby protecting rather than damaging the murals.

4. Microbiology of *Tomba degli Scudi*

The *Tomba degli Scudi* essentially functions as an *in situ* microbiological laboratory, where our team has been working for the past seven years. The key research phases are expressed in this chapter, providing a structured approach for probing similar hypogeal settings.

Atrium: Pre-restoration. Prior to the atrium restoration, a sanitization process was undertaken. Regrettably, this precluded the possibility of microorganism sampling ahead of the biocide application. The first microbiological analysis hence highlighted a dominance of biocide-resistant microorganisms, such as *Bacillus* species and fungi (Tomassetti et al., 2017). This initial exploration revealed that the treatment selectively eliminated more susceptible species, creating an imbalance within the microbial ecosystem.

Burial chamber: Pre-restoration. Throughout the restoration, professionals noticed an unusual white deposition on the tomb walls and ceiling. The wall paintings were obscured by a white, feathery carbonate layer, a calcite deposit known as moonmilk (Mura et al., 2020). Commonly found in karst caves, moonmilk is composed of calcite nanofibers, each less than 1 μm in width (Fig. 14) (Mura et al., 2021).



Figure 14. Burial chamber after the restoration. Two microbiological samples for each wall were studied.

In the Burial Chamber, the genesis of the white *patina* was investigated. Historical records provided no indications of prior interventions. Classical microbiological analysis coupled with a metagenomic approach unveiled a multifaceted microbial ecosystem responsible for the moonmilk formation within the tomb (Cirigliano et al., 2018). This finding showcases a rare instance in which microorganisms seemingly offer protection through the calcium carbonate patina instead of degrading the mural paintings (Fig. 15).

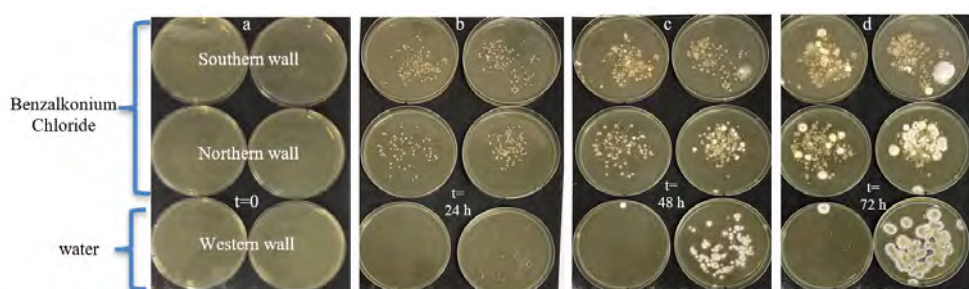


Figure 15. Two microbiological samples for each wall were directly tested for growth on complete medium plates (YPD, yeast extract, bacto-peptone and glucose). Southern and Northern walls were treated with benzalkonium chloride, whereas the Western wall was treated with water. (a) Two swabs for each wall were pressed on plates (time, $t = 0$). Growth continued for 72 h, and plates were imaged every 24 h (b, c, and d, respectively). The walls treated with benzalkonium chloride hosted a rich microbial community when compared with that of the wall treated only with water.

Atrium: Post-restoration. Although it became evident that biocolonization aided in mural painting preservation, moonmilk removal was deemed essential both for conserving the paintings in their original state and facilitating further investigations. However, post-moonmilk extraction from the *atrium* triggered a rapid microbial proliferation. Several months post-restoration, a biofilm enveloping over half of the wall surfaces was observed. Microbiological assessments ascertained that the biofilm primarily comprised a *Rhizobium* strain, typically found in soils and subterranean environments. After a comprehensive evaluation, the progression of this colonization was studied without the removal of the biofilm or biocide application. Expecting an eventual balance with the native hypogeal microbial ecosystem, systematic microbiological inspections of the mural paintings were performed. Spanning four years, the observed biofilm vanished, giving way to the indigenous microbial community. Furthermore, the microbial resistance to biocides from wall samples was scrutinized: a considerable proportion demonstrated minor sensitivity to Biotin T and resistance to benzalkonium chloride. Avoiding biocides proved prudent. Culturable strains were also assessed for their calcium carbonate precipitation capabilities. Some species exhibited biomineralization potential, hinting at the likely reappearance of moonmilk in the future (Cirigliano et al., 2022).

Burial Chamber: Post-restoration. Informed by the post-restoration outcomes of *atrium*, we initiated an experiment in the Burial Chamber to evaluate the activity of the commonly employed biocide, benzalkonium chloride. Post-restoration, two walls received a benzalkonium chloride treatment, whereas the northern wall was water-treated (Fig. 16). Direct growth on plates from samples (two from each wall) was observed over four days, and this procedure was replicated. Astonishingly, a greater diversity of species was derived from the treated walls compared to the untreated (Fig. 16). In the control, the northern wall, the predominant species was *Penicillium*, an expected outcome owing to its ubiquitous nature and the probable dispersal of spores by restoration activity. Subsequently, the cultured microorganisms were subjected to biocide sensitivity tests (Figs. 16 and 17). Demonstrating varied sensitivity to biocides, these tests utilized extremely high biocide concentrations, surpassing typical environmental treatment levels. The findings indicated the biocide ineffectiveness in the Burial Chamber, revealing considerable microbial resistance.

After six years of microbiological exploration in the *Tomba degli Scudi*, encompassing pre- and post-restoration phases of the *atrium* and Burial Chamber, valuable insights for all hypogeal environments were obtained. The predominant concern in these sites is biodeterioration. This survey illuminates the complications stemming from microbial

proliferation post-biocide treatment. Advisedly, the hypogeal sites carved in the rock should not undergo biocide treatments. Such treatments neither resolve issues, rather they exacerbate mural painting conditions by favoring the growth of bacterial strains. Essentially, biocide treatments are counterproductive. Subsequent to sanitation, microbial recolonization is inevitable given the inherent, stable hypolithic microbial community within the walls (Cirigliano et al., 2021; Ronca et al., 2023). Proper intervention necessitates a holistic, interdisciplinary strategy that integrates biology and geology. Each cultural heritage location possesses a delicate balance between its microbial community and rock composition. Within hypogeal tombs, the thermohygrometric values should be monitored, and restrict visitors access. Light exposure should be minimal to curb cyanobacteria and algae proliferation. Since the 1980s, in the Necropolis of Tarquinia, thermally insulated doors equipped with an anti-fog system were installed at the entrance of the tombs to stabilize the microclimates. Additional doors are situated at the dromos entrance, serving as a buffer and further enhancing thermal insulation. Beyond the aforementioned measures, the commitment remains to periodically assess the microbiological state of the tomb, and when required, undertake regular cleaning.

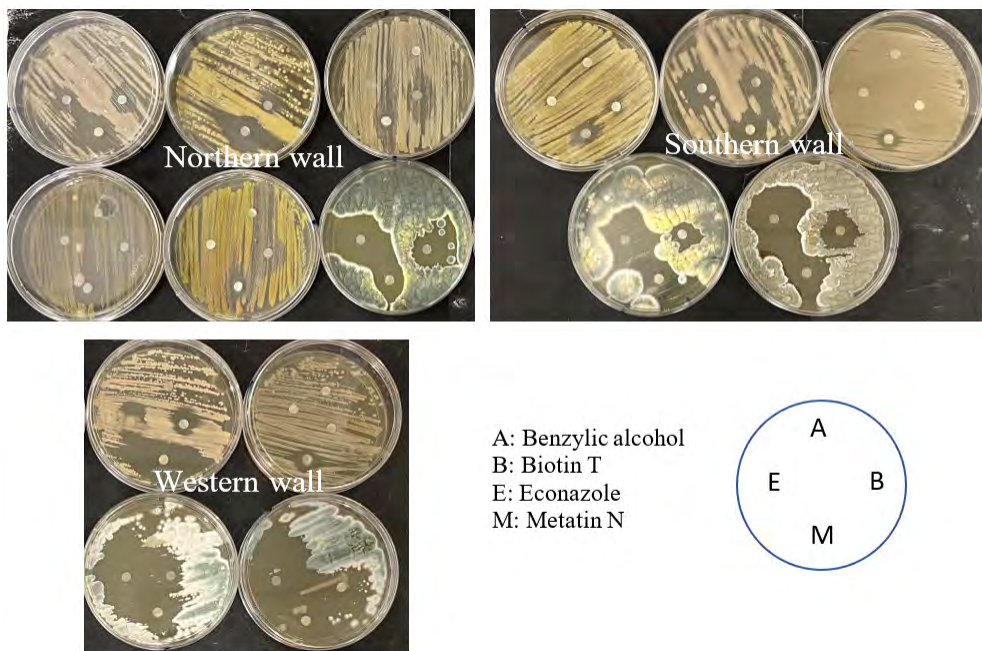


Figure 16. Biocide sensitivity test. Representative strains isolated from the mural paintings were grown on YPD plates in presence of paper disks soaked with 5 mL of the 1:10 dilution solution of benzylic alcohol, biotin T, econazole, and metatin N.

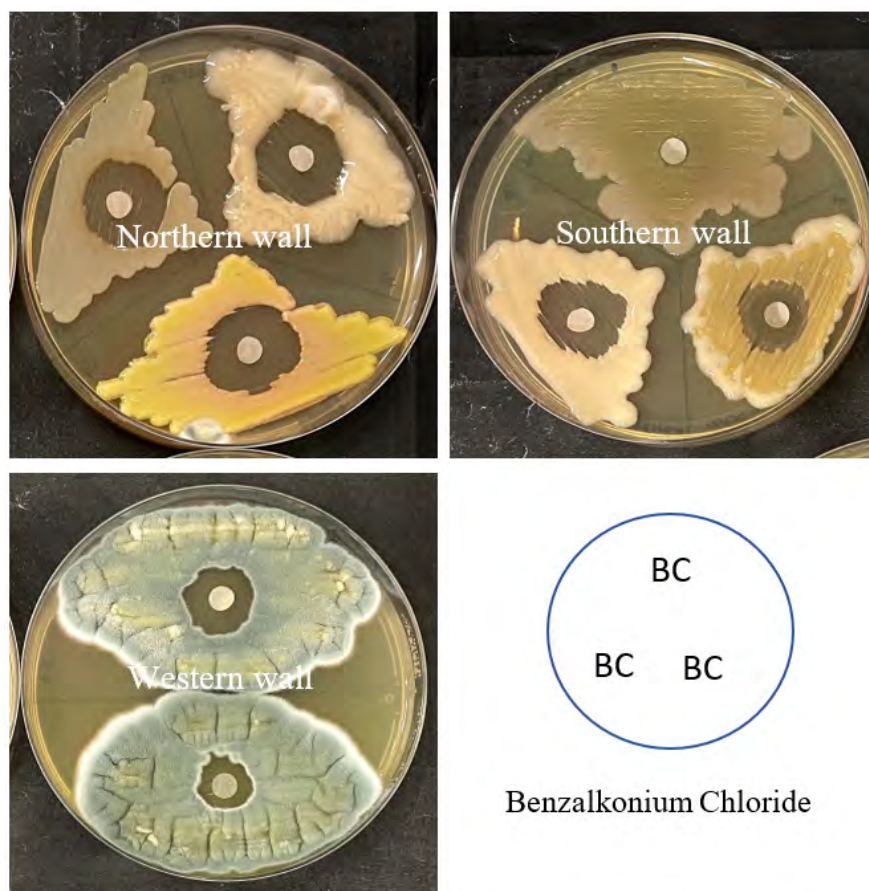


Figure 17. Biocide sensitivity test. Representative strains isolated from the mural paintings grown on YPD plates in presence of paper disks soaked with 5 mL of the 1:10 dilution solution of benzalkonium chloride.

5. Innovative 3D diagnostics and laboratory analysis

The initial phase of our investigative approach for the wall painting in the *Tomba degli Scudi* encompassed documentation via 2D ultraviolet fluorescence (UVF) imaging, further complemented by an advanced 3D method. This technique is instrumental in elucidating the conservation status of surfaces and, specific to the tomb, in detecting potential biological agents across various painting regions (Lanteri & Pelosi, 2021). UVF assessments were conducted pre and post surface cleaning and treatments to analyze the impact of restoration interventions.

The outcomes of the acquisition and subsequent processing are presented in Fig. 18–20.

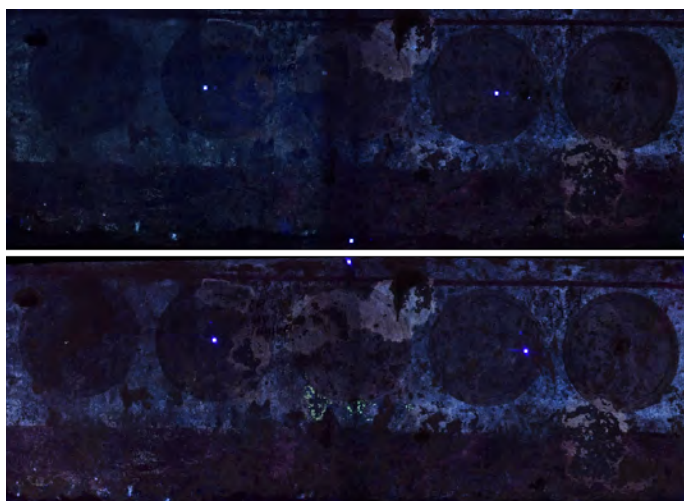


Figure 18. UVF orthophotomosaic of the right wall before (above) and after the restoration (below).

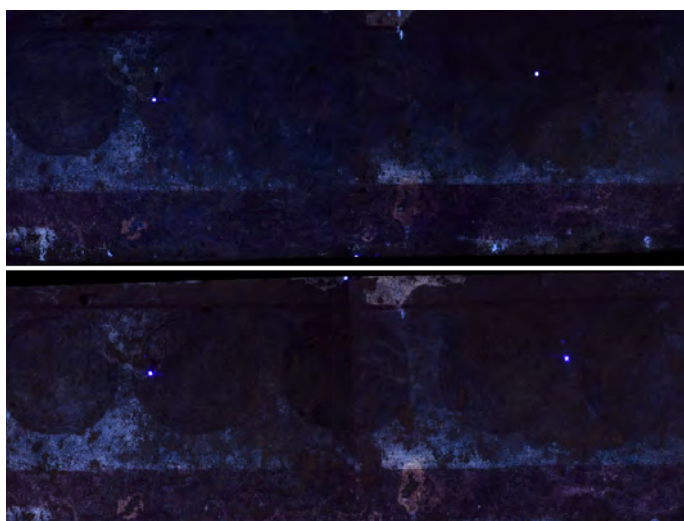


Figure 19. UVF orthophotomosaic of the left wall before (above) and after the restoration (below).

Predominantly, UVF images exhibit a dark hue, especially noticeable in the shields, signifying a lack of fluorescence. However, certain regions radiate an orange fluorescence, most conspicuous in the bottom right image of the rear wall, potentially indicative of biological activity (compounds resulting from the metabolism of biological entities). The white-blue fluorescence, prominently visible on the rear wall image, might be attributed to salt deposits on the surface. The light-blue fluorescence is possibly linked to the *scialbo* layer (pure lime) which is absent in the shields, but was accentuated post-restoration. Pioneering the 3D UVF

model, we acquired 30 photograms subsequently processed through Agisoft Metashape®. This software facilitates photogrammetric processing of digital visuals, including aerial and close-range imagery, to produce 3D spatial data coupled with high-definition photorealistic rendering. Employing a comprehensive Structure from Motion (SfM) method, the software merges digital photogrammetry with advanced computer vision capabilities [Lowe, 2004]. This culminated in the creation of a 3D photorealistic model of the tomb, with an illustrative view presented in Figure 21. An interactive model can be accessed *via* this link: <https://sketchfab.com/3d-models/tomba-degli-scudi-tarquinia-7a183dcbe1e84bb199babcc0b30c3905>

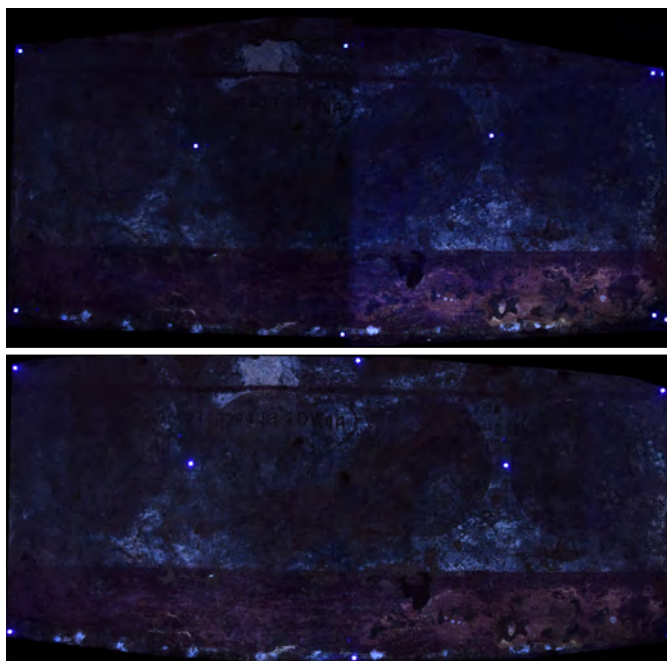


Figure 20. UVF orthophotomosaic of the central wall before (below) and after restoration (above).



Figure 21. View of 3D model of *Tomba degli Scudi*, with white targets visible.

The investigation of the wall paintings encompassed various laboratory techniques aimed at identifying materials (both pigments and binders) and discerning the stratigraphic design of the decoration. Specifically,

- X-ray fluorescence and μ -Raman spectroscopies were employed to respectively pinpoint the chemical elements and compounds linked to pigments in certain designated areas of the wall paintings;
- Fourier-transform infrared spectroscopy (FT-IR) and gas chromatography coupled with mass spectroscopy (GC-MS) served to detect both inorganic and organic binders;
- Stratigraphic analyses on cross-sections were conducted to examine the sequence of ground and painting layers under both visible and UV radiation.

The primary elements ascertained through XRF spectroscopy indicated the utilization of ochre, earths, and calcium carbonate as dominant pigments. The μ -Raman spectroscopy verified this, revealing hematite (red), goethite (yellow), and carbon black for the darker shade. Carbon black, containing lighter chemical elements, remained undetected by XRF. Moreover, μ -Raman identified calcite in all inspected sections, affirming the initial hypothesis posited through XRF analysis where calcium was the predominant element. Finally, the μ -Raman detected the organic compounds, which are yet to be specifically identified but appeared to be linked with the metabolic activities of biological entities.

FTIR analysis demonstrated the ubiquitous presence of calcium carbonate, primarily as calcite, with some aragonite (Mazzocchin et al., 2006) in the wall paintings. Notably, it also discerned minor amounts of proteic and lipidic substances potentially tied to present biomass (Zucconi et al., 2012). Additionally, FTIR detected minimal traces of silicates (related to original materials) and gypsum (associated with restoration efforts). The absence of organic binders received further confirmation from GC-MS. The employed methodology, drawing from recent studies (Casoli & Santoro, 2012; Groppi et al., 2021; Annarilli et al., 2022), yielded two chromatograms per sample: one from fatty acid derivatives and another from amino acid derivatives. Based on the derived results, the detected lipid and protein content, fluctuating between 0.03 and 0.06 $\mu\text{g}/100 \mu\text{g}$ of sample, cannot be ascribed to a deliberately added organic substance because of the minute quantities of identified analytes. The comprehensive results affirm that the painting technique eschews organic binders. To buttress this claim, cross-sections from painting micro-samples were further analyzed, as discussed in the subsequent section (Fig. 22).

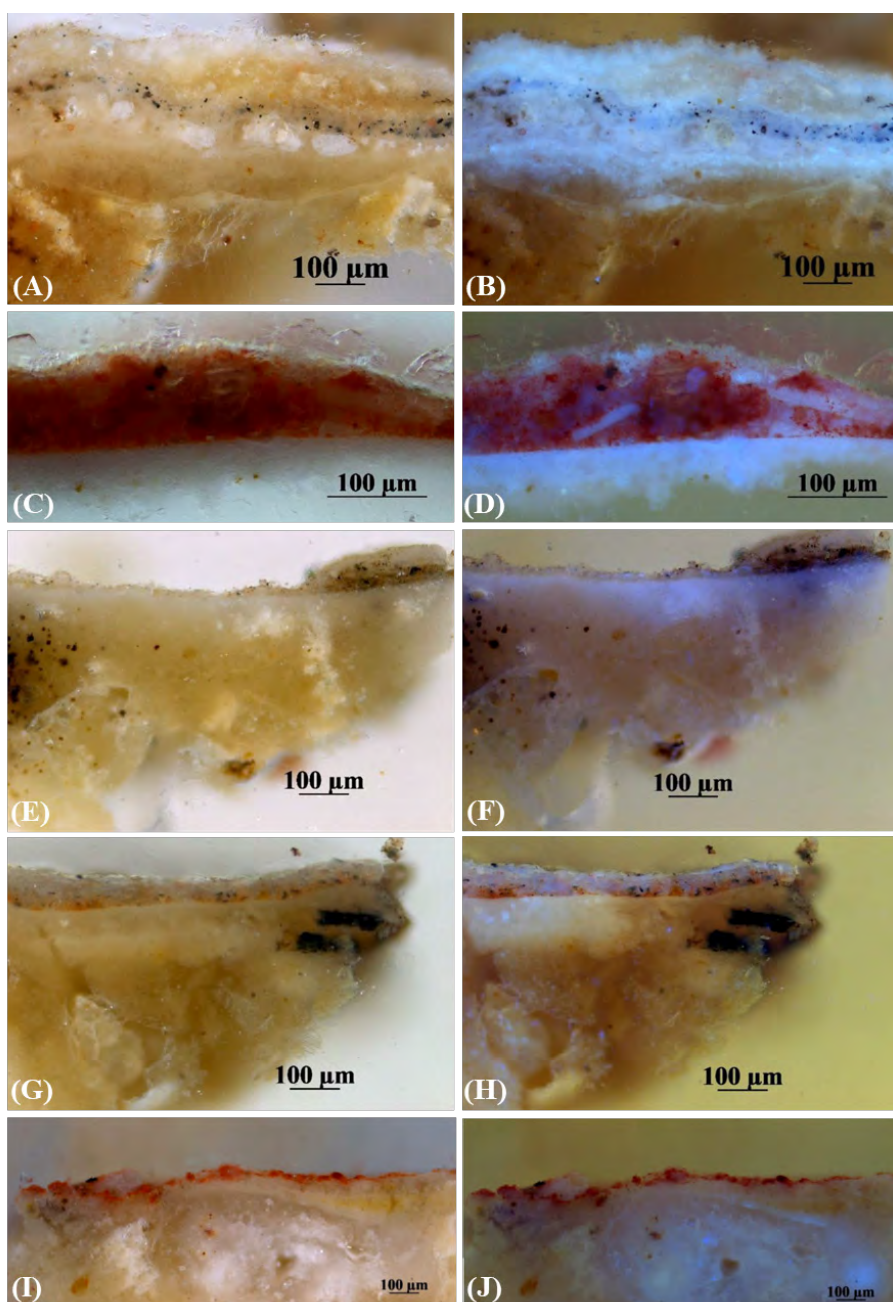


Figure 22. Microphotographs of the cross-sections at 100× magnification under visible (A, C, E, G, and I) and UV radiation (B, D, F, H, and J). Examined samples: *atrium*, south-west wall, gray, light-blue background (A–B); *chamber*, south-west wall, red frame (C–D); *atrium*, north-west wall, *scialbo* (E–F); *atrium*, north-east wall, brown color (G–H); *atrium*, north-west wall, flesh tone of the arm of Vel (I–J).

- G–H, stratigraphic sequence from the base: *intonaco* containing fragments of carbon black, *scialbo*, slender painting layer with minuscule black particles, possibly incorporated to intensify the reddish-brown hue, and a calcium carbonate surface layer exhibiting a pale blue fluorescence.

- I–J, stratigraphic sequence from the bottom: thick *intonaco* layer, *scialbo*, thin painting layer.

6. Restoration

After careful investigation of the conservation history and the factors contributing to degradation, the restoration approach entailed a rigorous assessment of the most fitting materials and techniques to employ. The primary objective in any restoration endeavor is to identify the materials that are harmonious with the originals. The selected materials and methodologies must align with the characteristics of the initial constituents utilized for the preparatory layers. Subsequently, the process demanded the identification of restoration materials and products, ensuring their chemical nature aligns with the demands of a hypogeal environment, permitting solely the introduction of inorganic constituents. All organic components, including acrylic or natural resins and gums, are vulnerable to rapid metabolism by microorganisms. Moreover, a 0.3% benzalkonium chloride water solution was consistently integrated into every stage to counteract external microbial colonization.

6.1. Cleaning

Given the dearth of prior restoration endeavors in the painted chambers of the tomb, the cleaning procedure was relatively straightforward. This phase primarily focused on eradicating the delicate moonmilk patina obscuring the artworks. The tasks involved addressing minor regions of carbonate concretions and clay deposits at the base of the wall, remnants of historical rainwater infiltrations. The moonmilk, being a biogenic deposit not chemically adhered to the substrate, was cleared using a simple aqueous medium. Generally, the carbonate concretions were malleable and could be mechanically removed; however, specific sections (half wall to the right of the entrance door and long inscription above *Velthur Velcha* wall) in the atrium necessitated preliminary softening using buffered ion exchange resins (anionics).

For eliminating moonmilk patina, a 1% benzalkonium chloride water solution was chosen. Application was done using a gentle synthetic bristle brush, with minimal agitation to the surface to lift the patina that rendered the surfaces coarse. In areas where the conservation state permitted comprehensive cleaning, residual moonmilk deposits were eradicated using

low-pressure nebulizers and soft sponges, methodically dissolving and blotting the sediment. Supported by the biocidal properties of benzalkonium chloride, the subtle surfactant potential of the product chemical composition aided in dispelling the patina, mitigating prolonged interaction with the fragile plaster and pictorial layer substrates (Figs. 23 and 24).



Figure 23. Cleaning tests with the removal of calcite depositions. (Left) north-west wall and (right) south-east wall of the tomb.



Figure 24. North-east walls before (below) and after restoration (above).

6.2. Stabilization and infillings

The pronounced decohesion evident in the plaster necessitated meticulous attention from the inception of restoration efforts. It is unfeasible to return plaster to its original state, and it is equally challenging to ensure enduring protection throughout its entire depth using conventional wall painting restoration products. Filling the superficial porosity risks disrupting the delicate equilibrium established over many centuries. Given the restrictive range and supply of restoration products, the decision was made to utilize a class of products that could fulfill the specified criteria: filling and reinstating the cohesion of the material, which was substantially

depleted of its binding matrix. Furthermore, it was paramount to prevent additional material loss and ensure the adherence of the pictorial layer to the plaster. A hydraulic mortar (Ledan TB1/ICR®, Tecno Edile Toscana) was selected, specifically designed for injection and tested explicitly for Tarquinia's wall paintings. After a span of 15 years, the impeccable state of conservation of the mortars was evident, showcasing their complete compatibility with the substrate and substantial longevity, even in especially challenging conditions such as humidity, salt presence, and microbial activity. By filling the majority of cavities and reestablishing chemical bonds between the plaster aggregates, degradation has been contained and even reduced. This is a provisional state, pending targeted environmental research and the installation of a system designed to mitigate water infiltration. To safeguard the aforementioned delicate balance and regulate the mortar penetration within the plaster, the mortar concentration required fine-tuning. After conducting preliminary tests to ascertain the product fluidity, two dilutions with demineralized water (ratios of 1:4 and 1:6) were devised. These dilutions were implemented both for in-depth consolidation and for re-adhering flakes to the uppermost layers. To address voids in the *sabbione*, yellow quartz sand, resonating with the rock substrate in hue and grain size, combined with a colloidal aqueous dispersion of nanometric silica (typically employed for consolidating clay and various stone materials) was utilized. In this context, it functioned as a binder for the sand, and when diluted in demineralized water at a ratio of 1:6, this dilution was significantly higher than what is traditionally employed for stone consolidation. This proportion was determined following empirical evaluations, aiming to replicate the consistency of the *sabbione*.

To address the voids in the plaster, numerous tests were conducted within the hypogeum under optimal temperature and humidity conditions. These were aimed at determining the right balance of binders and aggregates to mirror the mechanical strength of the severely compromised original plaster. The composition is as follows:

- Medium mechanical strength hydraulic lime (Saint Astier NHL 3.5)- 1 part;
- Slaked lime- 0.5 parts;
- *Macco*- 3 parts;
- Ground limestone (*travertino*)- 5 parts.

6.3. Aesthetic presentation

The aesthetic presentation of the painted surfaces underwent thorough consideration. In an archaeological context, the reintegration of artworks is consistently a nuanced and debated

matter. This is particularly relevant for the *Tomba degli Scudi*, given the significant extent of gaps and the prevalence of visible preparatory layers. The various gaps in the *sabbione*, plaster, and pictorial film complicate the discernment of the painted images, resulting in an apparent disarray. Consequently, the fillings must serve both a conservational and aesthetic purpose. They need to secure and stabilize the fragment edges, and simultaneously enhance the artwork's appreciation by aiding in the discernment of distinct layers and restoring them to their intended levels. Given these considerations and the varied conservation challenges, once the methodology was established, the restoration was executed in phases. Each gap was assessed individually and collectively.

On the foundational level, which comprises the fragile sandstone support known as *sabbione*, only the edges of significant and deep gaps were stabilized, primarily for conservation reasons. These minimal infillings were crafted using yellow sand, closely resembling the original in both color and grain size, and bound with a sparse amount of a 1:6 water-diluted colloidal silica solution. This high dilution of the binder produced a mortar that was both malleable and of low mechanical strength, reflecting the properties of the original material. This level was maintained incomplete was backed by the intent to preserve the historical integrity and state of the artwork, especially considering the overall deterioration of the paintings and the specific origins of these gaps. Notably, a number of these gaps can be traced back to distinct, documented historical events. The upper plaster layer saw only selective infillings, corresponding to its original elevation (Fig. 25). Although the *sottolivello unico* technique (entailing the unification of all infilling levels of a layer—wall, *arriccio*, plaster, *intonachino*, etc.—to a singular elevation for distinction from other layers) is commonly employed for wall paintings, it was deemed unsuitable here. Such a method would have substantially altered the visual representation of the artwork conservation status. Following the infilling of the preparatory layers, an initial surface assessment facilitated decisions regarding pictorial reintegration. Primarily, the tone of minute gaps and abrasions in the paint film was subdued. The light hue of both the original and filled plaster made the gaps more prominent than the actual painted images. To prevent the lacunae from drawing undue attention, their tone was slightly reduced, referencing specific areas where the plaster naturally appeared darker. Only stable, water-diluted powder pigments were employed for pictorial touch-ups. The decision to forego water colors or other conservation-specific colors was established during the initial 2016 restorations, to exclude any organic material, such as Arabic gum, which could potentially serve as a habitat for microbial colonization. Additionally, an additional binder is not required given the porous nature of plaster.



Figure 25. *Ravnthu Aprtnai* on the South-West wall. The deeper losses of the plaster have been partially infilled for conservation reasons and to make the image easier to read. They were then glazed with natural inorganic pigments to have a single tone of that level.

7. Conclusions

The extensive research and restoration efforts in the *Tomba degli Scudi* set a precedent but require further research for conclusion, suggesting avenues for future interventions to conserve painted tombs in the Tarquinia necropolis. Currently, the onset of rapid climate change poses emergent challenges in art conservation. An acute understanding of degradation mechanisms and informed choices in restoration techniques become paramount. Such reflections gain further importance as innovative conservation strategies become vital to safeguard these delicate and invaluable artifacts for forthcoming generations, echoing the richness of Italian art. The *Tomba degli Scudi* exemplifies the indispensability of multidisciplinary research undertaken by domain specialists in ensuring precise and efficacious outcomes. Thus, owing to the unique environments housing these artworks, each conservation scenario demands a tailored approach. Additionally, the exploration of the painting technique has spurred intriguing queries. These will be probed further in upcoming studies, aiming to deepen our grasp of Etruscan mural artistry, especially the Tarquinian style, within an expansive Mediterranean framework.

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References

- Andaloro M. (2002). Archetipo, modelli e sagome a Bisanzio. In: *Medioevo: i modelli*. Atti del Convegno internazionale di studi, Parma, 27 settembre – 1° ottobre 1999, a cura di C. A. Quintavalle, Milano 2002, pp. 569 – 574.
- Annarilli, S., Casoli, A., Colantonio, C., Lanteri, L., Marseglia, A., Pelosi, C., Sottile, S. (2022). A Multi-Instrument Analysis of the Late 16th Canvas Painting, “Coronation of the Virgin with the Saints Ambrose and Jerome”, Attributed to the Tuscany-Umbria Area to Support the Possibility of Bio-Cleaning Using a Bacteria-Based System. *Heritage*, 5(4), 2904-2921.
- Bianchi Bandinelli, R. (1939). Le pitture delle tombe arcaiche, in: *Clusium*, Roma, 1939, pp. 23 – 28.
- Borrelli Vlad, L. (1991). *Cartoni, modelli, disegno preparatorio nelle pitture delle tombe etrusche*, in: *Miscellanea etrusca e italica in onore di Massimo Pallottino*, Roma 1991, pp. 1179-1192.
- Brékoulaki, H. (2001). *L’esperienza del colore nella pittura funeraria dell’Italia preromana VIII secolo a.C.*, Napoli 2001.
- Casoli, A., Santoro, S. (2012). Organic materials in the wall paintings in Pompei: A case study of Insula del Centenario. *Chemistry Central Journal*, 6, 107.
- Cecchini, A. (2012). Le tombe dipinte di Tarquinia. Vicende conservative, restauri, tecnica di esecuzione, Firenze, 2012.
- Cirigliano A., Tomassetti M.C., de Kruif N.F., Cavallo I.F., Maras D.F., Mura, F. and Rinaldi T. (2022). Microbial recolonization of the mural paintings after restoration in the Etruscan Tomba degli Scudi in Tarquinia. In: *Biological Risk for Hypogea. Shared data among Italy and Republic of Korea*. Edited by Giulia Caneva & Yong Jae Chung. Editor Nardini, Florence.
- Cirigliano, A., Mura, F., Cecchini, A., Tomassetti, M. C., Maras, D., Di Paola, F. M., Meriggi, N., Cavalieri, D., Negri, R., Quagliariello, A., Hallsworth J.E. and Rinaldi T. (2021). Active microbial ecosystem in Iron-Age tombs of the Etruscan civilization. *Environmental Microbiology*. 23 (7), 3957-3969.
- Cirigliano, A., Tomassetti, M. C., Di Pietro, M., Mura, F., Maneschi, M. L., Gentili, M. D., Cardazzo, B., Arrighi, C., Mazzoni, C., Negri R., Rinaldi. T. (2018). Calcite moonmilk of microbial origin in the Etruscan *Tomba degli Scudi* in Tarquinia, Italy. *Scientific Reports*, 8:15839.
- De Kruif, F.N. (2021). *Il restauro della Tomba degli Scudi. Un nuovo approccio alla conservazione preventiva e al controllo della colonizzazione biologica in ambiente ipogeo* [tesi di laurea magistrale], Viterbo, Università degli Studi della Tuscia, 2021.
- Dreybrodt, W. (2012). Processes in karst systems: physics, chemistry, and geology (Vol. 4). Springer Science & Business Media.

- Groppi, F., Vigliotti, D., Lanteri, L., Agresti, G., Casoli, A., Laureti, S., Ricci, M., Pelosi, C. (2021). Advanced documentation methodologies combined with multi-analytical approach for the preservation and restoration of 18th century architectural decorative elements at Palazzo Nuzzi in Orte (Central Italy). *International Journal of Conservation Science*, 12(3), 921-934.
- Lanteri, L., Pelosi, C. (2021). 2D and 3D ultraviolet fluorescence applications on cultural heritage paintings and objects through a low-cost approach for diagnostics and documentation. *Proc. SPIE 11784, Optics for Arts, Architecture, and Archaeology VIII*, 1178417, 1-11.
- Lerman, A., & Mackenzie, F. T. (2018). Carbonate minerals and the CO₂-carbonic acid system. *Encyclopedia of Geochemistry; Encyclopedia of Earth Sciences Series*; Springer: Cham, Switzerland.
- Maggiani, A. (2005). *Simmetrie architettoniche, dissimmetrie rappresentative. Osservando le pitture della Tomba degli Scudi di Tarquinia*, in *Pittura parietale e pittura vascolare. Ricerche in corso tra Etruria e Campania*, Atti della giornata di studio, (Santa Maria Capua Vetere, 28 maggio 2003), Gilotta F., Napoli 2005, pp. 115-132.
- Marzullo, M., Grotte Cornetane. Materiali e apparato critico per lo studio delle tombe dipinte di Tarquinia, Voll. I e II, Milano, 2017.
- Mazzocchin, G.A., Orsega, E.F., Baraldi, P., Zannini, P. (2006). Aragonite in Roman Wall Paintings of the VIIIa Regio, Aemilia, and Xa Regio, Venetia et Histria. *Annali di Chimica*, 96, 377-387.
- Mura, F., Cirigliano, A., Bracciale, M. P., Rinaldi T. (2020). Characterization of Nanostructured Calcium Carbonate found in two ancient Etruscan tombs. *AIP Conference Proceedings*. 2257 (1), 020011.
- Mura, F., Cirigliano, A., Maras, D., & Rinaldi, T. (2021). Analysis of moonmilk nanofibers in the Etruscan tombs of Tarquinia. In *AIP Conference Proceedings* (Vol. 2416, No. 1, p. 020014). AIP Publishing LLC.
- Porcelli, G. (2021). *Il restauro dei dipinti nella camera sepolcrale della Tomba degli Scudi e lo studio della tecnica esecutiva nell'Italia preromana del IV secolo a.C.* [tesi di laurea magistrale], Viterbo, Università degli Studi della Tuscia, 2021.
- Ronca, S., Mura, F., Brandano, M., Cirigliano, A., Benedetti, F., Grottoli, A., Reverberi, M., Maras, D. F., Negri, R., Di Mauro, E., and Rinaldi, T. (2023). Biogenic calcium carbonate as evidence for life, *Biogeosciences*, 20, 4135–4145, <https://doi.org/10.5194/bg-20-4135-2023>.
- Steingraber, S., *Catalogo ragionato della pittura etrusca*, Milano, 1984.
- Steingraber, S., *Affreschi Etruschi. Dal periodo Geometrico all'Ellenismo*, Venezia, 2006.
- Tomassetti, M. C., Arrighi, C. (2019). Early Evidence of Modular Templates Used to Draw Human Figures on Mural Paintings: The Etruscan Tomba degli Scudi in Tarquinia, in *Studies in Conservation*, published online: 23 May 2019, <http://doi.org/10.1080/00393630.2019.1616151>, pp. 1 – 7.
- Tomassetti, M. C., Cirigliano, A., Arrighi, C., Negri, R., Mura, F., Maneschi, M. L., Gentili M.D., Stirpe M., Mazzoni C., Rinaldi, T. (2017). A role for microbial selection in frescoes' deterioration in *Tomba degli Scudi* in Tarquinia, Italy. *Scientific Reports*, 7: 6027.
- Zucconi, L., Gagliardi, M., Isola, D., Onofri, S., Andaloro, M.C., Pelosi, C., Pogliani, P., Selbmann, L. (2012). Biodeteriogenous agents dwelling the wall paintings of the Holy Saviour's Cave (Vallerano, Italy). *International Biodeterioration & Biodegradation*, 70, 40-46.

CHAPTER 18

THE RECYCLED CORK, A NEW GREEN METHODOLOGY FOR THE RESTORATION OF WOODEN ARTIFACTS: A CASE OF APPLICATION ON THE POLYCHROME SCULPTURE OF SAINT ANTHONY *THE ABBOT* FROM THE MUSEUM COLLE DEL DUOMO IN VITERBO

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Abstract

In conservation and restoration of artifacts of historical-artistic interest, the criteria of environmental protection are mainly aimed at cleaning and consolidation operations. For structural rehabilitation interventions, the search for new materials is concentrated on improving epoxy resins, which are currently the most commonly used material for this purpose. Epoxy resins meet many of the requirements, reducing the search for new products and slowing down the experimenting with new materials for solving structural problems. However, epoxies do not meet the criteria for reducing environmental impact. This work investigates the possibility of using reused cork stoppers, especially those used for bottling wine, to develop an eco-sustainable plaster and create tessellations for wooden fissures. The study was applied to the wooden sculpture depicting *Saint Anthony the Abbot* from the Colle del Duomo Museum in Viterbo, thus, allowing to evaluate the characteristics of this material in terms of workability, drying times, color, and pictorial reintegration. The results obtained were positive and encourage the use of recycled cork plaster and dowelling, which not only meet the requirements for structural operations, but also those related to reducing environmental impact.

Keywords: Cork, cork dust, recycled cork, cork stoppers, structural rehabilitation of wooden sculpture

1. Restoration and the environment

«Il dibattito culturale contemporaneo sugli interventi di restauro arricchito dalla componente ecologica e ambientale si affianca al consueto obiettivo della conservazione e della trasmissione alle future generazioni del nostro prezioso patrimonio artistico e culturale [...]. Il rispetto e la tutela di quei capolavori, che sono patrimonio di tutta l'umanità, infatti, non può prescindere dall'attenzione al rapporto importantissimo che esiste tra l'uomo e l'ambiente, nella consapevolezza che la salute del primo implica necessariamente la cura del secondo»¹. Reflections on restoration, beginning from the first two decades of 2000, regarding its impact on the global ecosystem, is placed into the cultural debate that correlates chemical contamination of the environment, consequences on ecosystems, and human health. The restoration of cultural heritage does not statistically have the same environmental impact as that of other sectors, but in any case, it foresees the use of chemical substances and organic solvents characterized by a certain toxicity. Currently, research has identified new methods enabling a significant reduction of the impact on the environment and on operators. In light of this, the "sustainable restoration" has invested much time researching, in the field of preventive restoration, the problems connected with cleaning and consolidation operations. For the cleaning of artistic artifacts alternative methods to the use of harmful and polluting chemicals have been developed in the last ten years. One example is bio-cleaning, which exploits the action of non-pathogenic and spore-forming bacteria. Another alternative is the formulation of low environmental impact solvents, such as the *Green Rescue* by Yococu², or adopting environmentally friendly methods and instruments such as laser and ultrasonic scalers in the medical field. Similarly, research has been carefully devoted to environmental issues related to materials used in the consolidation. Research has generated methodological alternatives regarding the environment and in terms of risk reduction for the operator. These

1 The contemporary cultural debate on restoration interventions, enriched by the ecological and environmental component, aims to preserve, and pass on our precious artistic and cultural heritage to future generations [...]. The respect and protection of those masterpieces, which are the heritage of all humanity, which cannot do without attention to the very important relationship that exists between man and the environment, in the awareness that the health of the first necessarily implies the care of the second » Introduction by Maddalena Ragni (Director General for Budget and Economic Planning, promotion, quality and standardization of procedures) in *L'innovazione per un restauro sostenibile*. [Innovation for sustainable restoration], Ferrara Exhibition Center Exhibition of the Art of Restoration and Conservation of Cultural and Environmental Heritage, 2009.

2 YOCOCU (Youth in Conservation of Cultural Heritage) is a social promotion association that brings together experts and young professionals, students, and researchers in the field of cultural heritage conservation. *Green Rescue* is an innovative product based on a mixture of low impact solvents for the operator and the environment, designed to remove natural and synthetic resins applied on various substrates. <https://www.yococu.com/it/prodotti/green-rescue/>

methodological alternatives include the *Nympha*³, *Nanocellulose*⁴ and *nano-Maia*⁵ projects, which are oriented toward experimentation, use of environmentally friendly materials, and intervention methods based on natural substances applicable in non-toxic solvent. The rehabilitation of wooden artifacts has not received the same attention regarding environmental impact issues. The term structural restoration indicates the interventions intended to “correct” deterioration phenomena of various nature and morphology to restore a lost material continuity. These interventions include, among others, grouting of the gaps in the support, tessellation of the fissures, consolidation of degraded portions, and integration with inserts.

Grouting operations of the wooden gaps are done for the material reconstitution of the deficiencies at the expense of the support. Integration can be performed with different techniques and methodologies. For example, grouting with epoxy resins is a widely used technique, given its effectiveness, in the restoration of wooden artifacts despite having negative effects on the environment.

Epoxies belong to the family of adhesives and are based on mixing of two components, resin and hardener, which together give rise to a chemical reaction that allows the mixture to solidify without shrinking⁶ (Ciatti et al., 2012).

The positive characteristics that make these materials be among the most commonly used in the wooden restoration sector are:

- excellent adhesive power;
- good consistency in workability;
- long catalyzing times;
- possibility of combining resin and hardener to obtain intermediate mixtures;
- possibility of adding charges to improve the elastic performance of the compound;
- absence of shrinking at the end of the process.

3 *Natural polysaccharides from Microalgae for the Protection of cultural Heritage* (NYMPHA), a new product based on polysaccharides extracted from unicellular algae, compatible with ancient materials and not harmful to humans and the environment is a CNR project (Istituto di Cristallografia - Crystallography Institute). <https://www.cnr.it/en/news/10561/al-via-il-progetto-nympha-polisaccaridi-di-microalghe-per-il-restauro-di-beniculturali>.

4 Scientific project for consolidation of wood with mixtures of hydroxypropyl cellulose (Klucel E) and nanocellulose of different concentrations before and after aging has been examined to evaluate their potential use as consolidants. (Safa, Mohamed, 2019)

5 Nano Material Applications for Innovative conservation of Art works. The nanoproduct object of nano-MAIA was initially developed for the consolidation and restoration of degraded textile materials, with possible applications on archaeological fabrics, wood and canvas parts of paintings, etc. Nano-MAIA is a project of the University of Rome Sapienza in collaboration with the ICR.

6 *Balsite*, a two-component epoxy-based filler, is the most used material for these operations.

While the negatives are:

- greater rigidity, after polymerization, than that of the restored wood (this can compromise the stability of the structure);
- irreversibility (removal can take place only and exclusively by mechanical means);
- incompatibility with the constituent wood;
- difficulty of disposal (they fall into the category of special waste and, therefore, must be disposed of according to specific criteria);
- toxicity (in the liquid/pasty state they are toxic, as they come from the petrochemical industry).

Their ease of application has significantly reduced the demand for new materials for structural restoration, in particular those intended for grouting operations and some types of bonding.

The only studies conducted to date focused mainly on improving processing and performance mechanics of epoxies, in terms of processing and performance mechanics, without considering environmental aspects⁷ (Megna et al., 2005).

This has partly contributed to the current lack of materials that can compete with epoxy resins, with consequences in terms of environmental sustainability and material compatibility.

1.1. Recycled cork

This study aims to develop an alternative operational strategy for the restoration of wooden artifacts. The need to create a new type of plaster, which also has a filling function, arises from personal experience. This has made it possible to understand how most of the materials used on wooden artifacts have chemical-physical characteristics that are not entirely compatible, also in terms of environmental criteria. Specifically, the study investigates the possibility of using cork, an eco-sustainable plaster obtained from a charge made up of a completely

⁷ The study involved the use of wood dust and small additions of cork dust bonded with various types of epoxy resins and elastomers (acrylic and polyurethane). This has shown improvements following the addition of cellulosic materials as the mechanical problems of polymeric materials. Epoxy resins offer excellent adhesion to the wood but have low ability to follow the movements of the wood. The introduction of the 50% cellulose filler in epoxy resins does not improve the deformability characteristics and fails to prevent the occurrence of radial fractures in the material.

natural material, as a plaster material. Its chemical composition makes it extremely ductile and 100% recyclable. A new approach based on the recovery of cork already used in various industrial sectors is proposed. Focus will be on using corks used for bottling wine, which, being used for food purposes, are free from highly unstable materials, which would make cork then unsuitable for reuse in our sector (Mestre et al., 2011).

Quercus suber is the only living organism able to produce cork and currently there are no synthetic materials comparable to this incredible material. Cork, to be used for any purpose, artisanal or industrial, must be extracted; the process of extracting cork is termed decortication, cork in fact is the bark of the cork oak. About 201,000 tons of cork are produced annually. Portugal is the leading producer of cork worldwide, contributing 49.6%, and in the export of cork stoppers⁸ (Oliveira et al., 2021)

The recycling of cork has many positive results: it allows production of technical stoppers, obtained from the agglomeration of recycled cork, with less exploitation of *Quercus suber*; and it reduces global waste and, above all, increases the production of new materials based on recycled cork. The recycling process starts from the collection of corks. In Italy and other cork-producing countries, associations have been created that take care of the collection, providing specially designated areas⁹.

Subsequently, the material is sent to associated stakeholders who, generally, are construction companies and/or manufacturers of building materials who reuse it.

The need to protect *Quercus suber* from an environmental point of view derives from its ability to contain desertification processes, and preserve groundwater, the landscape and its biodiversity. It must be protected as there is a low density of cork oaks and there is no natural seed exchange. Additionally, it is commercially exploited for the production of cork without considering the factor of “normal production surface,” which defines the maximum surface area of peel that the plant can bear without causing irreversible damage and without compromising the quality and quantity of the cork that can be produced.

The proposal to recycle cork as filler for a plaster and as a material for restoring wood comes from a personal interest in environmental issues. The theoretical and cognitive approach of cork, in particular that coming from stoppers, has allowed us to establish its characteristics: it is a natural material, light and compact, non-toxic and

8 2017 Portugal exported stoppers for 72% of total value.

9 Amorim Cork Italia in collaboration with the non-profit organizations present in Italy, the Ethical Project was born in 2011, through the Ethical project 100 tons of used corks are recovered every year.

hypoallergenic, extremely elastic, fireproof, cannot be attacked by insects and molds, transpiring, electrical insulating, acoustic, thermal insulating, and extreme resistance to chemical agents. Subsequently, the first analytical tests were carried out and various formulations of plaster were elaborated and subjected to mechanical tests, combining the crushed cork with various binders commonly used in restoration. The formula chosen at the end of the experiment was used to the polychrome wooden sculpture depicting *Saint Anthony the Abbot*, which was the object of restoration in its entirety. Experiments on a concrete case indicated that there aren't any harmful consequences on the product as the materials used are extremely stable and reversible. The work, preserved in the Colle del Duomo Museum in Viterbo, was chosen for two reasons: because it presented forms of degradation suitable for experimentation and because it was a work unknown to critics, of a devotional nature and never valued.

1.2. Materials and methods

This article reports the methodological choices and the results obtained from the application of recycled cork on the real case; it does not report results of the preliminary investigations and tests performed on cork during the experimentation phase and on the resins selected as a binder. To better understand the choices and the results obtained we should determine the state of conservation of the wooden structure of the Antonian sculpture, especially the conservation problems solved through the use of cork. The polychrome wooden sculpture depicting *Saint Anthony the Abbot* is housed at the Colle del Duomo Museum in Viterbo to which it was transferred in 1809 after the enactment of the Napoleonic legislation, which abolished all minor monastic orders, including the homonymous church of origin of the sculpture. The artifact has the dimensions $186 \times 60 \times 45$ cm; it is life size and carved in a single trunk of linden wood, which has not been emptied. A craftsman has added the face with the relative beard, the right forearm with the relative book, and, finally, an element located on the back of the sculpture, between the right shoulder and the side.

The points of degradation, which motivated the choice of this object for study on application of recycled cork, included the important fissures that the sculpture has both on the front and on the back and the partial gap induced by the action of xylophagous insects on the aforementioned element positioned on the back near the right shoulder.

Once the artifact suitable for experimentation had been selected, the phases of studying the material and its properties and possible applications began.



Figures 1 and 2. Representation of the fissures of the front and photograph of the partial lacunae of the back.

Cork is an external integumentary tissue of secondary origin, multilayered, and without intercellular spaces. Its properties, such as extreme chemical stability, resistance to biodeteriogens agents, and high durability, are attributable to its chemical composition. Its chemical composition consists of 43% suberin, 22% lignin, 10% cellulose and the remainder of various substances, such as saturated and unsaturated fats, phenols and polyphenols, and small quantities of polar and non-polar substances. This particular composition gives it specific properties: low density, gas and liquid impermeability, low electrical conductivity, chemical stability, durability, and high elasticity.

Its low density (0.21 g/m³ at a temperature of 23°C with relative humidity of 5%) makes it extremely light and resistant to compression. Its resistance to humidity is very important for its application in the field of restoration. High chemical stability makes it resistant, in an aqueous environment, to hydrochloric, sulfuric, and lactic acids at 10%; to concentrated citric acid, benzene and ethyl alcohol, whereas it has a slight sensitivity to acetic acid and 10% ammonium hydroxide solutions.

The study involved use of recycled cork stoppers of various types: Twintop, Twintopspark and one-piece¹⁰. These recycled cork stoppers were boiled in demineralized water to remove

¹⁰ The one-piece stopper is the oldest and the one currently used for the finest wines as its production involves

alcoholic and sulfite residues contained in wine. The procedure was repeated until clear boiling water was obtained. The wet corks were dried in the sun. To prevent stagnation in the lower part, in contact with the support surface, sheets of absorbent paper were interposed. This “cleaning” procedure was applied to all the plugs, both those intended for the formulation of the plaster and those to be used for plugging the cracks.

To form the filler of plaster, the corks were ground using a grinder until we obtained well mixed grain, which was sieved into three specific grain sizes: cork powder (<0.5 mm), fine grain size (0.5–1 mm), and medium particle size (2–3 mm). As in mortars, using various grain sizes can improve the characteristics of the mixture, reduce the amount of shrinkage, and increase mechanical resistance.

The introduction of a modular plaster in various granulometric charges according to needs is innovative and can be a subject of further studies.

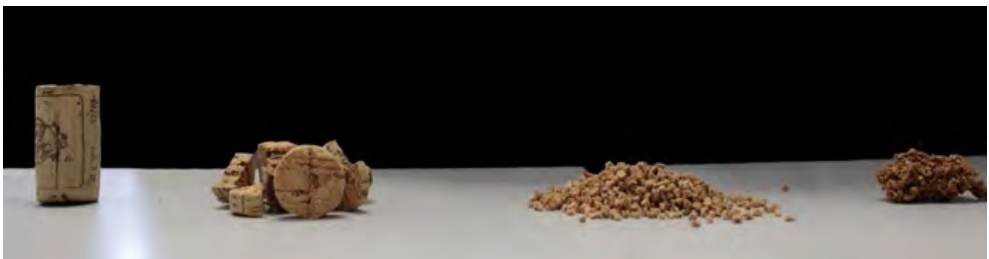


Figure 3. Processing phases of the stopper for the production of recycled cork-based plaster.

To develop a non-toxic plaster, research examined the choice between the various synthetic resins used in the restoration, paying particular attention to those soluble in ethyl alcohol and water¹¹.

The compressive type mechanical tests show how the properties of recycled cork improve considerably when it is shredded and bound with Paraloid B72 or B82 and Aquazol 500. Paraloid guarantees cohesiveness to the compound whereas Aquazol, owing to its

coring the cross section of the cork panel. The Twintop is produced using ground cork, bound by specific glues and finished by a mother cork washer, which is glued to the end part of the stopper in contact with wine. The latter also has a modified version: Twintop Spark, which differs only in its larger size and is used for sparkling wines or champagne. The agglomerated stopper belongs to the same category as the Twintop, but without the terminal mother cork washer.

11 The binders were chosen based on specific requirements: adhesive ability, solubility in low toxic solvents, compatibility and affinity with the constituent materials, miscibility with other resins, chemical inertness, use in the field of restoration of cultural heritage, reversibility, and resistance to microorganisms.

hygroscopicity, behaves like wood. A combination of these two resins does not interfere with the elasticity of the cork, but confers the compound with high resistance to compressive forces. To apply it on the sculpture, minor gaps were filled using a compound containing two parts of medium filler (1 mm) and one part of fine filler (<0.5 mm) and bonded with Paraloid B82+ Aquazol 500 in the ratio 3 :1, both at a final concentration of 20% in bioethanol¹².

The gap on the back, because of its extension, was restored in the upper part through a double-level tessellation performed with recycled corks and glued with polyvinyl acetate. The lower part, previously consolidated, was grouted with a compound comprising one part of thick filler (2–3 mm), two parts of medium filler (1 mm), and one part of fine filler (<0.5 mm) bonded with the same binder as the previous one.



Figures 4 and 5. The sculptor before and after restoration. The structural rehabilitation of the portion degraded by xylophagous insects carried out with recycled cork plaster is also visible.

The repair of the fissures by tessellation was also made with recycled cork stoppers. The singular chemical-physical characteristics of cork, especially its elasticity, allow it to be compressed without undergoing plastic deformation up to about half of its thickness, returning

12 Bioethanol is the ethanol produced by the fermentation process of biomass.

to its original volume when it is decompressed. Due to its porosity, it is an excellent thermal and acoustic insulator. Owing to the suberin that constitutes it, it is waterproof and, therefore, not perishable (Pereira et al., 2001). Because of these characteristics, cork conforms to the criteria for tessellations and sustainability. Before they were applied, the caps were shaped and worked to ensure perfect adhesion to the edges of the cracks. Integration involved the creation of a single-row tessellation on two levels. The plugs were inserted into place without using adhesives, as the elasticity of cork enables them to adhere by compression to the walls of the cracks. The operation was carried out at an ambient relative humidity of 50% when the constituent wood of the sculpture was in an average dimensional condition. The ideal relative humidity for the compression insertion of the cork dowels is to be related to the environment in which the work to be restored is usually located. It is advisable to operate below the average relative humidity values to minimize the risk of the dowels detaching if the wood contracts due to a sharp drop in the relative humidity itself. The inserts used to restore the fissures were finished with gouges, scalpels, and sandpaper, so as to follow the modeling perfectly.



Figures 6 and 7. Fissures before and after plugging with cork stoppers.

1.3. Results

From an operational point of view, the assessment was quite positive. The plaster can be worked on up to 1.5 h after application; the material takes from 3 to 10 h to dry, depending on the thickness and environmental conditions, after which it can be easily refined with abrasive paper and scalpel. The consistency of the material allows a high degree of finish. The material can be reintegrated pictorially both in watercolor and in varnish, and presumably also in tempera. Likewise, the grouting, if not finished with abrasive paper and left sub-level, guarantees excellent anchoring of the execution of the final plaster and glue grouting. With respect to reversibility, the material guarantees excellent mechanical results and does not require use of solvents. What makes the product very innovative, eco-sustainable, and compatible is the recycled cork and the presence of bioethanol, an eco-sustainable and non-toxic solvent used to solubilize the resins used as a binder (Vohra et al., 2014).

Additionally, the plaster can be recycled thanks to the possible extraction of the resins that make it up. Granulated cork can be recovered by removing the binder by means of baths with bioethanol (or other solvent), allowing the material to re-enter the recycling process.

With respect to application, the assessment of plugging with cork stoppers is very positive. The physical characteristics of cork allow it to be worked with extreme ease and this allows to reduce the execution times of each single plug and obtain an accurate level of finish. Unlike the traditional wooden dowels/wedges, the cork ones have a very high compressive capacity, which makes them easily adaptable to small deformations. Additionally, the high compressive capacity allows inserting the plugs and avoiding the use of adhesives, which inevitably introduce new degradation factors linked to their post-aging reversibility. The cork plugs can be reintegrated pictorially both with watercolor and varnish allowing aesthetic presentation.

Generally, the restoration of wooden cracks with plugs made from recycled cork stoppers meets all the criteria required for this operation, and also offers further advantages, including, compatibility with any wood species, resistance against xylophagous insects, and elasticity that accommodates the natural movements of the wood.

The use of recycled cork in restoration, apart from being an eco-sustainable alternative, guarantees non-toxicity, stability, and, above all, compatibility with the hygroscopic behavior of the wood.

References

- Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (2021). Progetto MAIA – “Materiali Avanzati in una Infrastruttura Aperta” Retrieved from: <https://materiali.sostenibilita.enea.it/projects/maia>
- Amorim cork Italia (2011). Retrieved from: <https://www.amorimcorkitalia.com/sughero-riciclo>
- Bento, M. F. S., Pereira, H., Cunha, M.A., Moutinho, A.M.C., van den Berg, K.J., Boon, J.J. (2001). *A study of variability of suberin composition in cork from Quercus suber L. using thermally assisted transmethylation GC–MS*, Journal of Analytical and Applied Pyrolysis Vol.57, pages 45–55.
- Calore, R., Frizza L., Xaca-Camier, M., Rizzonelli, L., Stevanato, N., Tisato, F. (2010). *Aquazol 500. Una possibile alternativa ecocompatibile alla colla animale nella preparazione degli stucchi per il restauro dei dipinti. Test preliminari per la stabilità, lavorabilità e comportamenti.* [Aquazol 500. A possible environmentally friendly alternative to animal glue in the preparation of stucco for the restoration of paintings. Preliminary tests for stability, workability and behaviors]. Proceedings of the congress “The final phases in the restoration of mobile polychrome works” Trento.
- Ciatti, M., Castelli, C., Santacesaria, A. (2012). *Dipinti su tavola. La tecnica e la conservazione dei supporti.* [Panels paintings. The technique and conservation of support]. Edizioni Firenze. Firenze, pages 180-181
- Consiglio Nazionale Ricerche, (2021). *Al via il progetto “Nympha”: polisaccaridi di microalghe per il restauro di beni culturali.* [The “Nympha” project is underway: microalgae polysaccharides for the restoration of cultural heritage]. Retrieved from: <https://www.cnr.it/en/news/10561/al-via-il-progetto-nympha-polisaccaridi-di-microalghe-per-il-restauro-di-beni-culturali>.
- De Luca, D., Borgioli, L., Burattini, S., Orsini, S.. (2013). *Manufatti dipinti su struttura tessile: proposte di materiali alternativi per la stuccatura delle lacune. Comportamento all'invecchiamento.* [Artifacts painted on a textile structure: proposals for alternative materials for filling gaps. Aging behavior]. Kermes N°90, Nardini.
- Galletti, G. C., Bocchini, P., Antonelli, A. (1996). *Pyrolysis and thermally assisted hydrolysis methylation/Gas Chromatography/Mass Spectrometry of sound and degraded wine bottle cork*, in Rapid communication in mass spectroscopy, Vol.10.
- Gil, L. (2009). *Cork Composites: A Review.* Journal Materials. 2, 776-789. Retrieved from: <https://doi.org/10.3390/ma2030776>
- Malavašić, T., Černilec, N., Mirčeva, A., Osredkar, U. (1992). *Synthesis and adhesive properties of some polyurethane dispersions*, International Journal of Adhesion and Adhesives, Vol 12, n°1, pages 38-42.
- Megna, B., Romano, M., L., Pizzo, B., Rizzo, G. (2005). *L'utilizzo delle cariche cellulosiche per migliorare la compatibilità con il legno* [The use of cellulose fillers to improve compatibility with wood] in III IGII National Congress - The state of the art - Palermo.
- Mestre, A., Gil, L. (2011). *Cork for Sustainable Product Design*, Ciência & Tecnologia dos Materiais, Vol. 23, n.º ¾v Retrieved from: https://www.researchgate.net/publication/234015112_A_Cork_for_Sustainable_ProduCt_deSign
- Natividade, J.V. (1956). *Subériculture.* École Nationale et Forêts, Nancy.
- Nóvoa, P.J.R.O., Ribeiro, M.C.S., Ferreira, A.J.M., Marques, A.T. (2004). *Mechanical characterization of lightweight polymer mortar modified with cork granulates*, Composites Science and Technology, Vol. 64, Issues 13–14, October 2004, Pages 2197-2205 Retrieved from: <https://doi.org/10.1016/j.compscitech.2004.03.006>
- Oliveira, V., Pereira, H. (2021). *Cork and Cork stoppers: Quality and Performance.* In Chemistry and Biochemistry of Winemaking, Wine Stabilization and Aging. Chapter 10. [IntechOpen. London Retrieved from: <https://www.intechopen.com/chapters/72229>
- Palmas, M., Del Pin, B. (1988). *Un metodo per trovare un modello di bosco normale e sostenibile a Quercia da sughero.* [A method to find a normal and sustainable forest model in cork oak.]. Cagliari.
- Pereira, H., (1988). *Chemical composition and variability of cork from Quercus suber L.*, in Wood Science and Technology Vol. 22, pages 211–218.

- Safa H., Mohamed, A. (2019). *A new mixture of hydroxypropyl cellulose and nanocellulose for wood consolidation*, Journal of Cultural Heritage, Vol. 35, January–February 2019, Pages 140-144.
- Six, T., Feigenbaum, A. Riquet, A.M. (2003). *Mechanism of migration from agglomerated cork stoppers. Part 2: Safety Assessment Criteria of agglomerated cork stoppers for champagne wine cork producers, for users and for control laboratories*. Retrieved from: <https://doi.org/10.1002/app.10230>
- Tola, A. (2012). *Innovazione tecnologica, eco-sostenibilità e sviluppo competitivo nel settore del sughero*. [Technological innovation, eco-sustainability and competitive development in the cork sector]. Franco Angeli, Milano.
- Various authors. (2009). *L'innovazione per un restauro sostenibile*. [Innovation for sustainable restoration].
- Ferrara Exhibition Center Exhibition of the Art of Restoration and Conservation of Cultural and Environmental Heritage. 25-28 march, Ferrara. Retrieved from: https://www.beniculturali.it/mibac/multimedia/MiBAC/documents/1237544439111_OpuscoloFerrara2009.pdf
- Various authors. (2021). I° Conference on Crystallography, Structural Chemistry and Biosystems, 4-6 october, Catania.
- Viti, V., Borgioli, L., De Luca D., Sabatini, L. (2011). *Restoration of lacunae on textile heritage: proposal of alternate material*, Multinational congress on microscopy, Urbino.
- V. Viti. (2011). *La reintegrazione delle lacune dei dipinti su tela: proposta e sperimentazione di materiali innovativi*. [The reintegration of the gaps of the paintings on canvas: proposal and experimentation of innovative materials]. Thesis.
- Vohra, M., Manwar, J., Manmode, R., Padgilwar, S., Patil, S. (2014). *Bioethanol production: Feedstock and current technologies*, Journal of Environmental Chemical Engineering, Vol. 2, Issue 1, March 2014, Pages 573-584.
- Yococu, *Green Rescue*. Retrieved from: <https://www.yococu.com/it/prodotti/green-rescue/>
- Zhao, J., Xu, Y., Wang, Griffin, W., J., Roozeboom, Wang, K.D. (2020). *Bioconversion of industrial hemp biomass for bioethanol production: A review*. Fuel, Vol. 281. Retrieved from: <https://doi.org/10.1016/j.fuel.2020.118725>

CHAPTER 19

PRESERVATION AND RESTORATION OF THE WOODEN ARTIFACTS WITH DECORATED CARVING AND KUNDEKARI TECHNIQUES

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Abstract

Architectural elements such as ceilings, beams, columns, column capitals, muqarnas, door wings, window and cabinet doors, and pulpits of structures such as mosques, tombs, palaces, pavilions, and mansions dating back to the Anatolian Seljuk and Ottoman periods are examples of precious wooden art. These artifacts are protected in museums or other places of use in buildings to prevent damage or loss due to theft or deterioration. Wooden works with kundekari and carved decorations are composite in structure. Factors such as organic and inorganic ornamentation and inlay materials, binders, upper surface layers paint and varnish, their positions in the structures they belong to, their usage and environmental conditions affect the protection plan. However, the prevention of existing deterioration in these works and extension of the life of the work with the least possible intervention while preserving its originality is critical. This paper discusses the conservation and restoration approach to the carved decorated wooden artifacts prepared with the kundekari technique within the framework of the wooden elements belonging to the architecture. Turkish wood art and conventional wood decoration techniques are presented from a general perspective to emphasize the importance of the subject and explain its cultural value. The causes of their deterioration are briefly mentioned. Finally, the difference between conservation practices in historical artifacts and modern wood impregnation techniques and the degree of intervention in wood artifacts are discussed.

Keywords: Kundekari, Turkish wood art, wood carving, preservation, restoration

1. Historical perspective

During Anatolian Seljuks and Principalities, artisans blended Turkish wood with Anatolian culture from the 12th century and to develop kundakari and carving craft. In the Ottoman period, kundakari, carving, and inlay techniques were used to create some of the most beautiful artifacts (Kerametli, 1961, p. 9; Yücel, 1977). In Anatolian architecture, wood was used in load-bearing elements, filling materials, complementary members, and fixed-use items. Architectural wooden elements, such as ceilings, consoles, columns, pillars, and column heads, are ornamented with various techniques. Woodcraft on door wings, window shutters, and cabinet doors covers is an essential component of the decorations in the buildings. Furthermore, these features are prominent in religious architecture, especially the pulpit, altar, sermon, lectern, Qur'an enclosure, and sarcophagus. In civil architecture, rich woodwork has been applied in many elements such as railings, eaves, buttresses, stairs, cupboards, furniture, frames, jewelry boxes, chests, thrones, and imperial caiques. Although carving spreads cover numerous applications, such as kundedari, which is also a construction technique that appears in the structural parts and furniture of religious architecture, especially in the minbar, mihrab, door wings, window shutter, and cabinet door. In these works wooden decoration techniques was used to decorate the kundedari structure (Bozer, 1989, p. 328; Öney, 1992, p. 139). The minbars of the Konya Alaeddin Mosque and Aksaray Grand Mosque (12th century), Beyşehir Eşrefoğlu Mosque (13th century), Birgi, Manisa, and Bursa Grand Mosques (14th century) are among the most beautiful examples of kundakari art. These pulpits are decorated with inlays and carvings consisting of floral motifs with curved branches, palmette leaves, and rumi (Demiriz, 1977; Bayat, 1991; Apa-Kurtişoğlu, 2015; Gündüz-Küskü, 2021). Among the wooden mihrabs, the mihrab of the Ürgüp Damsa Village Taşkın Paşa Mosque, exhibited in the Ankara Ethnography Museum, is a masterpiece of 14th-century woodworking. The mihrab, which is made of a walnut tree, is decorated with geometric and floral motifs, deep carving on a round surface, double-layered carving, and inclined cut (mail cut) techniques (Bakırer, 1971). The window shutters on the qibla wall, which is speculated to have been constructed at the same time as the minbar of the 14th century Birgi Grand Mosque, were made of walnut wood with deep carving with a round surface. Inscriptions on the upper panels and compositions of rumi and palmette motifs are used on the middle and lower panels, and double helix borders surround the panels (Bayat, 1992, p. 238). The gate of the 15th century Bursa Green Tomb, with its inscription and made of walnut in the original kundakari technique, is one of the precious woodcrafts. Star and polygonal compositions on the panels of the door wings and the blocks of the partitions are decorated with rumi carvings. Circular forms are formed with

curved laths on the upper and lower panels of the door wings. The stiles and rails of the door are decorated with Seljuk thuluth and Kufic (Figure 1). Its astragal is decorated with fish scale motifs (Demiriz, 1979, p. 397). The door wings of Suleyman the Magnificent Tomb, dated in the 16th century, are made of walnut wood, made with the original kundakari technique decorated with the mother-of-pearl, ivory, and bone inlays (Figure 2). The wooden window shutters in the lower row at the tomb were made of walnut wood with the kundakari technique (Ziyrek, 2011, p. 127) (Figure 3). The walnut doors of the 16th century Süleymaniye Mosque, made with the original kundakari technique, consist of ten-armed stars and protruding medallion compositions. Thin wood fillets are engraved on the backs of the laths that make up the geometric grid. The astragal on the main door wings of the mosque is covered with ebony and decorated with vegetal motif ivory partitions and ebony inlays. The inscription on the top panel of the main door wings of the Sultan Ahmet Mosque, dated the 17th century, is constituted in mother-of-pearl inlaid letters on the tortoiseshell background. The middle panel is formed with a ten-armed star kundekari composition and ivory sticks on geometric partitions, an ebony tree on some small pieces, and mother-of-pearl plate inlays are used on large-surfaced blocks. The last traces of this technique were evident at the beginning of the 20th century on the door wings of the Topkapı Palace Cardigan-i Saadet Office. The surface of the door wings, formed by covering the inscription on the upper panels and ten-armed star compositions on the middle and lower panels with mother-of-pearl, tortoiseshell ivory, and ebony, are decorated (Avunduk, 1996, pp. 61-64).



Figure 1. Door wings of Bursa Green Tomb (Photo. I. Özsaıt-Kocabaş).

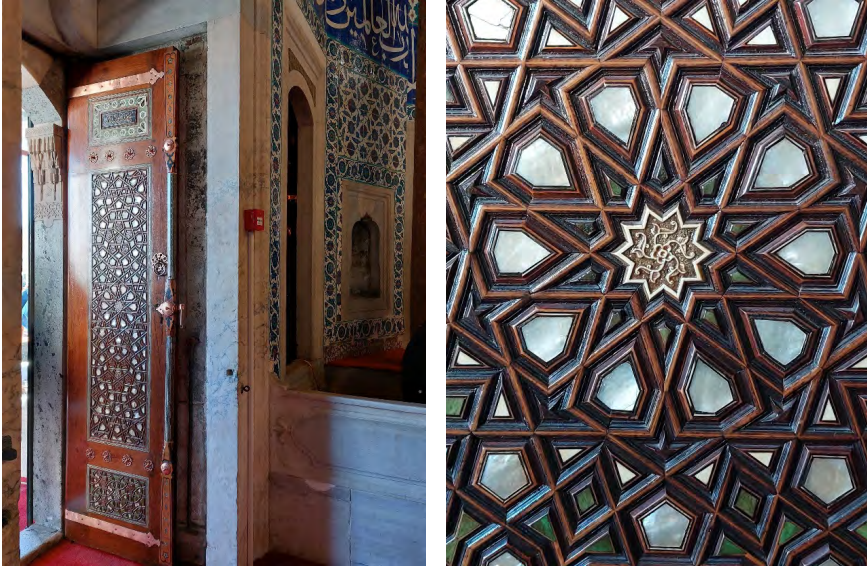


Figure 2. Door wings of Suleyman the Magnificent Tomb (Photo. I. Özsait-Kocabaş).

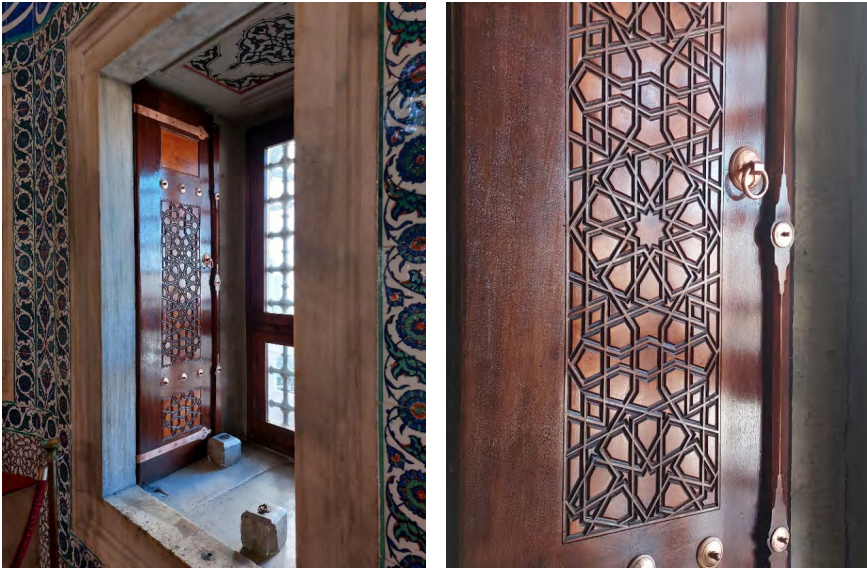


Figure 3. The Window shutter of Suleyman the Magnificent Tomb (Photo. I. Özsait-Kocabaş)

Geometric sequences and vegetal motifs with curved branches were preferred in the decorations of the Anatolian Seljuk period. Kufi and Thuluth scripts were used frequently (Kerametli, 1961, pp. 11-13). Geometrical and rumi ornamentation styles of the Seljuks were enriched with floral motifs in the Ottoman period. In the 16th century, the floral decoration

covered the entire surface and formed a unique style with the rumi motifs. In geometric compositions, eight-pointed stars were usually surrounded by four- or five-pointed stars. Twelve-pointed stars were commonly used. Ten-pointed stars were among Ottoman art of the most frequently used geometric compositions (Demiriz, 1979, pp. 30-31; Bulut, 2020, p. 47). From the 18th century, the motifs of the Baroque and Rococo styles of Europe began gaining weight with Westernization's effect. In this period, deep carved, fluffy large volutes, curved leaves, and oyster shell shapes were widely used (Yücel, 1977, p. 71). Woodcrafting, in which precious works were created, started to decrease gradually since this century, and at the end of the century, machines began to play a role in wood processing. However, traditional techniques continued to be practiced and passed from father to son. Currently, very few competent masters practice these arts with their cultural meanings. The art of wood carving and kundakari, which is the document of Turkish cultural history and traditions, can become extinct due to reasons such as mechanization, lack of sectoral demand, and aging masters not finding apprentices to transfer their knowledge of art. The loss of traditional woodcraft reveals the risk of losing the originality of the artifacts due to the inability to find competent people willing to work on restoring the historical timbers in our wooden cultural heritage and restorations made with incomplete information.

2. Wooden decoration techniques in traditional turkish art

Wooden decoration techniques in Turkish art are handled in five groups such as carving, cage, kundekari, inlay, and painting. Although these techniques could be used alone, unique examples have been revealed by applying several techniques together. In kundekari artifacts, the wood was selected according to the place of use. For example, walnut wood was typically preferred for the indoor types of furniture, such as mihrab, minbar, and lecterns. Conversely, oak, walnut, or chestnut was used in outer spaces, windows, and external doors. Furthermore, hard and dense woods such as maple, ebony, apple, pear, rosewood, boxwood, brazilian rosewood, and yew trees were chosen for ornaments (Öney, 1970, p. 135). Because of their smooth textures and colors, linden, walnut, hornbeam, beech, cedar, cherry, and mahogany were preferred in wood carving works.

2.1. Wood carving technique

Carving is the art of embuing motifs on wood by using various chisels or knives to shape the wood surface. Techniques include surface engraving, double-layer relief, reticulate engraving (cutting), and free-shaping according to application features. At the surface carving, motifs are shaped by cutting the same level of the wood surface at various depths using shal-

low-surface engraving, flat-surface and round-surface deep engraving, and inclined cutting (Ögel, 1965; Öney, 1992, p. 140). In the double-deck relief technique, flat and round surface deep carvings are used together. The reticulate engraved (cutting) technique is applied by carving or cutting out the motifs drawn on the wood as they are. In this method, the wood appears as lace (Kerametli, 1961, p.10).

2.2. Lattice technique

The lattice technique involves by combining wooden laths in compositions that form geometric shapes such as polygons, triangles, and stars and fixing them by the frame construction. The technique was used in minbar railings and window shutters (Figure 4). The technique has two types, simple and filled. The gaps between the cross lattice are left empty in the simple lattice technique. In the filled latticework, the spaces between the wooden laths are filled with carved polygonal and star blocks (Öney, 1992, p. 141).

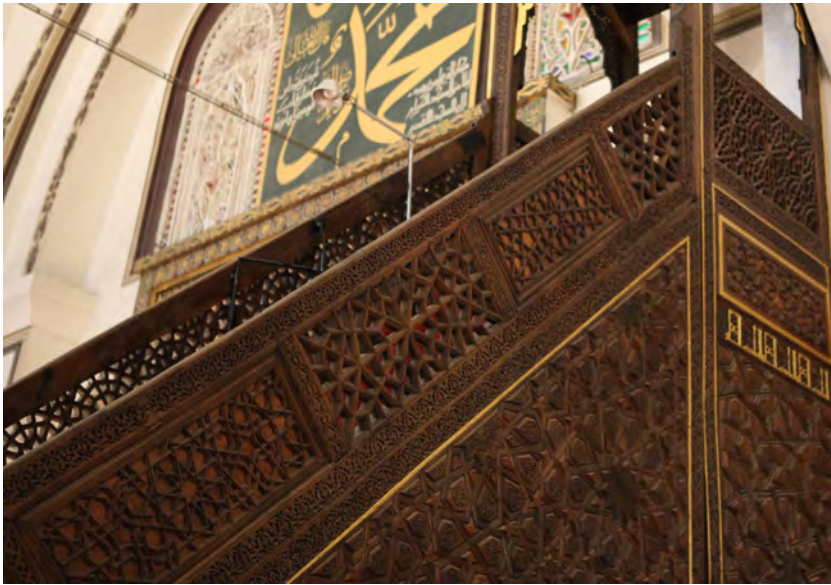


Figure 4. Kundekari, lattice, and carving techniques on the minbar of the Bursa Grand Mosque (Photo. I. Özsait-Kocabaş)

2.3. Kundekari technique

Based on the application, the kundekari technique is either called original and imitative kundakari. Original kundekari involves assembly. Alternatively, the imitative kundekari, which is easier to use, is only a visual copy of the decoration style of the real kundekari without

including the construction purpose and stages. Original kundakari is a construction technique and three-dimensional decoration art, which is realized by combining pieces of various shapes, consisting of orthogonal and polygonal, by interlacing and creating geometric compositions. This geometric system, designed according to the understanding of endless continuation, requires complex and meticulous calculation and knowledge of geometry (Mülayim, 1982, p. 58). In original kundakari, many parts are joined together with tenons, grooves, and channels without using nails and glue (Figure 5). Geometric shapes are obtained by combining the components and simultaneously creating the surface of the wooden element. This surface is fixed by placing a skeleton or solid wood plate behind it (Öney, 1992, p. 138). Original kundakari is made in two primary geometric forms rectangle and star kundekari. Rectangle kundakari consists of laths connected perpendicularly around rectangular and square blocks. Star kundekari is shaped with polygonal and star blocks and clamped by laths at an appropriate angle. In both styles, the grid system of laths around the blocks is locked with the outer frame. The kundakari technique can be used in simple forms, as well as decorated with delicate craft. The upper surfaces of the blocks can be ornamented by inlays mother-of-pearl, tortoiseshell, ivory, bone, precious stones, and various colored woods (Figure 6). Furthermore, floral and rumi motifs can be carved on ivory inlays or wooden blocks. The geometric blocks and surrounding lats can be chamfered and filleted (Bozer, 2002). Imitative kundekari can be nailed and carved, nailed and glued, and all carved according to how it is processed. These techniques were developed simultaneously with the original kundekari technique. The nailed and carved kundekari is created by carving polygon and star motifs prepared by drawing on a wooden plate and attaching laths that make up the geometric pattern between these motifs with glue or nails. Nailed and glued kundakari are created by gluing or nailing wooden blocks and laths between them on a single wood plate according to the geometric motif. The carved kundekari is formed by engraving the geometric composition on a solid wooden plate (Öney, 1992, p. 139).



Figure 5. Wooden fragments of kundekari consisting of mortises, grooves, and tongues
(Photo. I. Özsaıt-Kocabaş)

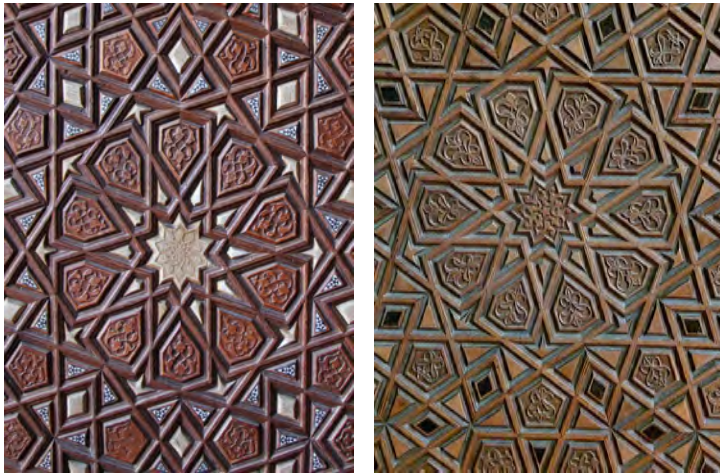


Figure 6. Examples of kunkaderi on doors of Süleymaniye Mosque (Photo. I. Özsait-Kocabaş).

2.4. Inlay technique

The art of inlay on wood appears with carving on geometric blocks in kunkaderi or as basic decoration on the surfaces of many pieces of furniture. The inlay materials placed in the slots carved according to the motifs on the wooden surface were glued with animal glue, and the resulting artifacts were protected with shellac. Hard and different colored woods such as boxwood, mahogany, and rosewood as inlay material; precious stones such as jade, ruby, and emerald; organic parts such as mother-of-pearl, ivory, bone, tortoiseshell; metals such as gold, and silver were used (Keremetli, 1961, pp.10-13).

2.5. Painting on wood technique

The pillars, column heads, muqarnas, consoles, beams, and ceilings of wooden pole mosques in Anatolia from the 13th century to the present are decorated with colored hand painting (Figure 7). This technique was developed during the Ottoman period and primarily applied in 15th and 16th-century religious architectural members, such as mahfil ceilings, and in civil architecture, ceiling, cabinet doors, and doors (Kantarcioğlu, 1992; Ersoy, 1993, p. 52). In this method, multi-colored decorations with geometric and floral motifs with red, yellow, blue, white, and black root dyes (Akok, 1946; Aslanapa, 1989, pp. 130-135). In addition, to this technique, the Edirnekari technique, which emerged in Edirne, was used in Ottoman wood decoration between the 14th and 19th centuries. Edirnekari was applied in old Turkish houses, palaces, and mosques, wooden elements such as balusters, window sashes, cabinets, and their doors, writing drawers, chests, minbars, and ceiling on floors decorated with carvings or inornate (Türkoğlu, 1967, p. 68).



Figure 7. Wooden members decorated hand-painting in the Mahmut Bey Mosque, wood columned and wood roofed (Photo. S. U. Olcay, F. Yılmaz).

3. Deterioration in wooden artifacts

Wood is a material that exhibits minor deterioration under suitable conditions. The deterioration rate varies depending on the type of wood, its environmental conditions, and the severity and duration of exposure to the disruptive factor. Many wooden artifacts inside buildings have remained intact and usable for centuries in dry environments. By contrast, wooden artifacts in outdoor areas can exhibit damage because of atmospheric effects and environmental factors. Due to atmospheric effects, rain and wind load, sand and dust particles carried by the wind, mechanical wear, surface losses, and roughness can occur in wooden artifacts (Figure 8). Increased aging, cracking, color changes, and grays out over time are observed due to combustion and solar radiation caused by the oxidation of the air (Unger et al., 2001, p. 47).



Figure 8. Loosening between wooden fragments, weathering, and discoloration on the mosque courtyard door wings (Photo. I. Özsaıt-Kocabaş).

The amount of moisture in the environment and wood directly affects the strength of artifacts. Wet-drying cycles are the most crucial cause of wood warping. When one part of the wood has a different moisture content compared with the other, bending, hunching, torsion, warping in the form of cupping, and shape changes occur (Bozkurt & Erdin, 2011, pp. 229-230). As the contraction and expansion movements in wood increase, structural deformations occur, which decreases the strength. In cases in which the elasticity of the wood exceeds its limit, cracks and ruptures occur. Different rates of swelling and shrinkage of each part in wooden construction, resulting in dimensional and formal changes, reveal problems in the joints. Pieces glued or fixed together create limiting forces or stresses. This inhibition of dimensional movements can cause cracking in tensile and buckling or crushing in compression. In historical wooden artifacts, plating and inlays are attached to the surface with animal glue that can soften with moisture. The sudden drying of the surface may cause cracking. By contrast, overwetting may result in the layers being lifted or blistered due to softening of glue. The deterioration of glue can lead to damage and loosening of the connection between the two elements. In this case, the tortoiseshell and mother-of-pearl inlays may fall off, leaving the glued wood pieces out of place (Figure 9). Similarly, varnish, lacquer, and paints on the surface are affected by the swelling and shrinkage of wood. These brittle layers crack when wood swells and flake off when wood shrinks (Hunt, 2012). Historical door wings and window shutters have metal elements such as metal strips, rosettes, locks, and knockers. These elements react with wood depending on moisture content, environmental conditions, and metal type creating chemical discoloration and staining, especially in woods with iron and its compounds, extractive substances such as tannin, and moisture. As a result, of the interaction of iron corrosion with the cellulose structure of the wood, nail holes become extensive, and the nails fall out of the wood. This situation causes loosening or separation at the joints of wooden elements (Unger et al., 2001, p. 46; Bozkut & Erdin, 2011, p. 281). Wooden members such as doors, window shutters, and minbars made with the original kundakari technique were created by combining small-sized hard woods with tongue and groove joints without being glued or fixed with nails. Therefore, they such wood members are more resistant to physical deterioration. Studies have revealed that deformations such as planar deviation, bending, and hunching do not occur due to changes in humidity in kundakari structures (Yücel, 1977, p. 63; Söğütlü & Sönmez, 2008). Since the geometric parts are placed at different angles to the fiber directions, and an air gap exists between the blocks, the distortions that will occur from the operation of the wood remain on the part basis. Internal stresses are minimized and do not spread to the whole (Doğruer, 2022, p. 83). Because each piece grasps the other, the shrinking parts are unlikely to fall. By contrast, if the wood material shrinks by losing moisture in imitative kundakari, irregular decoration surface, separations between the blocks, breaking and shedding of the pasted parts, and loss of parts may

occur. In carved artifacts of solid wood, longitudinal cracks and splits occur due to internal stresses. Detachments, fragmentation, and disintegration are observed in carved motifs (Öney, 1970, p.139). Furthermore, in the wooden members in the architecture, incorrect usage, insufficient protection, and uncontrolled factors in the cleaning and maintenance can create a deteriorating effect as much as the ambient conditions. Formal deformations caused by mechanical aging in elements such as door wings, losses in surface and cross-sections, and wearing, scratching, superficial lifting, and breaking of the ornament and polish layers are among the most common damages.



Figure 9. Wearing, breaking, and falling on the surfaces and inlay materials of decoration motifs (Photo. I.Özsait-Kocabaş).

Wood is a favorable environment for insects and microorganisms because of its composition and water content. The increase in humidity in its location supports this activation. The biological degradation of wood material occurs cyclically by bacteria, fungi, and insects. Bacteria pave the way for fungi, which can play an active role in the subsequent decomposition of wood. Bacteria and fungi convert cellulose and lignin in wood into easily digestible substances for insects. Fungal spores attached to insects are carried into the wood through cracks and holes.

Fungi that attack wood material cause color changes and rot in wood. Staining and mold fungi cause aesthetic losses on the wood surface because they do not damage cell walls (Bozkurt et al., 1993, pp. 53-54). Rot fungi attack lignin and holocellulose in the wood structure, decompose them with their enzymes, and destroy them. Fungal rot considerably reduces the mechanical strength of wood. Wood that is attacked by fungi changes color, decreases in weight, pits, cracks, and crumbles, and a mushroom-like odor occurs. Furthermore, the processing property of the wood element, which becomes brittle quickly and softens by losing its fiber hardness, is adversely affected; it does not resist nails, joints loosen, and it becomes more sensitive to shrinkage and swelling (Yücel & Kantarcıoğlu, 1997, pp. 54-55; Goodell et al., 2008, pp. 13-16; Hunt, 2012).

Insects use wood as a food source, shelter, and egg-laying area. *Hylotrupes bajulus* (house longhorn beetle), *Xestobium rufovillosum* (death watch beetle), *Anobium punctatum* (common furniture beetle), *Ptilinus pectinicornis* (fan-bearing wood-borer), and *Lyctus brunneus* (brown powder post beetle) are the most common insects that directly damage furniture, artworks, historic woods, door and window joinery, and painting frames (Unger, 2001, pp. 56-57; Ünal et al., 2009). Insects undergo complete transformation throughout their lives and undergo metamorphosis, encompassing four developmental stages, namely egg, larva, pupa, and adult. The feeding activity of the larvae causes primary damage to the wood. The greater the activity time and number of galleries are in the timber, the greater is the destruction. The exit holes the adult insect opens are less damaged than the larval stage. Deterioration occurs when the starch, sugar, protein, and cellulose in wood are used for nutrition, and the cell wall is destroyed (Toper-Kaygın & Sade, 2004). Termites are essential wood-destroying insects. The lamellae of latewood remain as support; the earlywood layer turns into dust (Figure 10). Because the outer surface of the wooden element always remains intact, the internal damage cannot be observed from the outside until the inside of wood completely crumbles. This phenomenon causes sudden collapses and severe damage to wooden structures (Unger et al., 2001, p. 76).



Figure 10. Longitudinal cracks and insect's exit holes on the decorated surface (left); termites in the window frame (right) (Photo. I. Özsait-Kocabaş).

4. Conservation and restoration of kundekari and carved ornamented wooden artifacts

Conservation methodology depends on criteria such as anatomic features and construction method of artifacts, environment, and place of location (museum, indoor, outdoor, passive or used component), and artifact character (archaeological find, artwork, architectural member, etc.), their dimensions, deterioration, and damage. Information and photographs reflecting the original state of the artifact are searched in archives and historical records. The wood artifacts history, architectural style, structural features, ornament materials, and artistic value

are investigated. Similarly, technical examinations are conducted about the current state of the building to which it belongs, its location in this structure, the climatic conditions of the environment, material analysis, deterioration and damage, and previous repairs. The artifact is recorded with photographs and drawings; analyzes are performed to determine the material type and properties, age, and deterioration status (Timar et al., 2013; Seçkin, 2023). Conservation and restoration steps are then determined. Practices progress with increasing treatments starting from consolidating the parts of the artifact, fixing the broken or removed parts in their place, and adding missing pieces. Numerous and various protection chemicals and methods have been devised. However, in carved and ornamented wooden artifacts, limited techniques are available so that the historical traces, traditional methods, and decorations on the wood do not disappear. In industrial wood protection applications, chemicals are absorbed into raw timber to be used in furniture and construction to increase its resistance against deterioration factors such as fire, weather conditions, high humidity, and biological activation and extend its service life. These chemicals can be classified into three broad categories, namely water-based, oil-based, and light organic solvent preservatives. They are impregnated with different methods such as pressurized applications, hot-cold tanks, dipping, diffusion, brushing, and spraying. These applications are made especially before the wood material is processed to absorb chemicals deeply and homogeneously (Bozkurt et al., 1993, p. 327). In applications on deteriorated wood during use, removal of the varnish layer on the surface is necessary for effective impregnation. However, this process is unacceptable for wooden members that are like artifacts. Furthermore, the protection materials should not come into contact with the paint and varnish on the wood surface. The primary purpose of artifact conservation is to stop deterioration, treat the damage, and preserve the integrity of the work by reinforcing the wood texture and the parts that will break off. To extend the life of the historical wooden member by preserving its originality, improving its current condition, repairing only the necessary parts, and avoiding new additions as much as possible, are essential.

The primary step in creating a conservation plan is to determine the characteristics of the wooden work, factors of deterioration, and type and degree of deterioration. Wooden artifacts with kundekari and carved ornaments belonging to the architecture are in the composite structure. This plan includes organic and inorganic decoration and inlay materials, binders, upper surface layers such as varnish, paint, and metal components such as hinges and locks. The use of nondestructive testing methods is essential when diagnosing an artifact's current structure and deterioration and measuring the effectiveness of subsequent consolidation. Nondestructive methods used in cultural properties are generally grouped under visual inspection, optics,

ultrasound, and electromagnetic radiation. X-ray fluorescence spectrometer (XRF), Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), optical microscopy, scanning electron microscopy (SEM-EDX), Raman spectroscopy, radiocarbon analyses are among the main methods used in cultural heritage (Aliatis et al., 2012). Ultrasonic and thermographic measurements, tomography, and resistographic methods can be used to evaluate the state of internal decay and determine the mechanical strength (Gezer & Aydoğan-Selçuk, 2020).

Preserving the treated artifact under appropriate conditions after conservation and restoration works and programming controls and maintenance are essential for preservation. Inspecting the artifacts and their environments in periodic programs, preventing the occurrence of factors that cause deterioration, and identifying and eliminating deterioration at the initial stage will ensure woodworks survive for many years without serious and costly applications. Applications within the scope of our subject are discussed around the matters to be considered.

4.1. Cleaning

Cleaning artifacts is performed to remove the dirt that fills the cracks, hinges, and locks, the gaps in the joints, and missing parts, to the recessed surfaces of the carvings and inlays. Moreover, the wooden member may have stained by reacting with the materials it comes into contact with, such as metal or concrete. Oil and soot stains are formed on the surface during use. Furthermore, the surface may contain fungal hyphae and insect exit holes or glue stains from old repairs. Depending on the condition of the work, these stains may need to be removed. The nature of the surface formations to be removed, as well as the characteristics of the surface layers, such as carvings, ornaments, paint, foil, varnish, and their deterioration, should be carefully evaluated. Mechanical and chemical cleaning applications are considered traditional methods. Mechanical cleaning is removing dirt from the wood surface with various tools. The force applied should only be effective on the dirt and should not damage the surface patina and the timber. The solid dirt layer is removed from the surface by breaking into pieces. Precision dental instruments, lancets, or scrapers can be used for this process. However, breaking the instruments into large pieces damages the artifact. Therefore, softening hard dirt and removing it in thin layers is essential. Rotten wooden parts should be handled with care. Dust, insect shavings, and fungal hyphae in the pores can be removed by wiping or brushing with a cloth. However, the hairs of the cloth may become caught in the cracks, or the dust that slips during brushing may get into other crevices and spaces. Broken, fibrous parts or loose inlay materials can be damaged if brushing or wiping dirt is carelessly performed. New cracks or small breaks may occur. Vacuum cleaning exhibits considerable advantages. Appropriate traction degree should be adjusted against the risk of breaking off small parts during suction.

Compressed air cleaning creates a rapidly flowing air mass over the wood surface. Air molecules hit and remove dust. The pressure must be adjusted correctly to prevent ruptures from the surface. Revealing the original surface by partially or entirely removing the paint layers applied during previous maintenance work should be handled carefully. Solvents (Gültekin, 2012, pp. 140-141), mechanical scraping method, micro sandblasting (Günel, 2010; Ersen et al., 2011, p. 21), or hot air guns (Ceylan & Keleş-Ocakcan, 2013, pp. 56-57) can be used to soften the surface during to remove the top paint layers.

In chemical cleaning, the wetness-dryness of the wood and the inorganic or organic structure of the foreign layers on the artifact should be analyzed, and chemicals suitable for the nature of the dirt and stains should be selected. The effect of the selected solvent (acetone, ethanol, toluene, xylene, etc.) on the patina, paint, and varnish layers on the surface of the work should be evaluated with spot tests. The amount of solvent used and the time the wood is exposed are essential. The solvents, acids, and alkalis used can severely affect the anatomical and chemical structure of wood, depending on the type of tree (Hamed et al., 2013, pp. 158-159). Therefore, during the cleaning process of wooden artifacts, acid and alkali should be chosen only when necessary. The application time and amount should be kept to a minimum, to ensure the removal of the dirt layer. Nonionic detergents are used because degraded organic materials are sensitive to extreme pH conditions. Because all cleaning procedures can damage the object, solutions consisting of two weaker cleaners are typically preferred over a single stronger solution that can cause damage. These solutions are applied to the wood surface with cotton swabs, pads, or paper pulp. Subsequently, the surface is neutralized with distilled water to remove residues from the wood surface. The chemical removal of dirt on timber, a porous material, can cause swelling in its hygroscopic structure. Therefore, care should be taken to prepare solutions based on alcohol, to use water carefully, and remove excess moisture from the surface with a sponge and sawdust after the process. Conventional cleaning procedures have risks of mechanical stress, discoloration of sensitive surfaces or swelling of paint, glue or wood layers, and solvents reacting with the original material. Studies have investigated new materials and techniques for cleaning historic and artistic works. Various cleaning methods, such as mixed solvent systems, nanostructured microemulsions, and various gel formulations with natural polysaccharide-based gels such as agar and gellan gum, and with artificial polymers including polyacrylamide, polymethyl methacrylate (PMMA), poly-2-hydroxyethyl methacrylate (PHEMA) have been investigated (Chelazzi et al., 2018; Auffret & Nikolaus, 2019; Weththimuni & Licchelli, 2023, p. 2; Lee et al., 2023). This manner is an accepted method because of gel usage, controlled solvent release, softness, ease of application, and en-

vironmental friendliness. The new nanostructured systems exhibit positive results in cleaning historical wooden objects with low solvent concentrations and their nontoxic, biodegradable structures (Cinteza et al., 2009, p. 120). Laser cleaning methods provide an option for paint and foil decorated, polished historical artifacts, and when dry and non-contact cleaning is required. Studies have revealed that the excimer laser provides more reliable results than conventional cleaning methods with its high control and selectivity feature in woods with porous and brittle layers, where it is difficult to distinguish between the original surface and the dirt layers (Georgiou et al., 1998, p. 739; Lubryczynska, 2009, p. 181).

4.2. Sterilization of fungi and insect-infested wooden artifacts

Treatment stages in biodegraded wood constitute the detection of the attacking pest, elimination of growth environment needed by pests, cleaning of fungal hyphae, insect meal, and droppings, and application of biocides and insecticides to problem areas. The tree type and structural characteristics of the artifact, the type of insect or fungi, the condition of the infection, the degree of damage, its place of use, its size, whether to be transported to the laboratory or not, its historical and artistic value, the presence of ornaments affect the selection of the conservation chemical and application method. Many chemicals and applications used to impregnate modern wooden materials are unsuitable for artifacts with ornamentation, carving, inlay, paint, and varnish on their surface. Brushing can be applied according to the condition of the artifact. However, because the chemical stays on the timber's surface and cannot be absorbed into the sapwood, and to be the friction's lifting effect on foil, painted, and sensitive coatings limits the application area. Injecting the preservatives into the wood or fumigating are preferred common methods. Furthermore, to protect the protective layer (patina) and varnish formed over time on the historical wooden works from biological activities without removing them, killing insects by freezing, disinfection by raising the temperature level in drying ovens, sterilization with gamma-rays, and creating a low oxygen environment with inert gases are among the used methods.

Fungi-infected wooden artifacts should be removed from their environment and transported to a sterile environment. As well as treating the artifact, the problems causing deterioration in the building in which it is located should be eliminated, and other items that the fungus splashed should be removed. Fungal hyphae on the walls should be removed and the surface should be sterilized. After treatment, the environment in which the wooden artifact is located should be regularly ventilated, and sufficient air circulation should be provided around them. The dust on the artifact should be cleaned routinely, and systematic controls and detailed photography should be used to control the rot. Fungi extensively damage wood by rotting of wood

tissues. The extent of the damage becomes essential, depending on the area covered by the rotting and the type of action of the fungus causing the decay. In the case of the rotten carved, decorated, and inlaid pieces, the living conditions of fungi should be eliminated, and the timber is disinfected and strengthened. The relative humidity of the environment should be above 65% and the wood moisture content above 10%, optimum of 30%–40%, for wood-destroying fungi to grow. The limit of heat resistance is 3°C–40°C, and the optimum temperatures should be between 20°C–35°C (Yücel & Kantarcıoğlu, 1997, pp. 54-55; Hunt, 2012). Lowering the constant low-temperature relative humidity and material moisture content slows and inhibits the life processes of many wood-destroying organisms (Unger et al., 2001, p. 338).

Insect control includes adult beetles and larvae. First, the presence of an active infestation in the wooden artifact should be diagnosed. Noise in wood without flight holes are indicate of larvas; living or dead adult insects can be seen in exit holes and window sills at flight time. Because insects generally cannot be eliminated with a one-time treatment, the application time and the number of repeats are essential. The wooden member should be controlled regularly, new flight holes formed in the spring and summer months should be monitored, and insecticide use should be repeated according to the insect species' spawning, hatching, and flight times. Liquid preservatives are applied on varnish and painted wooden artifacts by injecting them through exit holes, cracks, gaps, and joints. Before the application, the dust in the wood galleries should be emptied as much as possible. Precautions should be taken to prevent the preservative from dripping onto the wood surface and other elements on the surface during injection. The holes in the wooden element are filled with wax or glue-wood powder paste mixed with insecticide. Different mixtures are tested for this purpose (Broda et al., 2021). The holes are filled to prevent new eggs from being put into them, detect newly opened exit holes, and observe the success of the protection is, as well as aesthetic concerns. The surface of the artifact is checked regularly, and the injection process is continued until the new exit hole opening stops.

The use of fumigants is effective in disinfecting wooden elements against insects, termites, and fungi. Fumigation is a preferred method for disinfection of painted and sensitive wooden artifacts. In practice, the type of wood-destroying organisms, the spread rate of the infection, the dimensions of the wooden member to be treated, and the condition of the area in which the treatment is performed are critical (Selwitz & Maekawa, 1998). Fumigants that do not cause staining and corrosive effects should be chosen for varnished, painted, and composite wooden artifacts. Sulfuryl fluoride and ethylene oxide are widely used in the fumigation of various artworks and historical places (Yıldırım et al., 2012; Appiah-Kubi et al., 2021, p. 174). Fumi-

gation with inert gases is preferred. The gas atmosphere is created in fumigation chambers for movable wooden members. Immovable wooden members are treated by wrapping them with a gas-tight cover or enclosing them in a tent. Most gases used in fumigation are toxic to the conservator and the environment. The sealing of the fumigation area should be investigated. After the procedure, the application area should be ventilated. Fumigants penetrate the wood quickly, deeply, and homogeneously. However, because the protection of the gases does not continue after practice, applying a final treatment with liquid preservatives is necessary.

Low-oxygen atmospheres with inert gases have become a notable alternative to toxic chemicals that negatively affect humans, environment, and some artifacts. This method is based on the suffocation of insects by creating a low-oxygen atmosphere with inert gases such as nitrogen, argon, and carbon dioxide in an isolated environment. The application of modified atmospheres with inert gases can be accomplished in various methods, such as reducing oxygen concentration by absorption and replacing oxygen with nitrogen or argon, producing low-oxygen atmospheres by increasing the concentration of carbon dioxide, or replacing it with carbon dioxide and nitrogen mixtures (Selwitz & Maekawa, 1998, p. 17; Unger et al., 2001; Taşkın & Yıldırım, 2011). Temperature and relative humidity values are essential for the success of these methods. Modified atmosphere application can be realized in a fumigation room, stationary containers, gas-tight portable tents, or barrier-film bags for smaller objects depending on the size of the work to be treated (Selwitz & Maekawa, 1998). Nitrogen anoxia is one of the most effective, safe, and harmless methods to destroy insects on historical objects. This material can be used on portable painted and decorated artifacts or immovable wooden members. Argon is used in sculptures, decorative painted delicate woodwork, and valuable art objects. Argon and nitrogen are more effective in insect control than carbon dioxide is. However, carbon dioxide is preferred in built-in members and applications involving an entire building (Valentin et al., 1990; Valentin, 1993; Gulotta et al., 2015).

Unlike liquid preservatives and fumigants, physical control methods do not leave any residue on the surface and tissues of the artifact, and the preservatives do not have compatibility problems with the original substance. Hot-air treatments effectively remove fungi and insects from wooden artifacts and artworks in historic buildings. These treatments can be realized without moisture content regulation in large and fixed wooden constructions such as roof space, ceiling beams, and bearing elements (Unger et al., 2001, p. 328). However, humidity-controlled heating processes are preferred for decorated wooden artworks and historical artifacts to keep the moisture content of the wood constant. Thus, problems, such as torsions, cracks, splits, or lifted paint layers that will occur in the wood that dries due to

moisture loss should be reduced. For example, the thermo lignum process is carried out by preserving the relative humidity and moisture content of the wooden artifact while it is heated to approximately 55°C with circulating hot air in stable or mobile air-conditioning rooms (Pinniger, 1996; Nicholson & van Rotberg, 1996). The maintenance of a temperature of 55°C over an hour is a reliable killing temperature for most wood-destroying insects. The relative humidity and moisture content of the artifact are maintained in balance in the process, which consists of warming, holding, and cooling stages, which last for approximately 24 hours. The thermo lignum method did not cause dimensional changes or any swelling, flaking, cracking, or lifting in painted and gilded historical artifacts. However, resin diffusion was determined on shellac surfaces (Tscherne et al., 2016). Heat treatments have the risk of stresses, cracks, and bending the differences in the thermal expansion coefficients of the materials in wooden members with different wood species, with inlaid such as tortoiseshell, mother-of-pearl, and metal ornaments. Temperature-sensitive materials such as lacquer and glue may soften. Therefore, methods have been developed for composite and sensitive wooden artifacts to reduce the processing temperature (25°C–30°C) by combining controlled heat treatment with inert gas fumigation (nitrogen and carbon dioxide mixtures) (Hansen, 2011, pp. 74-275).

Controlled low-temperature treatment is used in museum artifacts to prevent pest activity or to halt activity in infested items. Cooling a room below +15°C is effective in slowing or stopping the growth, feeding, and reproduction of museum pests. Storage at <5°C can protect against insect attacks (Unger et al., 2001, p. 336). In the freezing process, the metabolic activities of most insects in various life stages slow down with the decrease in the temperature, and the insects freeze to death in the ongoing process (Pinniger & Winsor, 2004, p. 26). An effective method is to store the objects in clear polyethylene bags in the freezer systems at temperatures between –30°C and –40°C. Strang recommended keeping the artifact at –20°C for one week (Strang, 1997).

The potential benefits of microwave heat treatment in controlling fungi and insects at various life stages (egg, larva, and adult) have been noted in several studies (Andreuecetti et al., 1994; Makoviny et al., 2012; Lluch et al., 2013; Patrascu et al., 2018). Microwaves are not suitable for large-dimension applications. However, with portable microwave devices, fixed wooden objects such as door and window frames, pillars, wooden stairs, and floors in structures can be processed, considering safety considerations (Patrascu, 2018, pp. 161-162). The portable microwave system operating at 2.45 GHz has been reported to be effective by keeping the temperature below safe levels (e.g., 50°C –55°C) in destroying insects without detectable damage on small, sensitive, painted artworks (Bini et al., 1997). However, the he-

ating of nails and metal components in composite artifacts can cause wood to burn. The paint layers can darken and soften the adhesives (Unger et al., 2001, p. 345). Therefore, carefully considering the various parameters (transmitted power, heating time, etc.) involved in the microwave disinfection of decorated wooden artifacts is critical.

Ionizing radiation is used in the nondestructive examination and the preservation of cultural properties. Gamma rays are highly effective in the disinfection and consolidation of wooden artifacts. Consolidation with gamma rays is the solidification by curing with the radiation of liquid resin impregnated into wooden artifacts (Tran & Boutaine, 2017). Insect extermination and bacterial or fungal disinfection are accomplished by exposing the artifacts to gamma rays at corresponding radiation doses. The disinfection dose of insects is lower than fungi. Therefore, the doses of 0.5 to 1 kGy for larvae and insects and 10 to 20 kGy for microorganisms are used (Tran & Cortella, 2017, p. 222). However, irradiation using a dose of up to 10 kGy is effective in most organisms. Applications at this dose are suitable for glues, resins, and painted and varnished artifacts (Ponta et al., 2017). However, at high doses (above 30 kGy), some changes in wood's physical and mechanical properties may occur (Despot et al., 2012). Studies have revealed that X-rays exhibit excellent penetration in wood and effectively disinfect insects and microorganisms (Borgognoni et al., 2017). However, X-rays do not provide the desired effect in the control of wood-destroying organisms, and a dosage of 1 kGy can cause changes in lead pigments in painted objects (Unger et al., 2001, p. 346). Ionizing radiation treatments must be performed in a closed, isolated space that protects the practitioner from the effects of radiation.

4.3. Consolidation

Consolidation is regaining the strength of artifacts suffering structural damage, such as rotting, softening, fragility, cracking, loss of flexibility, and pieces, with various applications. The protection chemical should not cause shrinkage or swelling of the artifact during treatment, should not cause staining, discoloration, textural deterioration, and internal tensions in the appearance of the work, and should be compatible with the original wood structure. Furthermore, the chemical must be recyclable, protect the wood against excessive moisture and biological factors, if possible, and not have toxic effects on humans or the environment. After treatment, the chemical should allow bonding and top surface treatment and provide stable consolidation. The consolidation of carved and decorated wooden artifacts can be defined as increasing the strength of the wood, preserving its volume, and fixing the ornament, varnish, foil, paint layers, and adding support materials. The characteristics of the architectural members, regardless of whether they are portable or immovable, and the size and type of damage

are critical in selecting the consolidation method. The location of the architectural members or artifacts after treatments affects the conservation degree and method. These historical components can be used in the original location, such as mosque doors, can be exhibited with protection measures in their original building, as in the Bursa Grand Mosque's minbar (Figure 11), or can be kept in a controlled museum environment (Figure 12). Furthermore, whether the historical component is a bearing element in the place of use, whether it has a fixed or mobile function, and whether it is indoors or outdoors determines the type and amount of the consolidant. The selected chemical should penetrate as deeply as possible into the wood, providing sufficient stabilization of the wood. However, the consolidant mass does not occupy more volume than required, and the wood material does not lose its properties. Although consolidation can be performed only by the fixation of the surface layers according to the degree of deterioration in the artifact, it can develop as regional or more comprehensive interventions in fragile, powdered tissues depending on the size of the damage in the anatomical structure. It should be determined before consolidation whether repairs, support, and reinforcements will be made in work with fractures, missing pieces, cavities parts, and lost decorations.



Figure 11. Minbar of Bursa Grand Mosque (left) (Photo. I. Özsaıt-Kocabaş).
Figure 12. Door wings, early 15th century, exhibited in the Museum of Turkish and Islamic Arts (Photo. I. Özsaıt-Kocabaş).

When consolidating wooden artifacts, natural and synthetic materials are impregnated into the wood by dipping, brushing, vacuuming, or injection. Natural resins, waxes, and oils have been used throughout history to protect deteriorated wood. Linseed oil and tung oil are used to improve the surface aesthetics of wood or they have been preferred as a plasticizer and hardener and as a pigment binder in paints by mixing with other materials such as resins, oils, and pastes. Furthermore, they have been used to increase water repellency by being impregnated into the wood with its low viscosity and hydrophobic structure and to protect it against moisture and fungus attacks (Broda et al., 2021, p. 11; Walsh-Korb, 2022). Resin and waxes (colophony, beeswax, shellac, etc.) can fill the voids in the wood surface, bind the fragile parts on the surface, and increase mechanical stability. They are nontoxic, chemically stable, and hydrophobic. However, natural resins and waxes exhibit disadvantages such as poor penetration, low strength, low heat resistance, increasing brittleness with aging, and reduced reversibility. Because they tend to soften in a hot environment, their use on outdoor artifacts is risky (Unger et al., 2001, p. 389; Walsh-Korb & Averous, 2019). Beeswax is used alone as wax-resin mixtures (e.g., dammar, colophony, paraffin) or dissolved in solvents such as turpentine consolidation of painted and engraved artifacts by spreading or dipping. It has also been widely used to fill insect holes by mixing with insecticides (Plenderleith, 1956; Peters, 1984). However, beeswax treatment can increase the weight of the artifact, result in an oily appearance, color darkening and dust attraction of its surface. Therefore, some conservators do not accept natural resins and waxes, such as beeswax and colophony, as stand-alone preservation materials and even prefer to remove old repairs made with them from the artifact. For example, in a study on a wooden panel in the Museum of Islamic Art in Cairo, beeswax, as old repair, was wrenched out of wood and reinforced with microcrystalline cellulose and Krugel G instead (El Hadidi et al., 2020).

Because of their lower biodegradability and superior physicochemical properties, synthetic resins are widely preferred for consolidating and restoring wooden artifacts. Thermosetting resins are single or two-component. Curing by heating is performed to accelerate curing and achieve adhesion quickly. Thermosetting epoxy resins exhibit high bonding strength, chemical resistance, mechanical strength, and excellent processability (Shnawa, 2021, p. 1926). However, these resins are irreversible; the loss of elasticity and some yellowing may develop over time, darkening of the impregnated artifact may occur, the deterioration of the wood structure during heat curing may be observed, and the painted surfaces may be damaged (Unger, 2001, pp. 487-488). Despite its disadvantages, it is used for bonding and reinforcing in liquid form, mixing with powder products and filling spaces in paste form, or integrating with molds in

wooden works (Payer et al., 1998, p. 313; Cruz & Machado, 2003). Studies have been conducted on bio-based epoxy resin modifications such as lignin, plant seed oils, and tannin using epoxy resins and various bio-based materials to provide an environmentally friendly, less toxic effect and sustainable protection (Shnawa, 2021; Walsh-Korb, 2022, pp. 14-16). Thermoplastic resins are reversible. They become elastic and soft when heated. Many soluble thermoplastic resins are used in wood consolidation. Paraloid B72 (Acryloid B72) from acrylic resins is one of the most widely used consolidants in degraded wooden artifacts (Crisci et al., 2010). Paraloid B72 in the solid crystal form is soluble in solvents such as acetone, toluene, xylene, and ethanol and is absorbed into the artifacts by cold dipping, buffering, injection, and vacuum applications. Paraloid B72 is used to protect artifacts' surfaces, increase the strength by supporting and filling the texture, and bonding (Tuduce-Traistaru et al., 2011, p. 82). Studies on painted, gilded, and varnished woods and icons have stated that Paraloid B72 dissolved in xylene exhibits high resistance when used at a concentration of 5%–10%–15% in extremely brittle woods and a concentration of 20% in weakened and as fragments objects (Williams et al., 1998, p. 359; Nica et al., 2022). Polyvinyl butyral Butvar B98 resin can be an effective consolidate material (Sakuno & Schniewind, 1990). The solution of Butvar B-98 in equal parts of ethanol and toluene by soaking or vacuum infiltration has been applied to consolidate fragile inlaid wooden artifacts (Spirydowicz, 1996). Klucel G solution (hydroxypropyl cellulose) has been used to fix brittle paint layers and weakened polychrome wood surfaces (Johnson et al., 1995; Fulcher, 2017). Polyvinyl acetate is not used in their impregnation as it causes deterioration on painted surfaces. However, polyvinyl acetate emulsion is preferred as an effective adhesive over conventional animal adhesives for unpainted artifacts (Hulbert, 1998, p. 294). Polyethylene glycol (PEG) is a polyether that provides effective success in various deterioration conditions, especially in wet or water-saturated archaeological woods (Kocabaş & Özsaıt-Kocabaş, 2023).

New environmentally friendly materials and methods are being developed to protect wooden artifacts, which are more durable, can provide long-term stability and preservation, are reversible, have a low cost and low toxicity. Research on synthetic resins and modifications of natural resins, natural resin formulations based on reduced organic solvent fractions, and natural polymer-based composite materials has continued. Multi functional products that can provide surface protection, consolidation, and self-cleaning efficiency when applied, protective coatings, and antimicrobial films have been studied (Crisci et al., 2010; Walsh-Korb, 2022; Aksu et al., 2022; Weththimuni & Licchelli, 2023). Research and application examples include increasing the penetration and strength of wood with mixtures of Klucel E

and nanocellulose of various concentrations (Hamed & Hassan, 2019); increasing the water resistance of the wood with Paraloid B72 solutions modified with nano-ZnO additive (Tuduce-Traistaru et al., 2013); improving the photo-stability and bioresistance of treated wood with Paraloid B72 mixed with TiO₂ and the development of UV protective coatings (Iancu et al., 2022), trying lac modification with essential oils and synthetic resins to enhance the performance of shellac in certain aspects (Timar & Beldean, 2022); functionalizing containing ZnO and nanoparticles in the shellac-based varnishes to reduce photo and biodegradation problems (Weththimuni et al., 2021).

5.4. Restoration

The principle in the restoration of woods with historical and cultural value is to improve the current condition of the artifact and ensure its existence in the future with its original identity. The restoration grade is essential. Unnecessary intervention and aesthetic corrections to will change the originality of the artifact should not be made. During the applications, the ornaments and the brittle varnish layer on the surface should be protected as much as possible. The degree of interference to the original surface layers, integration of the carvings, inlays, and paint decorations, and completion of missing parts with new materials should be determined individually for each artifact according to its characteristics and where it will be placed after treatment. For example, stopping deterioration and consolidating artifacts stored under controlled environmental conditions in museums may be sufficient. By contrast, more robust and protective conservation methods and measures should be considered for wood in architecture with open spaces, high visitor numbers, and unstable environmental conditions. Increasing the structural strength, extra precautions against touching, pushing, and impact at the places of use, atmospheric effects, and surface treatments that will provide resistance against wetting must be considered. Removing rotten parts that have lost their strength and ability to carry themselves and replacing them with new wood is an unacceptable approach in archaeological and artistic artifacts. However, in the context of historical architecture's sustainability, the decaying parts of the damaged bearing wooden elements can be replaced with new parts for the structure to survive, which is consistent of the necessary permits (Ahunbay, 2019, pp. 237-238). However, the use of new wooden pieces in the historic wooden architecture increases with each repair as rotten parts are removed. With the progress of this situation, the original materials and construction techniques disappear, and the wooden elements risk losing their historical document quality. Therefore, the original wood pieces must be preserved as much as possible; in case of partial damage, only the rotting parts should be scraped instead of replacing the whole piece, adding new wood only to the necessary parts

(Figure 13). Subjects, including replacing old wood with new wood, completing missing parts with synthetic resins, the rate of these applications, and the extent to which the additions and repairs are noticed from the outside, have different opinions of restorators.



Figure 13. Partial repair with new wood (Photo. I. Özsaıt-Kocabaş)

If architectural timbers, such as doors and window shutters, are highly decayed, their rotting parts can be replaced with new parts. The new piece should be selected in the type, color, and texture of the original, if possible, from well-dried, old timbers grown in the same region and impregnated before use. The new material should be prepared in a way that is formally compatible and does not impair the appearance and integrity of the historical member, but with details that are understood as modern material upon inspection, and the date of repair should be written on it. The fallen or rotten parts of carved and inlaid wooden elements may cause other components to slip and the ornamental order to deteriorate. In some applications, this situation is solved by leaving the places of the ornaments empty or supporting them with undecorated wooden blocks. By contrast, in some cases, carvings, ornaments, and inlays are completed with techniques and materials similar to the original (Sav et al., 2014, pp. 60-62) (Figure 14). Processing the new wood to be used in these areas with the original decorations is one of the issues that experts approach differently. Making an indistinguishable copy of the original piece contradicts the rule that the restoration is perceptible. However, the possibilities that the visual integrity disrupted by the flat faces of wooden blocks placed in the missing areas, the misunderstanding of the ornamental pattern, and, as the number of interventions increases, the inability to transfer the traditional technique and decorative details in the artifact to the future should be considered. This situation, which should be carefully evaluated during the repairs, has been resolved with a traditional preservation philosophy for the uninterrupted continuation of cultural heritage in Asian countries with rich wooden architecture that adheres to specific rules. The purpose of preservation is to replace the decaying pieces with new pieces produced by processing in the same manner as their ancestors did to preserve the originality of all historical elements of the heritage site and transfer historical knowledge and value to

the future (Sanday, 1981, p. 29; Tomaszek, 2022). For example, in Japan, the ornamented and carved woods of the same shape, size, and characteristics of the buildings belonging to the same period that could not be saved from demolition are used in the parts that are to be renewed of other historical members. Thus, traditional techniques and texture have been preserved by using wooden materials and historical methods from the same period (Sekino, 1972; Koç, 2017). This approach allows traditional wood carving and the craftsmen to survive. Beyond the selection of methods and materials suitable for the artifact in restoration, the competence of people who choose and apply them should be emphasized. The involvement of expert restorers conscious of wooden cultural heritage, having a command of wood arts, and craftsmen working with traditional methods in repairing historical woods is one of the essential components in transferring these values to the future.



Figure 14. Partial repair on doors with rectangle and star kunderkari composition (Photo. C. Beşiktaş)

Architectural members are prepared from the multiple pieces of wood that are joined in various methods depending on their function. The ornamented parts are the components of this structure. For example, door wings and window shutters generally comprise a frame construction formed by vertical (stiles) and horizontal (rails) bars and panels between them. Metal parts such as nails, hinges, latches, handles, knockers, or rosettes exist. The kunderkari technique was made on panels of these members; inlay, fillet, and carved decorations were made on panels and astragals. As an example of larger-scale members, a wooden minbar consists of parts such as a pedestal, baseboard, closet, railing, sideboards, pavilion, cone, door, and stairs. Each of these are units that are combined with each other in various ways. Each unit has its own decoration. The fastenings of wooden elements are made with interlocks such as tongue-and-groove, tenon-and-mortise, dowel, and dovetail joints. Inlays are typically glued with animal glue. Furthermore, there may be deteriorated old repairs, layers of paint applied during maintenance, and parts and connections added later. To maintain stability in these composite structures, fixing the split or separated elements, correcting the twisting parts at varying

degrees, treating the crevices, cracks, and gaps, filling them when necessary, and adding bearing supports are crucial. Consolidation and reinforcement can be made by pouring resin through narrow channels opened at the joints of wooden elements for softening and loosening caused by rot in the joints. Wooden components may be removed in highly damaged elements with loosening or splitting caused by internal fractures in the joints. Correcting deformation on the warped timbers by hammering or applying opposite forces creates tension areas in the artifact and causes new cracks and breakages. These parts can be corrected when necessary by holding them to steam and drying them in molds, depending on the nature of the work. Depending on the condition of the work, natural glues such as animal glues and waxes can be preferred for gluing broken pieces in terms of their compatible features and preservation of the original texture. However, natural glues are used to restore indoor artifacts because they are prone to biodegradation, unstable in variable humidity conditions, and prone to plastic deformation according to ambient conditions. Modifying animal glues with additives such as inert fillers and plasticizers has considerably reduced these disadvantages. Synthetic polymers such as acrylic and polyvinyl resins, epoxy resins, silicones, and polyurethanes are widely preferred (Williams, 1998; Broda et al., 2021). In fastening broken parts or damaged joints, fiberglass rods, polyester supports, and pins made of wood or glass fiber-reinforced composites help join and strengthen historical wooden structures previously reinforced with resin injections. Furthermore, fiber-reinforced polymer surface tapes dipped in epoxy resin and fiberglass-reinforced composite profiles are widely used in strengthening the joints of artworks (Machowicz-Musiał, 2020). The inlaid repair materials such as V- or X-shaped wood or metal used on large-scale structural members prevent the growth of cracks and longitudinal splits (Hulbert, 1998). Fixing with fasteners and supports does not restrict the natural movement of the wood, creating stresses and causing new cracks and warping (Ray & Reilly 1998, p. 378).

Preserving the geometric parts, carvings, and decorations in the kundakari technique in the works should be considered during the structural repairs of the wood. In case of severe problems in the bearing parts of the artifact, the carving or decorations on the surface can be found in good condition. In such cases, the surface decorations should be consolidated, and additional precautions should be considered so that the restoration in the main construction and possible new additions are not reflected in the original carvings and ornaments. In kundakari panels, very thin and small geometric pieces are connected to each other with interlocking joints. Therefore, the broken parts can stay in place without falling. They can be fixed in place after consolidating them. In some cases, losses in the geometric weave, spills in the inlays, and gaps on the surface may occur. During their repair, care should be taken not to disturb the geometric pattern. The

cracked parts of carved ornaments should be protected as much as possible by bonding. Reintegrating the missing parts that weaken the strength of the structure is recommended, causing other wooden blocks or decorations to belong to the motif to fall or shift but avoid unnecessary completions (Hulbert, 1998). The gaps in the ornaments can be completed by carving the new wood added to them, adding flat wood blocks, or shaping them with synthetic resins. Filling the gaps, cracks, insect holes and galleries, and missing parts on the surfaces throughout the wooden structure are essential so that these places do not become new nests for organisms and are not filled with water and dirt. However, fillings made to eliminate all the defects on the wood surface due to aesthetic concerns cause the artifact to lose its originality and historical story. From a technical perspective, to effectively preserve a wooden artifact, fillers must protect the wood from further deterioration, be sufficient flexible to accommodate shrinkage expansions of the wood, adhere well to the surface, and be in harmony with the wood texture. In traditional repairs, filling materials are obtained by combining natural substances such as wood rasping, sawdust, and powdered cork with natural binders including animal glue and candles (Rivers & Umney, 2003, p. 30). Synthetic resins such as acrylic, vinyl, epoxy, polyurethane, silicone rubber mixed with synthetic microballoons, and natural polymer-based composite materials are preferred because of their excellent performance. Modified natural fillers with cellulosic materials such as wood powder, microcrystalline cellulose, nanocellulose fibers, and crystals, have been produced in combination with natural biocides and binders. Glass, acrylic, and phenolic microballoons are used in combination with thermoplastic and thermoset resins; microcrystalline cellulose/acrylate composites are typically preferred by conservators for consolidation and space-filling in wooden artworks (Cataldi et al., 2015; Broda, 2020; Kryg et al., 2020; Broda et al., 2021). Liquid and paste epoxy resins have extensive use in bonding and completing. A shaped integration can be made on the wood surface by using epoxy mixed with a microballoon, or polyester putties can be used by mixing with wood powder or balsa powder. If cavities and missing parts are filled with irreversible resins such as epoxy and polyester resins, a reversible resin such as Paraloid B-72 or Butvar B-98 should be applied on the surface to separate the original material and repair layer (Podmaniczky, 1998).

The ratio of the surface treatments, such as paint and varnish applied to the artifacts, is a different topic of discussion (Hunt, 2012; Hartman-Samet, 1998; Nica, 2022). The varnish protects wood and ornaments from direct eroding, wetting, and ultraviolet damage and supports its dimensional stabilization. However, when the varnish layers crack, they take water in and cause color and mold fungi to grow on the wood surface. Therefore, the maintenance of outdoor wooden members is performed at frequent intervals (Bozkurt et al., 1993, pp.158-159). The

critical problem in architectural wooden members is that the original surface layers generally do not survive due to repeated maintenance and repair. In many mosques, members such as the wooden minbar, door wings, and window shutters have been painted repeatedly during various maintenance and repair works. These applications in dense and multi-layered cover the original color and ornaments of the artifacts (Demiriz, 1979, p. 25). It should be carefully evaluated which coatings are original, matching of the new polish application with the previous repair varnish, the amount of the paint and varnish layers on the surface that will be removed, and the damage that their removal can cause to the artifact. It is an essential criterion in terms of preservation ethics that an artifact is handled in the environment it belongs to and the purpose in conditions suitable for which it was produced. Additionally, wooden architectural members that cannot be preserved *in situ* can be moved to museums to prevent damaged or disappearance. However, doors, window shutters, ceilings, and similar portable wooden elements prepared and decorated with old and valuable techniques such as kundekari and carving in historical buildings that collapsed and demolished for various reasons can be collected by antique dealers. These historical members can be used as table and coffee table pieces or make converted into new productions such as cabinets and decoration items by combining parts of different architectural elements. Traditional architectural elements are valued and have a construction far above this approach. The use of wooden members that cannot be taken part in museums and private collections, in scientific studies, such as the history of technology, and as material for education in schools or the restoration of other historical buildings or artifacts are among options that should be considered.

6. Conclusion

Wooden artifacts are handled with various conservation interventions according to their archaeological, historical, and ethnographic status, deterioration, and structural features. The factors, such as whether the artifact can be exhibited in a museum or in the architecture it belongs to, whether it will stand on fixed supports in exhibition and warehouse areas, or whether it will be used after treatment, are determinative for methods of conservation, restoration, and maintenance. By contrast, the basic approach is to stop the existing deterioration in these works and extend the life of the work with the least possible intervention while preserving its originality. The cultural significance of the details in the artifacts cannot be known and the safest way is to interfere with them as little as possible. Therefore, the tendency at preservation is to intervene only when structurally necessary, and in restorations, the traces of use, damaged edges, and superficial abrasions must be visible; by contrast, the imprint of the conservator should be as little as possible (Hartman-Samet, 1998). Thus, it is emphasized

that structural elements have a history. However, reflecting the initial state of the artifact and emphasizing its original aesthetics as intended as much as possible for the wooden elements used in architecture is also a philosophy. This approach aims to feature the magnificence of the period and the building as a tourism factor, in contrast to the trace of time in the artifacts. Therefore, restoration indicates the creation of a copy of the historical member rather than preserving the original structure of the artifact.

Adhering to the original construction technique and decoration features in restoration applications should be emphasized. However, competent wood masters who will work in repairs consider this an art while repairing the works and aim to produce magnificent craftsmanship means that the new master, who applies the traditional technique, leaves new traces on the artifact. The traditional technique used is a tool to retain the originality of the artifact to the future, not to recreate it.

Conservators and restorers should have a historical perspective about artifacts, familiar with traditional materials and periodical construction techniques, as well as be educated and experienced in scientific conservation and restoration to preserve the artifacts with their cultural evidence. Treatments with a balanced combination of traditional skills and materials and the technological possibilities of the day render it possible to preserve the historical traces and transfer the work to future generations. Comprehensive studies have been performed in this respect in Turkey. Young Masters Project (Traditional Touch to the Preservation of Wooden Heritage: Master Hands-Young Brains Cooperation Project), which achieved successful results, was conducted within the Grant Scheme for Common Cultural Heritage: Preservation and Dialogue between Turkey and the EU-II (CCH-II). The project developed a new education model in which traditional woodworking and artifact protection awareness is given at the high school level to keep the wood arts alive (Özsait-Kocabaş et al., 2022).

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References

- Ahunbay, Z. (2019). *Kültür Mirasını Koruma İlke ve Teknikleri*. İstanbul, Türkiye: Yem yayınları.
- Akok, M. (1946). Kastamonu'nun Kasaba köyünde Candaroğlu Mahmut Bey Camii. *Belleten*, X(38), 293–301. <https://belleten.gov.tr/tam-metin-pdf/805/tur>
- Appiah-Kubi, O. P., Liu, X., & Wu, Z. (2021). Conservation of wood and restoration of artifacts against wood-destroying organisms. *International Journal of Natural Resource Ecology and Management*, 6(4), 171–175.
- Aksu, S., Kelleci, O., Aydemir, D., & İstek, A. (2022). Application of acrylic-based varnishes reinforced with nano fillers for conservation of weathered and worn surfaces of the historical and cultural wooden buildings. *Journal of Cultural Heritage*, 54, 1-11.
- Aliatis, I., Bersani, D., Lottici, P. P., & Marino, I. G. (2012). Raman analysis on 18th century painted wooden statues. *ArcheoSciences*, 36.
- Andreuccetti, D., Bini, M., Ignesti, A., Gambetta, A., & Olmi, R. (1994). Microwave destruction of woodworms. *Journal of Microwave Power and Electromagnetic Energy*, 29, 153–160.
- Apa-Kurtişoğlu, G. (2015). *Anadolu Selçuklu Dönemi Ahşap Minberleri* (1st ed.). Konya, Türkiye: Selçuklu Belediyesi.
- Auffret, S., & Nikolaus, S. B. (2019). *Cleaning of Wooden Gilded Surfaces: An experts meeting organized by the Getty Conservation Institute, March 12–14, 2018*. Los Angeles: J. Paul Getty Trust.
- Aslanapa, O. (1989). *Türk sanatı* (2nd ed.). İstanbul, Türkiye: Remzi Kitabevi.
- Avunduk, A. M. (1996). *Mimar Sinan'ın İstanbul'daki camilerinde ağaç sanatı* (Doctoral dissertation, University of İstanbul University, İstanbul) Retrieved from <http://nek.istanbul.edu.tr:4444/ekos/TEZ/28976.pdf>
- Bakırer, Ö. (1971). Ürgüp'ün Damsa Köyü'ndeki Taşkın Paşa Camii'nin ahşap mihrabı. *Belleten*, 35(139), 367–382.
- Bayat, A. H. (1991). Birgi Ulu Camii minberi (712/1322). *Vakıflar Dergisi*, XXII, 133–150.
- Bayat, A. H. (1992). Beylik dönemi ahşap sanatı şaheserlerinden Birgi Ulu Camii pencere kapakları. In I. Ateş, S. Bayram, & M. Narince (Eds.), *IX. Vakıf Haftası, Türk Vakıf Medeniyetlerinde Hz. Mevlana ve Mevlevihanelerin Yeri ve Vakıf Eserlerde Yer Alan Türk-İslam Sanatları Seminerleri* (pp. 237–252). Ankara, Türkiye: Vakıflar Genel Müdürlüğü Yayınları.
- Bini, M., Andreuccetti, D., Ignesti, A., Olmi, R., Priori, S., & Vanni, R. (1997). A portable microwave system for woodworm disinfection of artistic painted boards, *Journal of Microwave Power and Electromagnetic Energy*, 32(3), 180–187.
- Borgognoni, F., Vadrucchi, M., Bazzano, G., Ferrari, P., Massa, S., Moretti, R., Calvitti, M., Ronsivalle, C., Moriani, A., & Picardi, I. (2017). X-ray sterilization of insects and microorganisms for cultural heritage Applications. *Nuclear Instruments and Methods in Physics Research*, B 406, 309–313.
- Bozer, R. (1989). Sinan eserlerinde ahşap işçiliği", *VI. Vakıf Haftası, Türk Vakıf Medeniyeti Çerçevesinde Mimar Sinan ve Dönemi Sempozyumu* (pp. 327–346). İstanbul, Türkiye: Vakıflar Genel Müdürlüğü Yayınları.
- Bozer, R. (2002). Ortaçağ Anadolu Türk ahşap sanatında kundakari tekniği. In H. C. Güzel, K. Çiçek & S. Koca (Eds.), *Türkler*, 7 (pp. 911–917). Ankara, Türkiye: Yeni Türkiye Yayınları.
- Bozkurt, A. Y. (1992). *Odun Anatomisi*. İstanbul, Türkiye: İÜ Orman Fak. Yayını.
- Bozkurt, A. Y., & Erdin, N. (2011). *Ağaç Teknolojisi*. İstanbul, Türkiye: İÜ Orman Fakültesi Yayınları.
- Bozkurt, A. Y., Göker, Y., & Erdin, N. (1993). *Emprenye Tekniği*. İstanbul, Türkiye: İÜ Orman Fakültesi Yayınları.
- Bozkurt, N. (2009). Sedefkarlık. *TDV İslam Ansiklopedisi*, 36. Retrieved from <https://islamansiklopedisi.org.tr/sedefkarlik>
- Broda, M. (2020). Natural compounds for wood protection against fungi-a review. *Molecules* 25(15), 3538.

- Broda, M., Kryg, P., & Ormondroyd, G. A. (2021). Gap-fillers for wooden artefacts exposed outdoors-a review. *Forests*, 12(5), 606.
- Bulut, M. (2020). Compositions and golden triangles in the Ottoman wooden door, and window leaves. *Journal of Art History*, 29, 45–61.
- Cataldi, A., Deflorian, F., & Pegoretti, A. (2015). Microcrystalline cellulose filled composites for wooden artwork consolidation: application and physic-mechanical characterization. *Material and Design*, 83, 611–619.
- Ceylan, O., & Keleş-Öcakcan, T. (2013). Fatih Camii 2007-2012 restorasyon uygulamaları. In M. Ceylan (Ed.), *Vakıf Restorasyon Yıllığı*, 7, (pp. 43–64). Istanbul, Türkiye: Vakıflar Genel Müdürlüğü.
- Chelazzi, D., Fratini, E., Giorgi, R., Mastrangelo, R., Rossi, M., & Baglioni, P. (2018). Gels for the cleaning of works of art. *American Chemical Society Symposium Series*, 1296, 291–314.
- Cinteza, L. O., Niculescu, G. (2009). Diagnosing efficiency of cleaning old wooden objects using new o/w microemulsions with environmental friendly components. In L. Uzielli (Ed.), *Wood Science for Conservation of Cultural Heritage: Proceedings of the International Conference Held by Cost Action IE060 in Florence (Italy)* (pp. 115–120). Firenze: Firenze University Press.
- Crisci G., M., La Russa, M. F., Malagodi, M., & Ruffolo, S. A. (2010). Consolidating properties of Regalrez 1126 and Paraloid B72 applied to wood, *Journal of Cultural Heritage*, 11(3), 304–308.
- Cruz, H., & Machado, J. S. (2003). Epoxy resins used for the repair of timber structures: the problem of short- and long-term performance evaluation. *WIT Transactions on the Built Environment*, 66, 203–209.
- Demiriz, Y. (1977). XIV. yüzyılda ağaç işleri. In O. Aslanapa (Ed.), *Yüzyıllar Boyunca Türk Sanatı (14. Yüzyıl)* (pp.61–71). Ankara, Türkiye: MEB Yayınları.
- Demiriz, Y. (1979). *Osmanlı Mimarisinde Süsleme I Erken Devir (1300–1453)*, Istanbul, Türkiye: Kültür Bakanlığı Yayınları.
- Despot, R., Hasan, M., Rapp, A. O., Brischke, C., Humar, M., Welzbacher, C. R., & Razem, D. (2012). Changes in selected properties of wood caused by gamma radiation. In F. Adrovic (Ed.), *Gamma Radiation* (pp. 281–304). Croatia: InTech.
- Doğruer, F. S. (2022). Architectural history and conservation considerations of the wooden minbar in the kudekari technique in the Taşkın Pasha Mosque, *Online Journal of Art and Design*, 10(2), 76–87.
- Ersen, A., Olgun, N., Akbulut, S. S., & Şenyurt-Yıldırım, B. (2011). Süleymaniye Camii 2007–2010 yılları restorasyonu ve restorasyon kararları, In M. Ceylan (Ed.), *Vakıf Restorasyon Yıllığı*, 3, (pp. 6–27). Istanbul, Türkiye: Vakıflar Genel Müdürlüğü.
- Ersoy, A. (1993). *XV. Yüzyıl Osmanlı Ağaç İşçiliği*. Istanbul, Türkiye: Marmara Üniversitesi Yayınları.
- El Hadidi, N. M. N., Abdel-Monem, H., Fawzy, M. M., & Hashem, G. G. (2020). Retreatment and conservation of a wooden panel previously treated with bees wax. *Advanced Research in Conservation Science*, 1(2), 48–65.
- Fulcher, K. (2017). An investigation of the use of cellulose-based materials to gap-fill wooden objects. *Studies in Conservation*, 62(4), 210–222.
- Georgiou, S., Zafiropoulos, V., Anglos, D., Balas, C., Tornari, V., & Fotakis, C. (1998). Excimer laser restoration of painted artworks: procedures, mechanisms and effects, *Applied Surface Science*, 127–129, 738–745.
- Gezer, E. D., & Aydoğan-Selçuk, B.(2020). Determination of damage and defects in historical wooden structures using nondestructive test devices, *Sigma Journal of Engineering & Natural Sciences* 11(2), 127–134.
- Goodell, B., Qian Y., & Jellison J. (2008). Fungal Decay of Wood: Soft Rot-Brown Rot-White Rot. *American Chemical Society Symposium Series*, 982, 9–31.
- Gulotta, D., Fermo, P., Toniolo, L., & Goidanich, S. (2015). Anoxic treatment for the disinfection of wood cultural heritage: assessment of the effects and harmfulness on different species, *Wood Science and Technology*, 49, 925–944.
- Gültekin, A. E. (2012). Süleymaniye Camii'ne ait ahşap askı topun konservasyon ve restorasyonu. In M. Ceylan (Ed.), *Vakıf Restorasyon Yıllığı*, 4, (pp. 132–144). Istanbul, Türkiye: Vakıflar Genel Müdürlüğü.

- Gündüz-Küskü, S. (2021). Bir sanatçı, iki minber: Manisa Ulu Cami (1376) ve Bursa Ulu Cami (1399) minberleri üzerinden düşünceler. *Turkish Studies*, 16(7), 155–176.
- Günel, M. (2010). Restorasyon çalışmalarında mikro kumlama uygulamaları. In İ. Nardereci (Ed.) *Kargir Yapılarda Koruma ve Onarım Semineri II* (pp. 132–136). İstanbul, Türkiye: İBB KUDEB.
- Hamed, S. A. M., Ali, M. F., & El Hadidi, N. M. N. (2013). Assessment of commonly used cleaning methods on the anatomical structure of archaeological wood. *International Journal of Conservation Science* 4(2), 153–160.
- Hamed, S. A. M., & Hassan, M. L. (2019). A new mixture of hydroxypropyl cellulose and nanocellulose for wood consolidation, *Journal of Cultural Heritage*, 35, 140–144. <https://doi.org/10.1016/j.culher.2018.07.001>
- Hansen, J. D., Johnson J.A., & Winter, D.A. (2011). History and use of heat in pest control: a review, *International Journal of Pest Management*, 57(4), 267–289. <https://doi.org/10.1080/09670874.2011.590241>
- Hartman-Samet, W. (1998). The philosophy of aesthetic reintegration: paintings and painted furniture. In V. Dorge & F. C. Howlett (Eds.), *Painted Wood: History and Conservation: Proceedings of a symposium organized by the Wooden Artifacts Group of the American Institute for Conservation of Historic and Artistic Works and the Foundation of the AIC* (pp. 412–423). Singapore: J. Paul Getty Trust.
- Hulbert, A. C. (1998). Conservation of the Fourteenth-Century Ceiling at Saint Helen's Church, Abingdon. In V. Dorge & F. C. Howlett (Eds.), *Painted Wood: History and Conservation: Proceedings of a symposium organized by the Wooden Artifacts Group of the American Institute for Conservation of Historic and Artistic Works and the Foundation of the AIC* (pp. 287–300). Singapore: J. Paul Getty Trust.
- Hunt, D. (2012). Properties of wood in the conservation of historical wooden artifacts, *Journal of Cultural Heritage*, 13(3), S10–S15. <https://doi.org/10.1016/j.culher.2012.03.014>
- Iancu, L., Grigorescu, R. M., Ion, R-M., David, M. E., & Slamnoiu-Teodorescu, S. (2022). The effect of UV irradiation on the stability of coated fir wood samples. *Materials and Mechanics*, 18(19), 8–14. <https://doi.org/10.2478/bsmm-2022-0012>
- Johnson, C., Head, K., & Green, L. (1995). The conservation of a polychrome Egyptian coffin. *Studies in Conservation* 40(2), 73–81. <https://doi.org/10.2307/1506506>
- Kantarcıoğlu, A. S. (1992). Ahşapüstü kalemişi bezemelerin koruma yöntemleri. *Türkiyemiz*, 23(68), 42–47.
- Keremetli, C. (1961). Osmanlı devri ağaç işleri tahta oyma sedef bağ ve fildişi kakmalar. *Türk Etnografya Dergisi*, IV, 5–13.
- Kocabaş, U., & Özsaıt-Kocabaş, I. (2023). Comparative analysis of lifting from on-site and conservation of the Yenikapı Shipwrecks. *Heritage* 2023, 6, 1871–1890. <https://doi.org/10.3390/heritage6020100>
- Koç, S. (2017). Japonyada bir koruma modeli olarak restorasyon. *Mimarist*, 17(58–60), 66.
- Kryg, P., Mazela, B., & Broda, M. (2020). Dimensional stability and moisture properties of gap-fillers based on wood powder and glass microballoons. *Studies in Conservation*, 65(3), 142–151, <https://doi.org/10.1080/00393630.2019.1630567>
- Lee, C., Di Turo, F., Vigani, B., Weththimuni, M. L., Rossi, S., Beltram, F., Pingue, P., Licchelli, M., Malagodi, M., Fiocco, G., & Volpi, F. (2023). Biopolymer gels as a cleaning system for differently featured wooden surfaces. *Polymers*, 15(1), 36. <https://doi.org/10.3390/polym15010036>
- Lluch, A. M., Lopez-Manzares, V. F., Mileto, C., & Diodato, M. (2013). Microwaves as a remedial treatment of wood. *Advanced Materials Research*, 778, 620–627. <https://doi.org/10.4028/www.scientific.net/AMR.778.620>
- Lubryczynska, M., Czernichowska, J., Uchman-Laskowska, I., Chmielewski, K., Mazur, M., Markowska, A., Koss, A., Marczak, J., & Strzelec, M. (2009). Wooden art works-laser cleaning case studies. In L. Uzielli (Ed.), *Wood Science for Conservation of Cultural Heritage: Proceedings of the International Conference Held by Cost Action IE060 in Florence (Italy)* (pp. 181–187). Firenze: Firenze University Press.
- Machowicz-Musiał, W. (2020). Fibreglass reinforced composites. Possibilities of use for restoring joints in historical wooden sculpture. *CeROArt* 12. <https://doi.org/10.4000/ceroart.8217>

- Makoviny, I., Reinprecht, L., Terebesyova, M., Smira, P., Souckova, A., & Pavlik L. (2012). Control of House Longhorn Beetle (*Hylotrupes bajulus*) Larvae by Microwave Heating. *Wood Research*, 57(2), 179–188.
- Martín, J. A., & López, R. (2023). Biological deterioration and natural durability of wood in Europe. *Forests*, 14(2), 283. <https://doi.org/10.3390/f14020283>
- Mülayim, S. (1982). *Anadolu Türk Mimarisinde Geometrik Süslemeler-Selçuklu Çağı* (1st ed.). Ankara, Türkiye: Kültür ve Turizm Bakanlığı Yayınları.
- Nica, L., Vasilache, V., Drob, A., Pruteanu, S., & Sandu, I. (2022). Preservation and restoration of an old wooden icon with complex carved ornaments, in a conservation state of precollapse. *Applied Sciences*, 12(10), 5073.
- Nicholson, M., & von Rotberg, W. (1996). Controlled environment heat treatment as a safe and efficient method of pest control. In: K. B. Wildey (Ed.) *Proceedings of the 2nd International Conference on Insect Pests in the Urban Environment* (pp. 263–265). Edinburgh: Heriot-Watt-University.
- Ögel, S. (1965). Anadolu ağaç oymacılığında mail kesim. *Sanat Tarihi Yıllığı*, 1, 110–117.
- Öney, G. (1970). Anadolu’da Selçuklu ve Beylikler devri ahşap teknikleri. *Sanat Tarihi Yıllığı*, 3, 135–149.
- Öney, G. (1992). Anadolu Selçuklu mimari süslemesi ve el sanatları (3rd ed.). Ankara, Türkiye: Türkiye İş Bankası Kültür Yayınları.
- Özsait-Kocabaş, I., Sarrigiannidou, C., & Güler, T. (2022). *Young Touch to the Traditional Wood Arts* (1st ed.). Thessaloniki: Mygdonia Publications.
- Patrascu, M., Radoiu, M., & Pruna, M. (2018). Microwave treatment for pest control: Coleoptera insects in wooden objects, *Studies in Conservation*, 63(3), 155–162.
- Payer, C., Corbeil, M-C., Harvey, C., & Moffatt, E. A. (1998). The interior decor of the Ursuline Chapel in Quebec City: research and conservation. In V. Dorge & F. C. Howlett (Eds.), *Painted Wood: History and Conservation: Proceedings of a symposium organized by the Wooden Artifacts Group of the American Institute for Conservation of Historic and Artistic Works and the Foundation of the AIC* (pp. 301–317). Singapore: J. Paul Getty Trust.
- Peters, K. (1984). The Chatham Island dendroglyphs - conservation and survival. *ICOM Committee for Conservation, 7th Triennial Meeting* (pp. 84.3.10-84.3.12) (AATA 21-2343) Copenhagen: ICOM & J. Paul Getty Trust.
- Pinniger, D. (1996). Insect control with the thermo lignum treatment. *Conservation News* 59, 27–29.
- Pinniger, D., & Winsor, P. (2004). *Integrated Pest Management: A Guide for Museums, Libraries and Archives*. London: Museums, Libraries and Archives Council.
- Plenderleith H. J. (1956). *The Conservation of Antiquities and Works of Art: Treatment, Repair, and Restoration*. London, Oxford University Press.
- Podmaniczky, M. S. (1998). Structural fills for large wood objects: contrasting and complementary approaches. *Journal of the American Institute for Conservation*, 37(1), 111–116.
- Ponta, C.C., Havermans, J. B. G. A., & Boutaine, J. L. (2017). Disinfection of cultural artefacts using irradiation. *Uses of Ionizing Radiation for Tangible Cultural Heritage Conservation* (pp. 93–103). Vienna: International Atomic Energy Agency.
- Ray, S. L., & Reilly, J. A. (1998). The treatment of painted wooden folk art. In V. Dorge & F. C. Howlett (Eds.), *Painted Wood: History and Conservation: Proceedings of a Symposium Organized by the Wooden Artifacts Group of the American Institute for Conservation of Historic and Artistic Works and the Foundation of the AIC* (pp. 373–382). Singapore: J. Paul Getty Trust.
- Rivers, S., & Umney, N. (2003). *Conservation of Furniture* (1st ed.). Great Britain: Butterworth-Heinemann.
- Sakuno, T., & Schniewind, A. P. (1990). Adhesive qualities of consolidants for deteriorated wood. *Journal of the American Institute for Conservation*, 29(1), 33–44.

- Sanday, J. (1981). Traditional crafts and modern conservation methods in Nepal. *Appropriate Technologies in the Conservation of Cultural Property* (pp.9–46). Paris: Unesco. <https://unesdoc.unesco.org/ark:/48223/pf0000047147>
- Sav, M., & Kuşüzümü, K. H. (2014). Mihrimah Sultan Camii'ndeki son restorasyon çalışmalarının değerlendirilmesi. In M. Ceylan (Ed.), *Vakıf Restorasyon Yıllığı*, 9, (pp. 52–63). İstanbul, Türkiye: Vakıflar Genel Müdürlüğü.
- Schniewind, A. P. (1990). Consolidation of dry archaeological wood by impregnation with thermoplastic resins. In R. M. Rowell & R. J. Barbour (Eds.), *Advances in Chemistry Series*, 225 (pp. 361–371). Washington, D.C.: American Chemical Society.
- Seçkin, N. P. (2023). Principles for condition evaluation and preservation of wooden material in traditional buildings. *Bab Journal of FSMVU Faculty of Architecture and Design*, 4(1), 94–104.
- Sekino, M. (1972). The preservation and restoration of wooden monuments in Japan. *Preserving and Restoring Monuments and Historic Buildings* (pp. 207–230). Paris: Unesco.
- Selwitz, C., Maekawa, S. (1998). *Research in conservation: Inert Gases in the Control of Museum Insect Pests*. United States of America: J. Paul Getty Trust.
- Shnawa, H. A. (2021). Curing and thermal properties of tannin-based epoxy and its blends with commercial epoxy resin. *Polymer Bulletin*, 78, 1925–1940.
- Söğütü, C., & Sönmez, A. (2008). Determination of dimensional changes on the kundakari constructed wooden panels. *Journal of the Faculty of Engineering and Architecture of Gazi Univesity*, 23(2), 349–356,
- Söğütü, C., Döngel, N., Togay, A., & Döngel, İ. (2014). İstanbul'da bulunan Mimar Sinan eseri cami ahşap kapı ve pencere iç kepenklerinin malzeme, boyut, süsleme ve yapım tekniği açısından incelenmesi. *Journal of Polytechnic*, 17(2), 49–57.
- Spirydowicz, K. (1996). The conservation of ancient Phrygian furniture from Gordion, Turkey. *Studies in Conservation*, 41(1), 166–171.
- Strang, T. J. K. (1997). Controlling insect pests with low temperature. *Canadian Heritage, Canadian Conservation Institute Notes* 3/3.
- Taşkın, H., & Yıldırım, N. (2011). The damages of *Anobium punctatum* (De Geer, 1774) in Küçüksu pavilion-Istanbul and fumigation applications. *Journal of the Faculty of Forestry, Istanbul University*, 61(2), 85–93.
- Timar, M.C., Gurau, L., Porojan, M., & Beldean, E. (2013). Microscopic identification of wood species-an important step in furniture conservation. *European Journal of Science and Theology*, 9(4), 243–252.
- Timar, M. C., & Beldean, E. C. (2022). Modification of shellac with clove (*eugenia caryophyllata*) and thyme (*satureja hortensis*) essential oils: compatibility issues and effect on the UV light resistance of wood coated surfaces. *Coatings*, 12(10), 1591.
- Tomaszek, T. (2022). *Authenticity and Wooden Architecture Preservation in Asia, A Chinese Perspective* (1st ed.). London: CRC Press.
- Toper-Kaygın, A., & Sade, E. (2004). Türkiye'de bulunan Anobidae familyasına bağlı türler ve bunlardan bazı önemli türlerin tanıtımı. *ZKÜ Bartın Orman Fakültesi Dergisi*, 6(6), 142–152.
- Tuduce-Traistaru, A. A., Timar, M. C., & Campean, M. (2011). Studies upon penetration of Paraloid B72 into poplar wood by cold immersion treatments. *Bulletin of the Transilvania University of Braşov Series II: Forestry, Wood Industry, Agricultural Food Engineering*, 4(53.1), 81–88.
- Tuduce-Traistaru, A-A. T., Sandu, I. C. A., Timar, M. C., Dumitrescu, G. L., & Sandu I. (2013). SEM_EDX, water absorption, and wetting capability studies on evaluation of the influence of nano-zinc oxide as additive to Paraloid B72 solutions used for wooden artifacts consolidation. *Microscopy Research and Technique*, 76, 208–218.
- Tran, Q. K., Boutaine, J. L. (2017). Trends in consolidation of porous materials. *Uses of Ionizing Radiation for Tangible Cultural Heritage Conservation* (pp. 105–111). Vienna: International Atomic Energy Agency.

- Tran, Q. K., & Cortella, L. (2017). The state of the art in radiation processing for cultural heritage in France. *Uses of Ionizing Radiation for Tangible Cultural Heritage Conservation* (pp. 221–228). Vienna: International Atomic Energy Agency.
- Tscherne, F., Wilke, N., Schachenhofer, B., Roux, K., & Tavlaridis, G. (2016). *International Journal of Conservation Science*, 7(1), 295–300.
- Türkoğlu, S. (1967). Edirne Müzesi'ndeki edirmekârî ağaç işlemleri. *Türk Etnografya Dergisi*, X, 67-74.
- Unger, A., Schniewind, A.P. & Unger, W. (2001). *Conservation of Wood Artifacts A Handbook*. Berlin: Springer Press.
- Ünal, S., Özcan, E., & Kaygın, A. T. (2009). Wood-destroying Coleopteran species in the historical buildings in Kastamonu. *Turkey, African Journal of Biotechnology*, 8(10), 2349–2355. <http://www.academicjournals.org/AJB>.
- Valentin, N. (1993). Comparative analysis of insect control by nitrogen, argon and carbon dioxide in museum, archive and herbarium collections. *International Biodeterioration & Biodegradation*, 32(4), 263–278.
- Valentin, N., Lidstrom, M., & Preusser, F. (1990). Microbial control by low oxygen and low relative humidity environment. *Studies in Conservation*, 35(4), 222–230.
- Walsh-Korbs, Z. (2022). Sustainability in HeritageWood Conservation: Challenges and Directions for Future Research. *Forests*, 13(1).
- Walsh-Korb, Z., & Averous, L. (2019). Recent developments in the conservation of materials properties of historical wood. *Progress in Materials Science*, 102, 167–221.
- Weththimuni, M. L., & Licchelli, M. (2023). Heritage conservation and restoration: surface characterization, cleaning and treatments. *Coatings*, 13, 457.
- Weththimuni, M. L., Milanese, C., Licchelli, M., & Malagodi, M. (2021). Improving the protective properties of shellac-based varnishes by functionalized nanoparticles. *Coatings*, 11, 419.
- Williams, D. C. (1998). A survey of adhesives for wood conservation. In K. Dardes and A. Rothe (Eds.), *The Structural Conservation of Panel Paintings: Proceedings of a Symposium at the J. Paul Getty Museum* (pp. 79–86). Los Angeles: Getty Conservation Institute.
- Williams, M. A., Ferrell, M. M., & Baker, J. (1998). Technology and conservation of decorative surface systems of horse-drawn vehicles. In V. Dorge & F. C. Howlett (Eds.), *Painted Wood: History and Conservation: Proceedings of a symposium organized by the Wooden Artifacts Group of the American Institute for Conservation of Historic and Artistic Works and the Foundation of the AIC* (pp. 345–362). Singapore: J. Paul Getty Trust.
- Yıldırım, N., Taşkın, H., & Karaman, R. (2012). İstanbul-Beylerbeyi Sarayı'nda Coleoptera türlerine karşı sülfürlü florit kullanılarak yapılan fumigasyon uygulaması. *Journal of the Faculty of Forestry, İstanbul University*, 62(1), 47-52.
- Yücel, A., & Kantarcıoğlu, S. (1997). *Müzelerdeki Eserlerin Bozulmasında Mikropların Rolü* (1st ed.). Ankara, Türkiye: Kültür Bakanlığı Yayınları.
- Yücel, E. (1977). Osmanlı ağaç işçiliği. *Kültür ve Sanat*, 5, 58–71.
- Ziyrek, A. (2011). The tombs and the cemetery of the Süleymaniye complex, In M. Ceylan (Ed.), *Vakıf Restorasyon Yıllığı*, 3, (pp. 123–132). İstanbul, Türkiye: Vakıflar Genel Müdürlüğü.

CHAPTER 20

THE RESTORATION OF THE FRIEZE AND PAINTINGS ABOVE THE FIREPLACE IN RIARIO'S HALL OF PALAZZO GALLO (BAGNAIA, VITERBO, ITALIA)

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Abstract

This essay is about the restoration work of the grotesque ornament's frieze and the paintings above the fireplace in the Riario Room of Palazzo Gallo in Bagnaia, a hamlet near Viterbo (Italy). The frieze, located in the most exposed point of the room, was in a terrible state of conservation, and the elegant images of the early 1500s were barely visible due to numerous previous interventions and repeated manipulations. With this summary of the work done for my degree, I would like to focus on the various types of technical outcomes derived from the study of this masterpiece. The intervention witnesses the contest of the commitment and the taste of the artist in Viterbo between the 15th and 16th centuries. The dating of the painting has been investigated by comparing them with similar ones. The procedures used in the creation of the artifact, as well as the characteristics of the materials and the different methods used in their application, have been analyzed in depth. By focusing on the past conservative actions and tampering, this work determines that the state of preservation has been illustrated from the preparatory layers to the pictorial film. Moreover, the diagnostic techniques used in support have been reported in conjunction with the description of the restoration intervention. Therefore, this work is the result of an interdisciplinary collaboration between art historians, restorers, and technical diagnosticians, the latter being critical in the development of scientific inquiries, both traditional and cutting-edge, such as pulse compression thermography and hypercolotimetric multispectral imaging.

Keywords: Frieze, Riario, Bagnaia, Restoration, Fireplace

1. Palazzo Gallo, History and Style

Bagnaia, a village near Viterbo, has a long and deeply intertwined story with Viterbo, a city that can be considered the theatre and mirror of the Roman papacy events. The small town is famous for its Villa, a place of delights conceived by distinguished artists and prominent clergy figures. Like many sites of the Patrimony of St. Peter, this cast's identity and artistic instances merge with the peculiarities of the place, developing elements and unrepeatable shapes that are still admired today.

Bagnaia's fortune is primarily due to its well-sheltered location with abundant streams and waterways and its strategic position, which links Viterbo to the Cimini Mountains and Rome. An ancient "castrum" gradually changes appearance, thanks to the Roman cardinalate, who were fond of this location (Zanardi, 2021). When Raffaele Riario, one of the event's silent protagonists, moved to Bagnaia, he wanted to create works that reflected his position. He was a very wealthy and intelligent man who was seduced by what could express greatness: lavish palaces and works of art. His activity as a client is intense, as are the episodes in his life; his charges are numerous. Famous residences are associated with his name, such as Palazzo della Cancelleria, Palazzo Corsini alla Lungara, Palazzo Altemps in Rome, and Riario's Episcopate in Ostia, some of which are important in defining an artistic style similar to Palazzo Gallo's paintings. The activity of the Riario family in Bagnaia is expressed by Giuliano Gallo, who soon has a Palace designed and conceived after the taste of the cardinal, who leaves everything in the hands of his nephew, Ottaviano Riario.

At that time in Bagnaia, something visually typical of the early 30s of the 16th century was conceived, but specific to the Riario family, one of the most refined and influential during the papacy of Julius II Della Rovere, Raffaele Riario's uncle.



Figure 1. Entrance of Palazzo Gallo.



Figure 2. The facade of the palace on the valley.



Figure 3. Detail of the frieze and the painting on the fireplace in the center of south wall.

The documentary source consists of only a few brief reports, yet there is a glimpse of intertwining events that led Giuliano Gallo and his heirs to live in the Palace. In 1514, the purchase of real estate is documented in the inner area of Bagnaia, in the district of S. Stefano, within the walls of the village, on behalf of Ottaviano. Two brief notes could concern works at the Palace, but this is not certain due to other Riarios' works and construction sites in Bagnaia, such as the Palace or the buildings, inaugurated by the Riarios for the Barco and the hunting lodge of the famous Villa Lante (Fagliari Zeri Buchiccio, 2007). The first news reported Giuliano Gallo paying Ludovico Becci 21 ducats on January 1, 1537, to "renovate the hall of the Bagnaia's house that was ruined" (Byatt, 1981). The financing for the road was secured in 1556 (Brothers, 1988), and the first sale of Palazzo Gallo occurred in 1571, before it was sold to the Municipality (Frittelli, 1977). In 1576, the council came into possession of "a complex of over twenty rooms including the stables and the colombaia; beautiful paintings in the rooms of representation, a huge fireplace in the living room and a delightful porch on the piazzetta" (Frittelli, 1988) and since then it has been arranged differently. Only four of twenty rooms of importance and value can be admired, including the large Hall at the entrance of the porch, whereas the other rooms have been divided, sold, or has lost their pictorial decorations.

In the right wing of the main floor, there are three rooms adorned with friezes and heraldic coats of arms related to the Riario family and their protégés, Gallo's family, the municipality of Bagnaia, and Rome, to commemorate the families' provenance. The frieze repeats the same

motif on all four walls: a central heraldic shield supported by two winged putti, touching a mythical figure of a woman with a phytomorphic tail from which acanthus gyral's are generated. Many of these figures wear headgear and have various hairstyles, but they are all writing with a stylus on a tablet supported by turned arms. Meanwhile, the gyral's host puttini that tighten their inflorescences, alternating to white-winged horses with horn. The gyral's design consists of the bust of an armed putto grabbing the horn of the fantastic animal and closing the motif, which is reflected the same way on the four walls. A fireplace surmounted by a painting accompanying the frieze, presenting the same motif of a large coat of arms supported by two winged putti and, in this case, two small heraldic shields next to it, can also be found on the south wall of Sala Riario, the subject of the restoration here discussed. The emblems depict Raphael Riario, Bagnaia, and the Gallo family, whereas the central coat of arms on the frieze belongs to Niccolò Ridolfi, one of the most important bishops who succeeded the Riaris. The coats of arms on the other walls belong to Federico Cesi (west wall), Agostino Spinola (north wall), and Marco Corner (east wall). In the other rooms, we find the coats of arms of Bagnaia and Gallo (Sala Gallo or Mascherone) and Giovan Girolamo de Rossi and Raffaele Riario (Sala de Rossi or dei Dolphins) once more. The paintings are lively and have the typical rhythm that exalts the family, revealing to us traces of the client's tastes and the artists' offer.



Figure 4. Detail of the frieze.

Precious garlands of fluttering ribbons surround the coats of arms on the frieze's blue background, and the rosy putti is firmly supported by a fake architectural frame with motifs

of “kyma” trilobed and astragalus with spindle and beads alternated with stripes and a black band that closes the frieze. In the upper frame, monochrome pattern bands are followed by those with eggs, darts, and a continuous wave, all the way to the wooden ceiling. The precious decoration of the slab’s wooden table deserves special mention because it shows the characteristic and peculiar ways and styles of a team of painters’ work; the unified style between the friezes and the ceiling, repeated in the three rooms, attests to the organic nature of the residence painting project. Three murals in the rooms of the Palace deviate from these works: in Sala Riario, two paintings on religious subjects, made in 1619, facing the east and west walls, respectively, a *Crucifixion*, and the *Virgin between St. Sebastian and St. Millerio*.

The final paintings, those outside the porch, deserve a careful description. The environment enhances the square by adorning the Palace’s facade with figurative panels set in a fake architecture that mimics the real one of the building, complete with columns and wooden beams from the attic. A painting depicting the Barberini coat of arms, flanked by cartels and virtues, is centered above the gate and was created between 1632 and 1644 during the administration of Antonio Barberini (Zanardi, 2021). The painting is also flanked by two panels, which, like the wooden ceiling, belong to the first decorative phase of the rooms. These are decorated with heraldic coats of arms, a motif already found in the interior. As their subject, the murals have two putti holding an oversized coat of arms affixed to a garland, tied with ribbons, fluttering on the bottom, below two pairs of the family emblems.

Without documents on the site, it was necessary to contextualize the paintings in a broader context, proposing a dating and possibly an attribution. Although no specific figure of a painter or architect has been identified for Palazzo Gallo, some suggestions perfectly place the taste and technique of a client and an artist workshop. Several paintings found in noble buildings and churches bear similarities to the trends expressed at Palazzo Gallo.

Among the remarkable cases evoked is Riario’s Episcopo. The frieze of the great hall’s decoration, combined with a painting similar to Roman bas-reliefs, is a source of inspiration for the realization of Palazzo’s Gallo paintings. One can admire putti fumbling with tridents against birds. They are created by generating the phytomorphic tail of a female figure holding a crossed shaft. In the spiral, winged puttis are accommodated, and they support cartouches with the rising motto “hoc opus sic perpetuo,” which refers to Riario family. Illusory hanging garlands with the coats of arms of the Della Rovere and Riario families hang from the frieze, painted in monochrome on a blue background, and the scenes are developed into an architectural frame.



Figure 5. Riario's Hall, Episcopo (Ostia, Roma), and detail of the frieze.

Authors of the pictorial cycle are Baldassarre Peruzzi, Jacopo da Sesto, and Jacopo Ripanda. This painter is also connected with Raffaele Riario for the creation of the decoration of the wooden ceiling in Palazzo Corsini (Pezzuto, 2016), an artwork that shows many particular stylistic similarities with the residence of Bagnaia.

Instead, Baldassarre Peruzzi was not only the painter who fully represented Raffaele Riario's favorite antiquarian style during his long career; he was also able to influence other artists in Viterbo's area. As a matter of fact, it was possible to admire a frieze by Peruzzi in the S. Giovanni degli Almadiani in Viterbo, built in 1510, where the artist decorates the sacristy in monochrome (Faldi, 1996). Once again, there is a picture evocative of the Riario's Hall paintings. In this case, the winged putti fly over insidious birds and dolphins, bringing a crown and presenting toward a vase full to the brim of flowers. The evangelist was refigured in clipeus on the four walls into an architectural frame.



Figure 6. Detail of the frieze from the lost sacristy of the S. Giovanni of Almadiani church. Viterbo.

Another church with similar paintings is S. Maria delle Fortezze. Two chapels, seemingly painted by the same artistic workshop, were decorated between 1525 and 1532 (Susi, 2007).

In particular, the west chapel's frieze that separates the Virgin Mary's two scenes (the *Assumption* and the *Coronation*) and retraces entirely the one in Riario's Hall stands out. It is smaller and more schematic; putti with court sword are absent, and the female figures and the vase in the corner vary slightly.

In the south chapel, where a *Nativity* and a *Christ seated in mandorla* are painted, one can see a strong resemblance between the Palazzo Gallo's putti and that of the Sybil. Still, the difference is limited to the size and specularity of the images. Other affinities were observed between the dolphin on the frieze around the vault of the chapel and the grotesque that animates the wooden ceiling of Palazzo Gallo.



Figure 7. South chapel (on the left) and west chapel (on the right) of the church S. Maria delle Fortezze. Viterbo.



Figure 8. Detail of the frieze in the west chapel of S. Maria delle Fortezze (top).
Detail of the frieze in Riario's hall (bottom).

The major emphasis of the church also concerns this construction's event. Ottaviano Riario committed to building it, and he entrusted the work to Vincenzo Danese Ambrogio di Bartolomeo da Milano and Battista di Giuliano da Cortona (Padelli, 2003), who are also present on the construction site of the Villa Lante hunting lodge (Fagliari Zeri Buchicchio, 2007).

These similarities, also in the executive procedure with the use of the same cardboard, suggest the operation of the artist team in both S. Maria delle Fortezze's chapels and Palazzo Gallo.

Choosing and selecting details, the same characters are also found in Jesus's church, close to Fortezze church. The fluttering ribbons of the musicians' angels, the motive of the dolphins, and the grotesque share the same style as the mentioned example.

The team of forgotten painters of this critical season of Viterbo's painting can be discovered by conducting a deeper study of this location. These models are useful for anchoring the Palazzo Gallo's painting to a specific style of antiquarian vocation in vogue at the beginning of the 16th century. This style is particularly popular among the Rovere and Riario families, so much so that it has been adopted for use as pagan painting in religious competitions (Caporossi, 2020). Inspired by the taste of its noble protector Riario, Gallo's family proposes this style in their palace, making it unparalleled for its ancient richness in the Bagnaia contest. In conclusion, it is important to underline how a detailed artistic and technique study can help discover hidden aspects of the artwork and confide the possibility of referring to more reported contests.



Figure 9. Putti's comparison between Riario's Hall frieze (left) and that one beside the right sybil in the sud chapel of Fortezze church (right).

2. The executive procedure

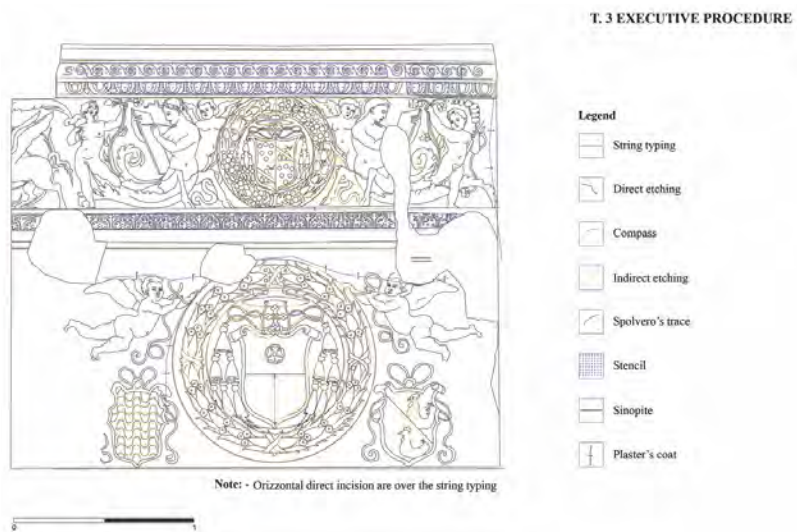


Figure 10. Restoration's graphic documentation. Executive procedure.

We can learn much about the artist workshop that painted the halls of Palazzo Gallo by observing the execution technique of the painting. The meticulous planning of the artwork was rebuilt, thanks to visual investigations and the invaluable assistance of diagnostics, showing the painters' high level of competence in decorating the surface. Examining the central part of the south wall in depth, one can hypothesize on the artists' *iter* to move from the wall to the frieze and to the fireplace's paintings, gathering their signs and retracing the construction site procedures.

The fireplace stands in the center of the wall, and the flue space was obtained by a crack in the mixed peperino and brick blocks, the typical masonry in Bagnaia during Riario's authority (Serone, 2007). The fireplace's back wall is made of bricks, and the firebox is covered with at least two thin layers of plaster. The fireplace framework is made of three large peperino blocks wedged against each other and frontally carved with a refined "tip of diamond" motif. Meanwhile, slanted bricks are placed on the overmantel up to the top of the ceiling. The roughcast was applied to the solid wall, and the Arriccio is laid on it, even though the one used for the flue is different: it is thinner and more adhesive. On the Arriccio, a sinopite separates the frieze from the rest of the wall. The plaster layers that follow are large and few. They appear to have been carried out quickly, one after the other, from the south wall, right to left, and top to bottom: we counted four of them.

The wall's sections were divided according to the project and by typing the string and marking the point with a direct etching. Doing so makes it possible to create twelve bands, which define the frieze between its ornamental framework and its lower black strip. It is very likely that to centralize the decoration better, the artists stretched the string from the edges of the upper frame of the fireplace to the inner edge of the beam below the ceiling. Just below the frieze's figurative designs scene, three notches are cut along the etching, overlapping the three strings where the lower frame begins. The median line of the painting goes through the central point, where other notches are found near Riario's coat of arms. Meanwhile, the side-line strings mark the outline of the arm and hand holding the women's ink pen. Interestingly enough, these strings coincide with the writing female protome's hoof. The artists managed to find the area in which to paint the coat of arms using these kinds of reference and compasses. As aforementioned, the selected areas are the frieze of Ridolfi's araldic shield and over the fireplace of Riario.



Figure 11. Strings stretched from the fireplace's frame to the beams. One can observe the construction lines of the painting. Just below Ridolfi's emblem, the points marked in correspondence of the string.

After dividing the area, the drawing model was carried on cardboard to extract both *spolvero* and indirect etchings. The indirect etchings, mainly found to the right of Ridolfi's araldic shield, were also used to draw elements and features of the coat of arms. Moreover, Bagnaia's emblem shows a grill that helped the painters apply the colors.

The *spolvero* is used to define the outline of the characters; it can be seen in see-through, very fine, and extremely close points (3–4 mm). The *spolvero* is also used when the drawing becomes smaller and more accurate, just as the figures' hands holding their ink pens or court swords.



Figure 12. Regular etching under Bagnaia's coat of arm and spolvero for frieze's detail.

To form the means and procedures of the artistic workshop, poly acetate transparency with the 1: 1 outlines trace was used. Finally, the correspondence of the cardboards was verified. However, the images showed small discrepancies with each other. It was hypothesized that the cardboard could have been segmented; likewise, it is reported in manuals and treatises on painting. In order to maintain the cardboard, several copies of the first one were obtained. The cardboards were generally used in the construction site because they could be easily cut and trimmed, turned upside down, or rotated because they had more handling and could also be used in parts. A peculiar feature of *spolvero* and etching is the minor variation in certain areas. For example, the right putti's hand is different from the one drawn with *spolvero* emerging from the underlying white background. Regarding the etchings, which are mostly on the right side, some do not exactly follow the final drawing on the frieze, particularly regarding the right part of Ridolfi's coat of arms.



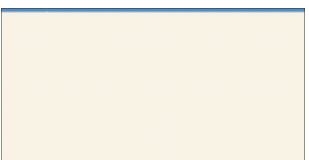
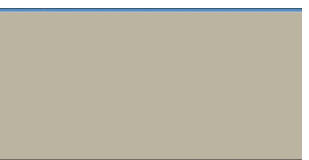
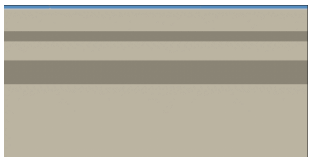
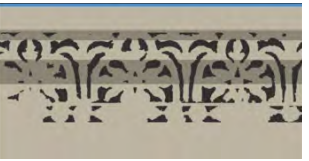
Figure 13. Overlapping of the pictorial draft and the brushstroke's matter.

The underlying passage of paint was applied to a still-wet plaster immediately after cutting the etchings and drawing them with the *spolvero*. When applying the paint, the red color was used for the frieze – except for the characters and emblems on it – while the white was

chosen for the frames and the lower part of the wall. On this fresco painting were finally added, diluted in slaked lime, pigments combined with a low percentage of organic medium, identified thanks to diagnostic analysis.

Following a quick succession of execution passages, the frieze’s red background is first completed by dark shading, providing relief to the characters and the plant-related adornment. The light-blue background follows this and, finally, the completion of the characters. When painting the figures, the artists were definitely more careful and precise. They began with a light base that was modulated half-tone by half-tone to represent the incarnate. Fine darker hatchings define the figures and add depth to the *chiaro-scuro*. The last delicate brushwork is for the mythical figures’ hair, the features, and the highlights. When resorting to oblique lightning, one can appreciate the thicker and denser way of applying the paint. Moreover, it is easier to read the overlay of the paint application.

For example, with this system, the completion of the frame can be deduced via a stencil with a quick and systematic construction. Table 1 presents the succession of pictorial layers that overlap the etching on the plaster.

Table 1. The schematization of steps with stencils		
		
		
		
		
Scrolling the lines from top to bottom and from right to left reconstructs the lower frame shown in the picture.		

Traditional pigments of the 16th-century wall painting were found while investigating the palette. Diagnostic analysis, such as XRF, was used to isolate the elements constitutive of the mixture: for the red cinnabar and/or red earth; yellows are made of terra di Siena, like the color of incarnate obtained by tempering it with S. Giovanni's white; for the blue of the ground or the shields, elements similar to smalt such as cobalt and arsenic were found. The green tone employed is green earth, as in the Riario's shield garland, or pigments containing arsenic, copper and zinc, used for recent revisions of the painting. These were in the coats of maintenance paints over the fireplace and in the green in the frieze. Through hypercolorimetric multispectral imaging (HMI) and the elaboration of infrared false color and ultraviolet fluorescence (UVF), we can cross and analyze the distribution of the material on the surface (Lanteri & Pelosi, 2021).

3. Previous restoration and tampering

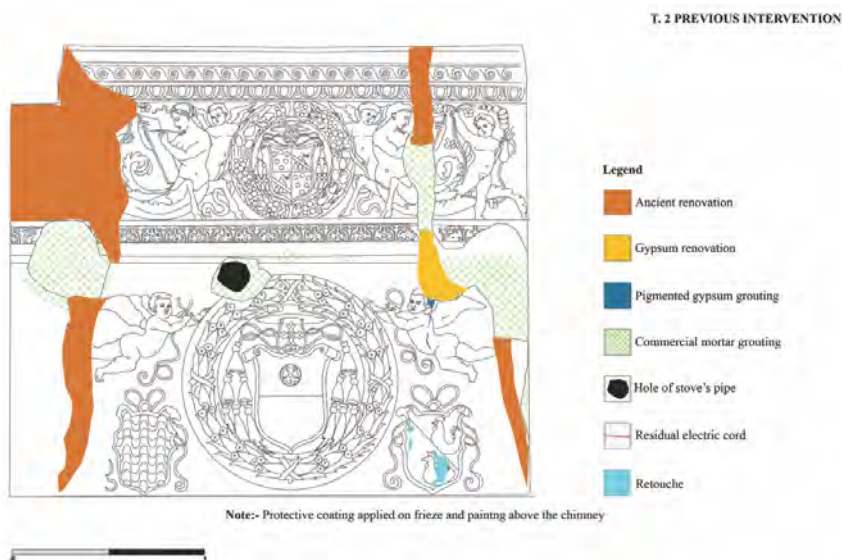


Figure 14. Excerpts from the graphic documentation of the restoration. Previous intervention.

The palace's history can be partially reconstructed by observing the ancient restoration and maintenance work carried out in the room, a path that does not fill many knowledge gaps due to a lack of information on past events. Despite this, the path of this work of art can be understood in close connection with the architectural context of the palace. The presence of extensive renovations in the area of intervention shed light on the structural problems and building that manifested themselves in various forms of surface deterioration. In 1569, masonry damage was so severe that falling materials filled the watercourse in the valley where the house is located (Frittelli, 1988). This useful information confirms what can be deduced from the paintings and

their state of preservation, particularly the restored section of the wall. In this area, along the discontinuity of the walls and the fireplace, structural damage and the settling of the building caused various problems to the paintings, to the point that more than one intervention is required.

The first restoration was completed between the end of the 16th and the beginning of the 17th centuries, and it runs almost entirely through the frieze from the ceiling to the upper frame of the fireplace. On the left, under the beam, the large area of the putti with the horse with wings, a piece of the lower frame of the frieze, the tip of the wing, and the right foot of the winged putti holding the Riario's crest can be seen until it is lost in the white background. On the right side of the painting, the re-make affects the area of the tablet of the female figure next to the frieze and the foot of the puttis suspended above the Gallo family shield, up to the corner of the peperino frame; this intervention's components have been lost or replaced. The same reconstruction can also be seen on the north wall, mirroring the first at the beam, where the unicorn with wings is painted, as well as in the de Rossi Room. The portions in the latter are more circumscribed, except for a larger area on the right side of the fireplace.



Figure 15. Details of the ancient restoration below the left beam.

Fallowing to the creation of the sacred paintings, when the Riario Hall was most likely destined to be used as a chapel (Zanardi, 2021), a further and circumscribed restoration was carried out, indicating the need for further work on the painting. The restored area corresponds to a portion of the right Riario putti's head, the apex of his wing, and the painting's clear background. The plasterwork with chalk, was approximate, re-proposing the surrounding decoration in a poorly mimetic manner.

The reconstruction was followed by the installation of beams in the masonry, the locations of which were identified during the restoration under two large stuccoes along the lower black band of the frieze. The presence of similar stuccoes in the Hall suggests a probable more articulated beam system and hence similar tampering at various points on the south and west walls.

Other important changes in the overall environment have been reconstructed, thanks to the memories of those who grew up in Palazzo Gallo. Indeed, the rooms have been handed over to war evacuees since 1943, and the sequence of events can be more easily reconstructed. To accommodate at least two families, several partitions were raised, and the openings were modified by transforming a window into a door with a small balcony and closing the door that led into the large Frittelli Hall. In the palace halls, the domestic life used the rooms for daily activities. In order to make the room more comfortable to live in, a cheap kitchen has been installed on the left side of the fireplace with its flue inserted in the central part of the paintings above the fireplace, slightly off-center to the left. This obliterates part of the garland around the Riario garland, the lower frame of the frieze, and the pictorial background.

At the end of the 1980s, the main floor of the building was recovered and returned to the municipality of Viterbo, which had already incorporated the Bagnaia building in 1928. After removing the kitchen, the balcony, and other additions, such as the partitions, the room's original dimensions, and openings were restored to the space. Originally used as storage for various materials, the rooms later became the headquarters of cultural associations that spearheaded the palace's enhancement.



Figure 16. East facade with two little balconies; the upper one was in Riario's Hall.

Considering the overall condition of the interventions carried out directly on the surface, a few limited contemporary retouches can be seen on the frieze. In contrast, the paintings above the fireplace have undergone progressive concealment with partial reductions in the paintings. The importance of the periodic maintenance in this work section warrants special mention during the intervention. Several layers of overpainting were identified beyond a gypsum-pigmented iron oxide plastering that fills parts of the cracking that continues under the chalky overpainting. The first coat of maintenance paint of the background corresponds with the earliest reconstructions; in fact, the new ash-white layering plastered the original painting to the parts reintegrated during the restoration, with all the others overlapping the chalk reconstruction, and their number and consistency increased significantly during the years the rooms were used as flats. A revitalizing or protective coat was applied, but, unlike the coats of maintenance paints, its presence can also be seen on the frieze and ceilings.

During restoration in the last few years of the last century, after filling the lacunae coinciding with the ancient beams, together with vertical plastering on the frieze that fills in the lack of the woman's tablet on the right side of the Ridolfi crest, leveling compounds were applied to level the surface. Moreover, two coats of semi-washable white tempera were applied.

Students from a regional course as a restoration collaborator technician initiated an initial intervention in 2004, which involved the exterior paintings of the porch and a small portion of the frieze in the Riario Hall. Furthermore, two stratigraphic pieces were created in the paintings above the fireplace during the intervention, with the median part between the Ridolfi and Riario emblems at the height of the black band that closes the frieze, which was partially discovered.

Since 2017, the association "Amici di Bagnaia," in collaboration with Tuscia University, has performed a series of decorative parts restorations to restore the health and legibility of the paintings, to deepen the knowledge of the area.

During the dissertation and restoration work on the paintings in 2020, a cognitive and comprehensive approach to the history of the Hall and the paintings was taken, including conducting interviews with Bagnaiola community members who could directly or indirectly, help reconstruct the history of the second half of the 20th century. Further efforts have been made in the constantly interdisciplinary dialogue between diagnostics and art history, researching conservation practices for the best possible solutions to initiate the complex restoration work.

4. State of preservation of preparatory layer

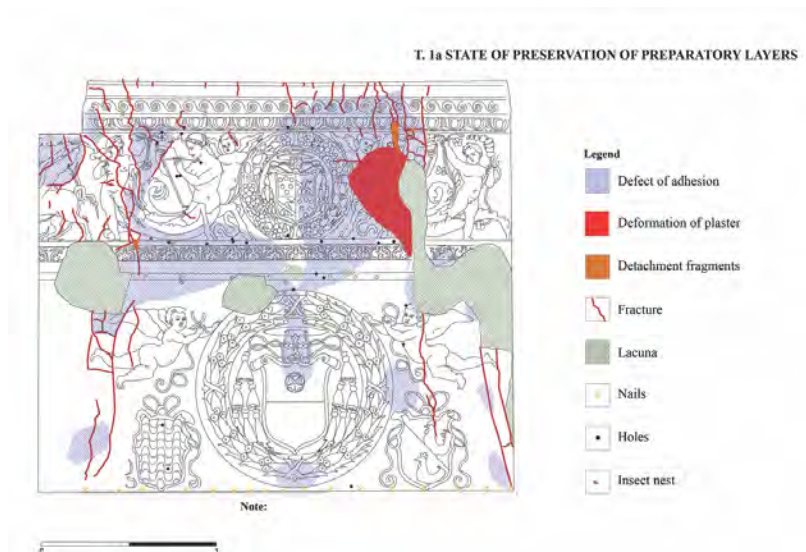


Figure 17. Excerpts from the graphic documentation of the restoration.
Preservation state of preparatory layers.

The actual preservation of the preparatory layers is determined by observing the current state and their graphicalization. When analyzing the available data, a critical and fragile area was pinpointed along the section between the flue and the masonry. The same area also showed discontinuities at the support level.

It has always required special attention over time, which has frequently caused problems with the state of the paintings. Three renovations can be found on the right side of the frieze: an ancient one, a modern gypsum one, and grouting of premixed mortar to the right of Ridolfi's coat of arms. In this critical area, a deformation of the plaster persists along with significant adhesion defects, determining a detachment of up to 2 cm, which reduces and then stabilizes from the middle of the coat of arms. Further adhesion defects were found below the left beam and along the right arm of the putti painted on the ancient renovation. The band between the frieze and the fireplace painting also shows detachments along the entire lower frame of the frieze. More localized defects follow the band between the flue and the wall, just in the fireplace frame.

The adhesion defects of the plaster are due to ancient settlements and the instabilities of the building, not to overlook the manipulation of the space during the 20th century: the opening of a door and the placement of a balcony (with a small bathroom); furthermore, the partition walls of the building near the trusses, and then their removal, certainly compromised the adhesion of the plaster.

Deep fissures on the surface indicate the area's fragility between the flue and the solid wall. The deepest correspond to the edge of the ancient renovation, which is also cracked. In fact, the plaster of the renovation seems to have suffered a deeper decay than the original. The general framework of fissures becomes even worse when added to the plaster adhesion defect mentioned earlier. The fragments detached: The fragments detached from preparatory layers and isolated by the fissures were in danger of falling. Finally, the cracks were recorded near the nail holes and in the section of the painting just below the ceiling, which are of minor importance and are attributable to the execution techniques of the work.

Plaster's flaws are primarily the result of previous manipulations in the room. Aside from the lacuna on the frieze caused by the deformation of the plaster, the others are caused by the installation of smaller beams and the stove's pipe. In these cases, the amount of lost painting is greater than the actual size of the inserted object. On the contrary, despite their quantity, the nails' drillings are small and precise; they were used to secure the electric cord to the painting's surface. Some of these are still operational, while others have been decommissioned. As stated above, nail drilling has often caused small fissures and a general structure weakening. Occasionally, some holes have been infested by insects that have used them as nests.

5. State of preservation of pictorial film

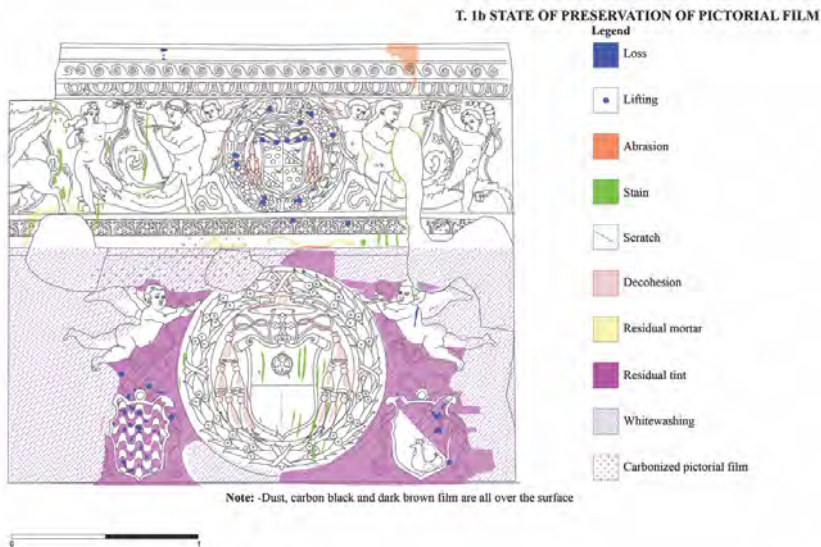


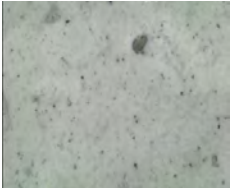
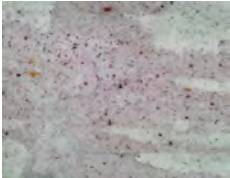
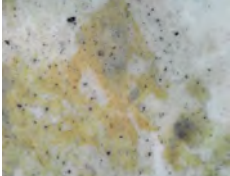
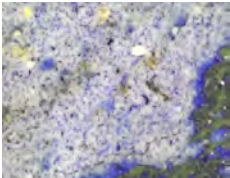
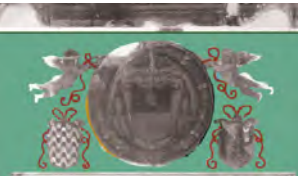
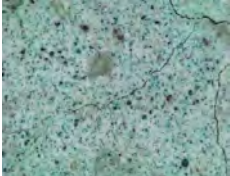
Figure 18. Excerpts from the graphic documentation of the restoration.
State of preservation of pictorial film.

When it comes to the overall preservation of the pictorial layers, its overall state is good. The frieze and the paintings over the fireplace are noticeably different, with the latter subjected to more manipulations and different maintenance work. The pictorial film is almost intact on the frieze, though small lacunae are spread all over it. These can be ascribed mostly to an execution technique with *secco* finishing touch which, when too thick, happens to be too fragile and causes the layer to part from the surface. Accidental scratches cause some of the falling of the pictorial film. Paint falling is often combined with located lifting due to the detachment of the paint surface.

Abrasions are limited in a few spots, except for the zone above the frieze near the right beam, due to the friction of some metallic materials. There has been a general depletion of the cinnabar used in the cardinal's hat. It was registered on the crests. As previously stated, reviving or some protectant was applied to the surface, but over time it became dusky, blurring the painting's shades and particulars. Furthermore, a deposit of lampblack was spread on its surface, further disrupting the piece's lecture. The heat of the fire, as the area where the kitchen tube got into the wall or where the most severe cracks caused soot leakage, intensified the black lamp. The flashes of mortar and the stains are rather spread. The first were mainly around the grouting, near the left beam and the Riario frieze we find minor whitening due to splashes on the piece.

The paintings above the fireplace were heavily compromised. In addition to altered revitalization and carbon black deposit, a point of serious burn of the pictorial film along the stove pipe and a series of coats of maintenance paint and whitewashing mortifies the painting. As shown in table 2, 12 layers of painting have suffocated and hidden parts of the figures over time. The oldest layer, preserved in the restoration, corresponds with the first remaking and re-proposes the original white background; a gray layer followed this, almost certainly post-plaster makeover, a pink layer (S2), and a yellow layer (S3) following a strong abrasion of the background that received the paint. Two pictorial phases follow each other, each offering a basic color that is toned down with a band just below the frieze: the first blue with a double blue line, the second green with a darker line (S3, S4). Many edges of the figures are already covered and simplified in these drafts, as are many shots on pictorial ribbons and parts of coats of arms. According to what is hypothesized at this time, the stove pipe above the Riario's coat of arms lays out a further green coats of maintenance paint (S5), followed by another rose: the one observed before the restoration and the last between the puttis and the minor coats of arms around the shield. The rear coat of

maintenance paint, a light gray, adapts to the external surface of the figures and separates the frieze from the wall. The two subsequent yellows (S6, S7) cover the feet and parts of the legs and wings of the putti, as well as fill the lower part of the coat of arms. A green layer and a fixative (S8, S9) coincide with the last color of the housing phase and the grouting with premixed mortar, the last two coats of white (S10, S11) were laid with the restoration of the Hall in the ‘90s.

Table 2. Coats of maintenance paints and whitewashing on the paintings on the fireplace		
Graphic Reconstruction	Description	Image from video microscope
	Phase 0 Original state / historical restoration	
	Phase 1 Antique pink with a revival of the black band, whilec covers the first gray layer, not entirely preserved	
	Phase 2 The first yellow corresponds to layer S3	
	Phase 3 Blue with double frame Ultramarine Blue and repainting (S4)	
	Phase 4 Green finished with a dark green frame, followed by another green (S5) after the installation of the stove	

	Phase 5 Modern pink that covers S5 (the area in transparency seems to be just a haze) and probably reviving coat	
	Phase 6 Gray	
	Phase 7 Yellow S6	
	Phase 8 Light yellow S7, installation of the cap on the fireplace hood	
	Phase 9 Light green S8 with fixative S9	
	Phase 10 First and second coats of white paint (S10 and S11)	

To understand a similar stratification of previous and whitewashing, a careful observation of the surface and a laborious work of interpretation were required, which, along with historical research and removed coats of maintenance paint's dowels, indicated the best presentation in the restoration phase.

6. Restoration's intervention

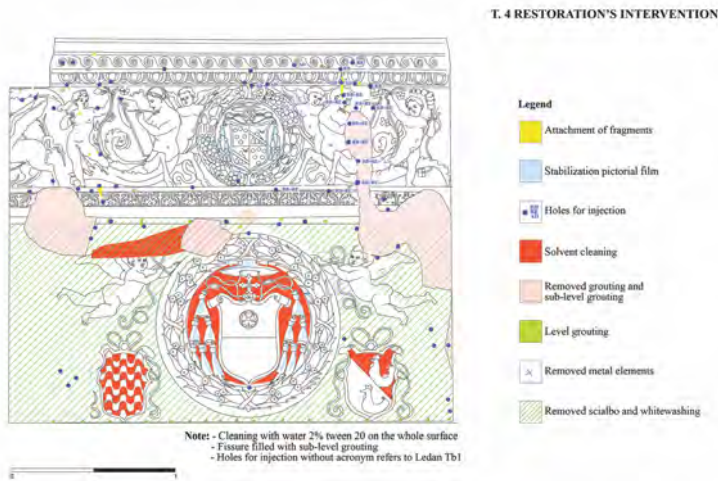


Figure 19. Excerpts from the graphic documentation of the restoration. Restoration intervention.

As repeatedly pointed out, the first approach to the work was an exploration aimed at a knowledge of the work as wide as possible. We created graphic documentation by developing photographic documentation, which is a useful tool for analyzing the state of conservation and is required to illustrate the intervention. The documentation's continuous reflection and progressive updating has accompanied the gradualness that has distinguished this intervention. In addition to delicate aesthetic decisions such as coats of maintenance paints revision and whitewashing, preservation emergencies such as frieze detachment were urgent; these circumstances have imposed as much caution as possible and necessary support provided by the diagnostic techniques applied to cultural heritage.

The first steps were to repair the broken pieces and the painting film, followed by the cleaning procedures. The adhesion of the preparatory layer fragments was restored using acrylic resin in a 25% or 50% dilution as needed, conveying water and ethyl alcohol 1:1 through the cracks by gluing the detached plaster or Arriccio revealed during the removal of the previous grouting. The detachment of the pictorial film was also fixed with a microacrylic resin, and the k 52 (to 20% in isopropyl alcohol and water 1:1) was injected with an insulin syringe under the detachment, while tamponating, making light pressure, and ensuring the states' adhesion. To secure raised areas and better control the procedure, the same operation was performed during the coats of maintenance paint's removing. Finally, the points that

showed decohesion were treated with the same consolidant after a first slight cleaning and a lower concentration (10%). the cardinal attributes in the coats of arms were treated, standing the product with a brush.

The cleaning was carried out with the same methodology identified in the previous restoration works on the frieze, water-based, and surfactant (Tween 20 and 2%), in a compress on Japanese paper for a few minutes and removing dirt using latex sponges, after color tightness tests. Other tests were run, but the same system was chosen because it is practical, versatile, cost-effective, and has a low environmental impact. Cleaning systems could also be expanded or changed in certain areas. If the treatment was easily obtained on the frieze by repeating what and where necessary, the area of carbonization of the pictorial film, repainting of the minor coats of arms of the fireplace, and the Riario shield required more attention. The stove's flue duct was combined with the use of a polar solvent and ammonium bicarbonate (10% w/v). Nevek mixed with Mec (3:1) was spread over the area when the solution was applied on Japanese paper. The carbon coating was removed after 15 minutes using a long swab finish and melamine sponges. On a light background, to further lighten the stains penetrated through the dullness, a microabrasive pencil was punctually intervened. The repainting on the minor coats of arms was removed by removing the layer and topping the area with triammonium citrate (at 3% w/v for 3 minutes), then rinsing it. The surface was further finished with the use of anionic resins worked in contact with the paint film for about a minute, removed and cleaned with a swab on the bottom of the Riario frieze, where the penetration of the fireplace fumes was greater. When exposed, the preparatory layers were also cleaned with 10% (w/v) ammonium bicarbonate water and rinsed the surface.

Using image diagnostics with the HMI, a technique capable of providing different processing and information on the work (Laureti et al., 2019), it was possible to quantify the result of the cleaning in mathematical terms, in addition to delineating specific areas of repainting on which work was carried out, such as the fireplace crests. The results were compared using colorimetric information from each point and comparison tiles, and an average of E 21, 91 was recovered in terms of tone, shade, and color intensity. As shown in the figure below, each questioned point shows its position in the color space CIELAB1976 as well as data on brightness and degree of red-green and yellow-blue (coordinates $L^*a^*b^*$) so that we can calculate the values to add data to the restoration.

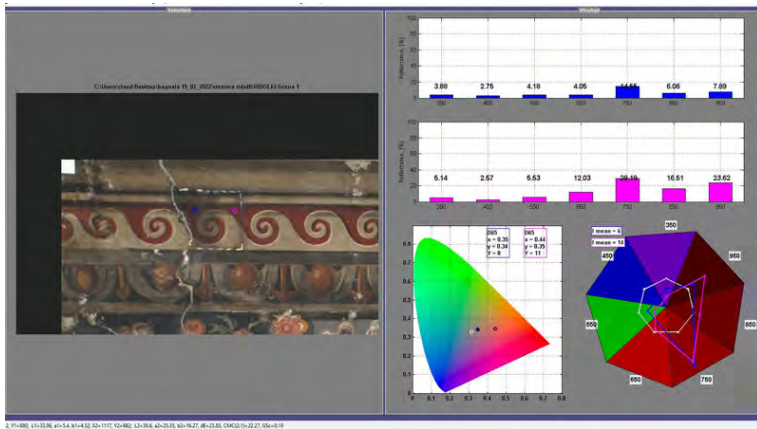


Figure 20. Colorimetric measurements in a piece saved from the cleaning and connected values and position on space color CIELAB1976 (values are reported in the bottom string).



Figure 21. Thermography set during the consolidation (it is visible the thermocamera and the frame with halogen light).

As previously stated, consolidating the preliminary layer, a complex and delicate part of the intervention, necessitated the development of unique strategies. As a first step, areas of punctual detachment were distinguished from larger areas with substantial vacuum to be filled. Passing from the bottom up and using as much as possible the previous cracks, the paint adhesion defects above the fireplace and in the left area of the frieze were stabilized using Ledan TB1. Ledan Ristat B and Ledan Ristat Extra and Ledan Adhesive were used from the middle band's height and throughout the plaster deformation area. Using this injection mortar was decisive in fixing the most critical points, creating a sort of pinning that secures the support to the preparatory layers. The product's characteristics allowed it to be injected

without dripping, thus locally filling the vacuum; the operation primarily involved the middle and upper areas of the deformation and the left edge to fix the parts most susceptible to mechanical stress. The remaining vacuum was filled with successive injections of Ledan Ristat (B and Extra), each time adhering to the setting times specified in the technical data sheets. Consolidation was also performed using small pipes to fill the detachment as much as possible while gradually closing the cracks and holes with mortar when necessary.

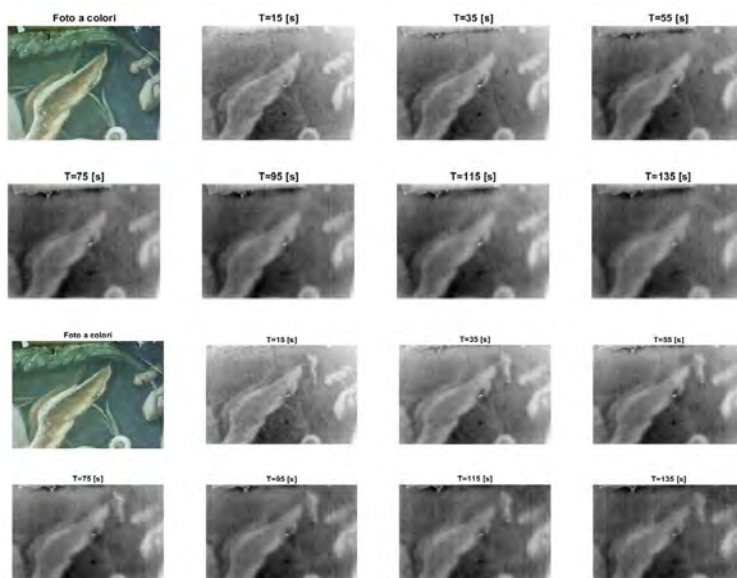


Figure 22. Thermograms in different times of the preparatory layers' consolidation area. On the top before the operation, on the bottom after it.

A special collaboration with the University of Calabria was used to investigate pulsed compression thermography (PuCT) in order to more articulately analyze the relationship between the incidence of adhesion defects and the consolidation of preliminary layers during restoration. Exploiting classical thermography techniques (Volinia, 2004) and with the support of fine processing, the object's material continuity is recorded through the penetration of the thermal pulse and its propagation. This non-destructive technique illustrates the behavior of thermal waves resulting from an intermittent impulse at set times; thus, the impulse's absorption, refraction, or reflection can be seen in thermograms. At a minimum heating (around 2°C), compatible with the object's conservation, variations in the intensity of the gradation in the pre-painting layers would suggest discontinuities in the plaster. The advantage of active thermography over passive thermography is a more restrained shot capable of identifying the layers of the painting and is not limited to global information on the surface; however, it is less immediate and forces the analysis to a not overly large framing.

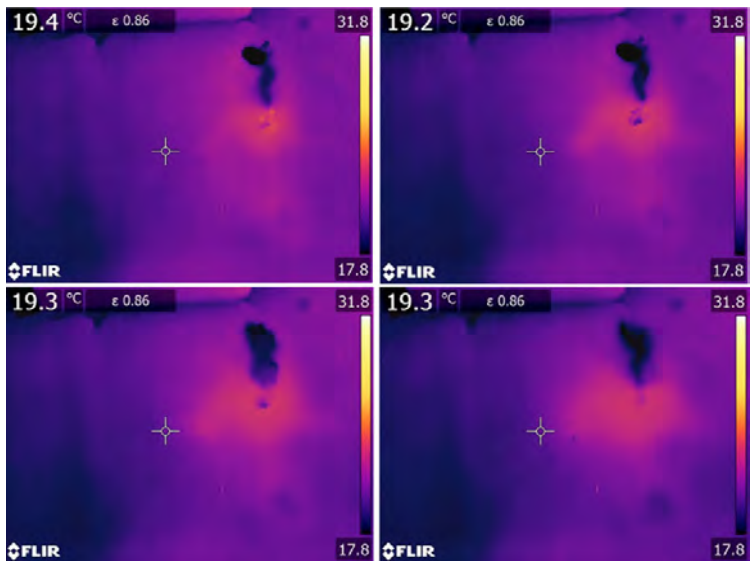


Figure 23. Thermograms with passive thermography. From left to the right, top and bottom, note the expanding hydraulic mortar clearer and warmer.

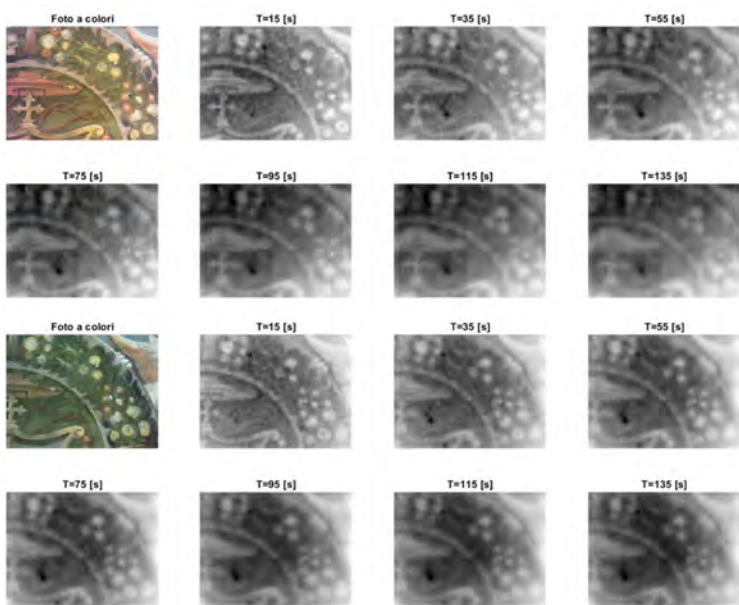


Figure 24. Comparison of PuCT thermograms of Ridolfi's coat of arm. On the top before the consolidation, on the bottom after it.

The painting surface was stimulated using a thermal imaging camera, a tripod with 10 halogen lights mounted with pulses every 10 seconds, a computer, and the device (TiePie HS5 handscope) to generate and acquire the thermal waves, which is completely visible in the first few seconds of filming. The thermogram provides a more detailed view of the work over time, revealing suspicious points and darker detachment areas. Almost the entire right-hand side of the frieze was investigated before and after consolidation, although the noncoincidence of some shots made an objective judgment impossible.

Another ideal demonstration was carried out for a detachment under the left beam, where Ledan Tb1 was used. The injection into a crack was initially prepared with a 1:1 mixture of water and ethyl alcohol. However, the rejection suggested drilling a slightly lower hole, where the effects of consolidation could be best tested with PuCT and simple passive thermography. The area was imaged in PuCT before the operation and immediately afterwards, restoring as visible in picture 24 the sharp and slightly disturbed crack shape, while the gray tones of the background appeared lighter and modified. Passive thermography captured a few moments during the consolidation operations, allowing the diffusion of mortar between layers to be appreciated due to temperature differences.

This technique made it possible to investigate potentially underestimated aspects of the work. As previously stated, it was difficult to compare precise images of the before and after consolidation, but it is a step forward that could also explain other aspects of the work's constituent materials, such as the points just below the paint film with dark colors, which are difficult to explain if attributed to the state of conservation. However, with passive thermal imaging, in addition to the vision of the difference between wall support and fireplace, this appreciable and curious result was obtained during the Ledan injections.

The coats of maintenance paint and whitewashing in the paintings on the fireplace were completed in stages. Following a preliminary cleaning of the area to better understand the succession of layers, the most recent ones (the green S5) were removed by experimenting with various systems, the best and most manageable of which turned out to be scalpel and dry method. Specific research was conducted into using white backgrounds in heraldic painting, on walls and fireplaces, and coats of maintenance paint removing were applied up to the first repainting of the background, covering nearly the entire area. The decision was thus made to remove the colored coats of maintenance paint, bringing the background down to this level, and, with a lengthy finishing operation using scalpels, brushes, and melamine sponges, it was freed of any residual overpainting.



Figure 25. Frieze and paintings of the fireplace during the restoration and the HMI shots.

Previous groutings were removed because they were no longer appropriate. It was necessary, in addition to having a consolidated situation around, to carry out the operation safely, to remove the excess mortar from the edges and then cut and separate them (with scalpel and micro electric drill) from the surrounding plaster. Once isolated, they were demolished with a hammer and a chisel, as was the mortar where the stove pipe was located.



Figure 26. Comparison between part of the frieze before the restoration's intervention and after the aesthetical revision.

Following the restoration of the masonry structure's continuity by inserting two shaped bricks into the hole of the smoke duct, an aesthetic overhaul was carried out, in keeping with the previous restoration work at Tuscia University. Where necessary, the large cracks were filled with an under-level grouting, composed of lime, pozzolan, and river sand (1:1,5:1); they were worked in such a way as to appear rough, to imitate the curl. The finer sifted mortar was used to close deeper cracks. The nail holes were filled level with a mixture of marble powder and slacked lime paste (2:1) to be re-taped later. The lacunae in the background of the paintings above the fireplace, which were scratched out in the outer parts during the time of the first coats of maintenance paint, were filled with a mortar made of micronized calcium carbonate powder and lime (2:1). The decision not to level the large void is due to the need to wait for the restoration of each portion of the frieze in order to fully assess the appropriateness and best strategy for reintroducing these flaws, which, in any case, testify to an ambiguous period in the Hall's history.



Figure 27. Comparison between part of the paintings of the fireplace before the restoration's intervention and after the aesthetical revision.



Figure 28. Central portion of the south wall after the restoration.

It was necessary to balance an impoverished situation on the fireplace paintings and the frieze band, which, as seen, was weaker at the structural level, in order to give the painting new unity through retouching. For the reintegration, Winsor & Newton watercolors were used, with special emphasis on ivory black and soils; the integration of the lacunae with marble dust was mimetic, but distinguishable at close inspection, and the fillings on the white background were veiled to balance them with the surrounding painting. Where the pictorial surface appeared abraded, spatulate, or fallen, a smoother view of the image was restored, making it easier to appreciate the compositional balance. Finally, isolated dark spots on a white background were softened with isopropyl alcohol-diluted Gamblin varnish colors.

In addition to the final result, which restored previously unseen hidden parts and new balance and harmony to the entire room, a successful part of this restoration concerns the cooperation and attitude with which the diagnostic investigations were intertwined with the intervention. Employing the most traditional and recent techniques made it possible to ascertain and verify the hypotheses developed through observation. Thus, it was possible to stop points on the executive technique of the painting and have a deeper understanding of the previous interventions of the state of conservation. Four samples were taken to obtain stratigraphic sections to compare with each other, to investigate the original plaster and paint layers better, and with other samples acquired in 2018. In addition to determining and classifying the mortars, a white fresco as a preparatory layer was confirmed as the first layer in the frieze frame and on the paintings of the fireplace. In the traditional samples, a previously performed Fourier Transform Infra Red Spectroscopy analysis was added, which individualized organic binders and traces of oxalates, suggesting the artists' use of colors diluted in lime with a small addition of glues or greasy substances.

The palette was determined using XRF analysis because it was possible to identify elements always present and thus traceable to materials in the preparatory layers or paint backgrounds, such as lead, which was present in low percentages but always referable to pozzolanic aggregates. Overlaying the results of the 22 points on the HMI information, as shown above, provides more immediate feedback on the palette. Smalt, for example, which is identified by potassium and cobalt in blue backgrounds, appears pale red in photographs at first glance. The same is true for repainting with zinc, copper, or arsenic-based colors. These are more visible with the various UVF or false-color shots, or with special functions of the Spectrapick and Pickviewer software used to manage the photographic shots taken with special cameras, special flashes, and filters of the ProfiloColore system (Melis et al., 2013). The successful collaboration with the University of Calabria and the experimentation of PuCT, tested for the second time on wall paintings, were added to these techniques. This, as mentioned, not only shed light on the masonry support, referring to the execution technique,

but also enlightened more than one aspect on the state of conservation and the intervention carried out, igniting more than one curiosity.

The ongoing dialogue with the parties involved in this restoration, historians and diagnosticians from Tuscia University and University of Calabria, as well as the desire to achieve the best possible result to improve this important but long neglected work, allowed for the development and articulation of every issue related to the restoration of the paintings in the Sala Riario. The work proved useful and indicative not only in terms of a cognitive approach to early 16th-century paintings with decorative subjects in rooms with fireplaces, with all the consequences that can result from the presence of a fireplace or a centuries-old use of a residence, but also on an operational level, for the proposal of conservation procedures and diagnostic investigations. Such complex, articulated, and gradual work allowed the work to be brought back to light and restored to the community so that it could be properly appreciated and valued.

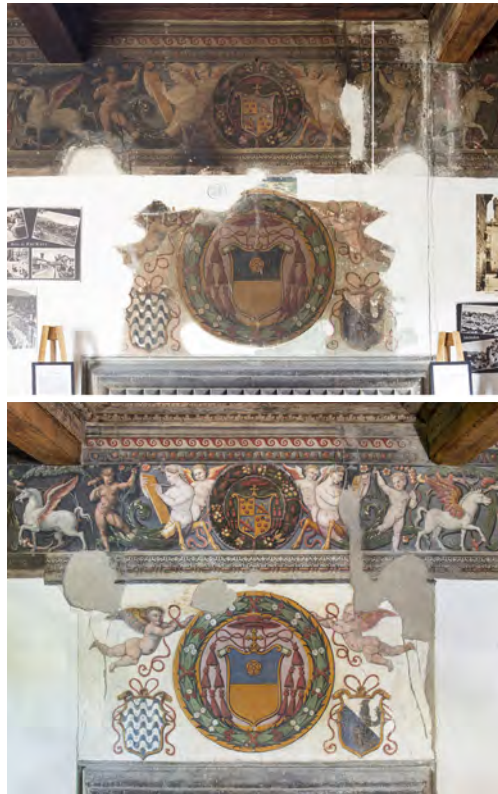


Figure 29. Central portion of the south wall before and after the restoration's intervention.

References

- Byatt, L.C. (1981). Il cardinale Niccolò Ridolfi ed il Palazzo di Bagnaia. *Biblioteca e società*, 4, pp. 3-8.
- Caporossi, L., (2020) “Infiniti què virtuosi che la mala sore sempre perseguita”. Pastura e la decorazione della cappella Vitelleschi. In G. Insolera *Il Pastura nel duomo di Tarquinia. Gli affreschi di Antonio del Massaro da Viterbo dopo il restauro* (pp. 49-75). Roma, Italy: Gangemi.
- Fagliari Zeri Buchicchio, F.T. (2007). Note su alcuni cantieri edilizi nella Tuscia del XVI secolo. In *L'età di Michelangelo nella Tuscia* (pp. 52-70). Viterbo: Bagnaia
- Faldi, I. (1996). Viterbo a pezzi. S. Giovanni Battista degli Almadiani. *Biblioteca e società*, 1-4, pp. 3-5.
- Frittelli, V. (1977.) Bagnaia. Cronache d'una Terra del Patrimonio. Roma, Italy
- Frittelli, V. (1988). Bagnaia di dentro: il palazzo comunale. Viterbo, Italy
- Lanteri, L., & Pelosi, C. (2021). 2D and 3D ultraviolet fluorescence applications on cultural heritage paintings and objects through a low-cost approach for diagnostics and documentation. *Optics for Arts, Architecture, and Archaeology*, VIII, pp. 1-10. <https://doi.org/10.1117/12.2593691>
- Laureti, S., Colantonio, C., Burrascano, P., Melis, M., Calabrò, G., Malekmohammadi, H., Sfarra, S., Ricci, M., Pelosi, C. (2019). Development of integrated innovative techniques for the examination of paintings: the case studies of The Resurrection of Christ attributed to Andrea Mantegna and the Crucifixion of Viterbo attributed to Michelangelo's workshop. *Journal of Cultural Heritage*, 40, pp. 1-16. <https://doi.org/10.1016/j.culher.2019.05.005>
- Melis M., & Miccoli M. (2013). Trasformazione evolutiva di una fotocamera reflex digitale in un sofisticato strumento per misure fotometriche e colorimetriche. In Rossi, M., (pp. 28-38). Santarcangelo di Romagna, Italy: Maggioli.
- Padelli, I. (2003). La chiesa ed il convento di S. Maria delle Fortezze in Viterbo: documenti e ipotesi attributive (Doctoral dissertation) Retrieved from: <https://sba-unitus.on.worldcat.org/search/detail/1138576161?queryString=La%20chiesa%20ed%20il%20convento%20di%20S.%20Maria%20delle%20Fortezze%20in%20Viterbo%3A%20documenti%20e%20ipotesi%20attributive&clusterResults=false&groupVariantRecords=false>
- Pezzuto, L., II. (2016). L'ultimo Jacopo Ripanda e le case di Raffaele Riario (1513-1517). *Mitteilungen des Kunsthistorischen in Florenz*, 58, pp. 270-277.
- Serone, G. (2007). Le mura medievali di Bagnaia: analisi diacronica di un manufatto architettonico. In *Il tesoro delle città*, 5, pp. 473-491.
- Susi, L. (2006). I Dipinti Murali di Santa Maria delle Fortezze: Analisi dei Materiali Costitutivi e Proposta di intervento (Doctoral dissertation) Retrieved from: <https://sba-unitus.on.worldcat.org/search?queryString=%2C%20I%20Dipinti%20Murali%20di%20Santa%20Maria%20delle%20Fortezze%3A%20Analisi%20dei%20Materiali%20Costitutivi%20e%20Proposta%20di%20Intervento&clusterResults=false&groupVariantRecords=false>
- Volinia, M. (2004). Una norma che, ancora, non c'è: tra cantire sperimentale e realtà di cantiere. La termografia all'infrarosso applicata ai beni culturali. In *Lo stato dell'arte. Conservazione e restauro. Confronto di esperienze* (pp. 104-112). Genova: Palazzo Reale
- Zanardi, M. (2021). Bagnaia e Villa Lante. Dal castrum medieval a luogo di delizie. Roma, Italy

CHAPTER 21

THE CONTRIBUTION OF DIGITAL RECORDING IN THE RESEARCH, CONSERVATION AND DISPLAY OF ARCHAEOLOGICAL SHIPS

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Abstract

Recording techniques play a vital role in boat and ship archaeology, enabling the understanding of complex hull shapes. Accurate data capture from rotten, waterlogged timbers requires considerable time, effort, and expertise. The recording process impacts research quality, as well as conservation practices and museum displays of archaeological ships. Over time, ship recording techniques have evolved, with advancements in systematic excavations from analogue to digital methods. Contact digitizers, scanning technologies, combined with advanced software, provide a better and faster understanding of construction features. They also facilitate the manipulation, control, fairing, and reconstruction of the partial ship remains, bringing them close to their original shapes. Additionally, conservators utilize digital technologies to monitor structural changes both during the conservation procedure and at museum displays for long-term preservation. This chapter aims to reveal how digital approaches have enriched the knowledge gathered from boat and ship remains and contribute to conservation efforts and the maintenance of archaeological ships displayed in museums.

Keywords: Archaeological Ships, Digital Recording, Nautical Archaeology, Conservation, Ship Reconstructions

1. Introduction

In boat and ship archaeology, proper recording is a fundamental principle, much like in all archaeological studies. The recording process becomes even more crucial due to the complex shape of ship hulls and dimensional instability of timbers that form the hull. Capturing accurate and comprehensive data from the often poorly preserved and waterlogged ship timbers is key to understand the nature of the archaeological ships and past individuals or societies who built and used them. The recording significantly impacts the quality of research, as well as the conservation and eventual display of archaeological ships, perhaps more so than other material remains in the field of archaeology.

Archaeologists studying boat or ship remains strive to uncover the methods and techniques used in their construction, understand the role of the ship, analyse its design, and reconstruct its original shape. Researchers typically undertake a meticulous effort of site recording initially, aiming to gather as much information as possible from the surviving remains, whether they are submerged underwater or fortunately located on land or in drained zones. If ship cargoes are available, they can provide valuable insights into various aspects of the ship, such as its purpose of use, the potential routes it sailed, life on board, and the utilization of ship spaces. Once the cargo is removed, the challenging process of timber recording commences. This first phase focuses on mapping the “as found” shape of the original hull. However, certain crucial details, such as joinery details and the outboard surfaces of most hull members, are often not visible and cannot be recorded until the hull is dismantled. Therefore, a subsequent effort of post-excavation recording is required to gain a better understanding of the hull characteristics. While certain projects, particularly those involving early modern ships such as iconic *Vasa* and *Mary Rose*, may choose to remove ship hulls without dismantling them, others opt to dismantle the timbers. The dismantling process allows for individual ship timbers to be recorded in a controlled laboratory environment using 1:1 scale drawings. The drawings serve to record important details such as outlines, sections, numbers, and sizes of fasteners, as well as joineries and surface details like tool marks, grain directions, and stains. While some of these details may initially appear trivial, they often prove to be significant during the advanced stages of research (Hocker, 2003). Recording is an inevitable and necessary process that continues throughout the life of an archaeological ship, following the post-excavation phase. It serves as a foundation for subsequent activities such as reconstruction, conservation efforts, and museum displays.

2. Field recording

The techniques used in ship recording have undergone significant advancements since the 19th century, aligning with the emergence of systematic excavations in northern Europe.

Earliest methods relied on simple sketches and illustrations, which, in some cases, were enhanced through the addition of section drawings and detailed site descriptions (Maarleveld, 1997; Muckelroy, 1978). The introduction of modern diving gear allowed nautical archaeologists work on shipwrecks underwater around 1960's. The early scientific excavations conducted underwater brought traditional survey techniques and equipment into the underwater environment. These techniques included the implementation of a grid system, the use of tape measures, plumb lines, and the application of triangulation methods. However, the limitations inherent to the underwater environment, particularly diving time constraints, immediately necessitated the development of more practical and faster solutions. As a result, stereo-photogrammetry, which was used for "as found" recording of the Skuldelev ships in Roskilde, was later implemented underwater during the Yassiada Byzantine Shipwreck Project in Bodrum-Turkey in 1963 (Crumlin-Pedersen, 2002, Bass, 1975). While photogrammetry continues to be employed today with more advanced software and high-resolution cameras, its effectiveness underwater relies heavily on clear visibility conditions at the site. In 1980, the challenges of recording in low visibility conditions during the Mary Rose Project were overcome with the introduction of an innovative software known as the "Direct Survey Method (DSM)." This method was specifically developed for the underwater sites with limited visibility that are characterized with complex three-dimensional architectures. The DSM involved taking tape measurements directly from reference points to the object being surveyed, allowing the determination of precise points in three dimensional space. By employing the DSM, researchers were able to achieve much faster and more accurate recordings with quantifiable error (Rule, 1989). After the last decades of the 20th century, the use of digital techniques became commonplace in nautical fieldwork. While total stations and CAD software were the preferred methods for recording ships on land, the application of photogrammetry and the Direct Survey Method (DSM) became more widespread, particularly for underwater recording. Rescue projects have greatly benefited from these techniques, as they mitigate the pressures exerted by various stakeholders and, consequently, minimize the potential impact of modern development on archaeological sites. For instance, during the rescue excavations at Yenikapı, Istanbul, nearly all of the 37 early medieval boat remains were effectively recorded in the field using total station surveying techniques that allow archaeologists to save all boat remains while working within demanding construction timelines (Figure 1) (Pulak, 2015; Kocabaş, 2015; Özsait-Kocabaş, 2008).

Advanced digital recording methods have greatly reduced the amount of time underwater archaeologists need to spend on the seafloor, leading to increased budget flexibility. These



Figure 1. Total Station survey at a Yenikapı Shipwreck (IU Yenikapı Shipwrecks Project Archive).

techniques also provide opportunities for non-intrusive surveys, allowing researchers to gather valuable data without physically disturbing the archaeological site. Additionally, digital recording methods enable the creation of virtual museums, providing the public with experiences of shipwrecks and maritime heritage.

3. Post-excavation recording and reconstructions

Recording individual ship timbers following the “as found” site recording phase is a valuable tool for understanding construction details and creating reconstructions of partial archaeological ship hulls. Archaeologists working on Skuldelev Viking ships initiated one of the earliest examples of the practice of recording individual ship timbers at full scale on transparent acetate sheets. (Crumlin-Pedersen, 2002). The technique can be employed in two distinct methods: contact tracing, which involves placing the sheet directly on the surface of the timber, and elevated plane tracing, where the acetate sheet is positioned on a suspended glass plate above the timber being recorded (Figure 2). In both ways, surface details and edges are traced using permanent markers with different colours to represent various features of the ship timber. For instance, black may be used for outlines, red for wooden fastenings, green for nails, and so on. (Jones, 2017; Steffy, 1994). Each face of an individual timber is recorded separately and also notes, sections and offset measurements were added as needed. Besides its primary purpose of recording fragmented ship timbers and gathering data for analysis and reconstruction, this method also serves as a means to document the waterlogged wood for further observations. These records can be compared to the same wood after undergoing conservation treatment, allowing for important insights into the impact of conservation efforts (Crumlin-Pedersen, 2002).



Figure 2. Elevated plane tracing of a ship timber (IU Yenikapı Shipwrecks Project Archive).

The procedure quickly gained recognition and became a standard technique in timber recording. However, the generated graphic data is two-dimensional and represents a flattened projection of the timber's shape onto a reference plane, rather than capturing its true three-dimensional form. Due to the nature of ancient hull timbers, which are often not parallel-sided and have surfaces with tapering widths, varying thicknesses, and intricate twists and curvatures, recording them in a two-dimensional manner becomes inadequate (Hocker, 2002). The method also had limitations when applied to curved timbers, primarily due to the occurrence of parallax error. Parallax error arises when the recorder's viewpoint is not properly aligned with the marker, resulting in inaccurate determination of the object's position from the correct perspective (Steffy, 1994). Another drawback of the method was the requirement to reduce the lengthy drawings, often spanning several meters, to a more manageable scale. This was especially challenging when creating physical scaled models for the purpose of reconstruction studies. Despite the usefulness of two-dimensional trace recording, the inherent limitations mentioned above, coupled with the advancements in digital technology, prompted

second-generation nautical archaeologists to seek more effective methods for accurately recording the complex shapes and features of ship timbers. In the early 2000s, contact digitizers were utilized for the first time in recording archaeological ship timbers at the National Museum of Denmark Centre for Maritime Archaeology. Contact digitizers, which were originally developed for industrial applications, particularly for inspection and reverse-engineering tasks, are coordinate measuring devices capable of accurately recording the locations of points in three-dimensional space with sub-millimetre precision. Typically, these machines consist of a stationary base, several interconnected rigid tubes that have joints allowing for both rotation and extension, and are equipped with a probe that usually has a handle and control buttons. The location of points or streams of points, representing the features of the timbers and chosen by the operator, is recorded by tracking the probe tip. Points and lines captured during the process are displayed in real time, allowing for immediate visualization (Figure 3). The preferred software, typically Rhinoceros3D, utilizes a layering system that facilitates the organization and sorting of the recorded data (Hocker, 2002, Jones, 2015). Once the three-dimensional recording of the actual shapes and features of ship timbers is completed, it becomes possible to convert the line drawings into solid surfaces and generate digital models (Figure 4). Additionally, the digital data can be utilized for 3D printing, enabling the creation of physical models that accurately represent the recorded ship timbers (Figure 5).

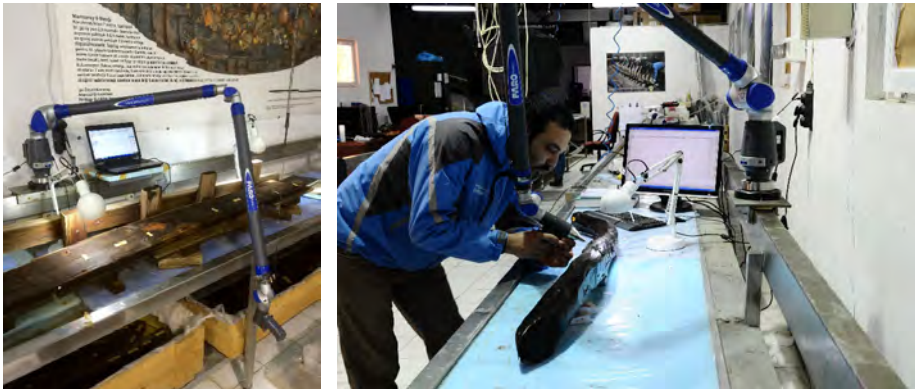


Figure 3. Recording with FaroArm contact digitiser (IU Yenikapı Shipwrecks Project Archive).

Contact digitizers are not the only option for capturing 3D data from archaeological ship timbers. Laser and structured light scanning are also viable alternatives. These devices employ lasers that automatically trace lines over the surface of the timber, while a measuring device samples the location of the reflected light. This process generates a point cloud that represents

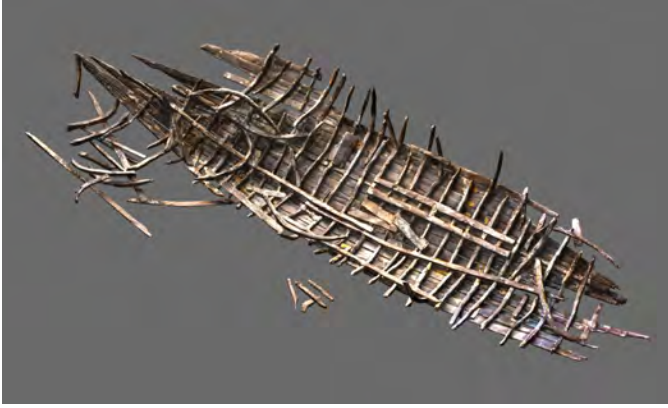


Figure 4. As found 3D model of a Yenikapı Shipwreck (YK27)
(IU Yenikapı Shipwrecks Project Archive).



Figure 5. Physical scaled model of Newport Medieval Ship (Photo. E. Türkmenoğlu).

the object in three dimensions. Although laser scanners offer a more effective methodology for recording complex surface topography and require less recording time, it can be said that contact digitizers are more commonly used for post-excavation research. The reason behind this preference lie in several factors. Contact digitizers provide the advantage of allowing operators to select and sort information during the recording process, enabling more careful analysis and interpretation of the object. In contrast, scanners are often criticized for generating excessively large and redundant data, making it challenging to process with moderate computers. Additionally, defining edges accurately can be difficult with scanner-generated data (Hocker, 2002).

However, advancements in scanning technology have made the management of large volumes of point clouds more feasible today. A group of researchers recently introduced the “3D annotated scans method,” which was successfully implemented on a 12th-century ship in Wismar, Germany. This method involves recording ship timbers using handheld structured light scanning, followed by a 3D annotation phase where the recorder interprets the timber by directly tracing observed features on the digital model (Van Damme et al., 2020). While this methodology is still being developed, it is expected to be adopted by several projects where limited resources and the urgent need for conservation require a faster post-excavation recording.

Typically, after the post-excavation recording of ship timbers, a reconstruction study is conducted in any project, the extent of which depends on the surviving remains of the ship. The reconstruction study aims to understand the original form and structure of the ship, as well as its construction techniques, through the analysis and interpretation of the recorded data. However, the dynamic nature of the wood as it moves and responds to changes in its surrounding environment complicates the reconstruction process. Throughout its service life, a ship undergoes changes in shape due to factors such as hogging and sagging, as well as the need for repairs and alterations. When a ship is sunk or abandoned, the process of disintegration begins, which is influenced by environmental conditions. In subtropical marine environments, the presence of shipworms, along with corrosion and oxidation, accelerates the degradation of the ship’s timbers. Additionally, the pressure exerted by cargo, ballast, and settled silt can further reshape the hull. Moreover, the excavation or disassembly process itself can cause distortion to the timber shapes (Steffy, 1994; Tanner, 2020). These various factors pose significant challenges to accurately reconstructing and documenting the original form of the ship. However, with the aid of digital recording, controlling, manipulating, and fairing the changing hull shapes of the archaeological ships has become more practical than ever before. The latest digital approaches, developed and applied by pioneering projects such as the Newport Medieval Ship Project and the Drogheda Boat Project, offer best practices for the application of relevant software in recording, reconstructing, and testing reconstructed ship structures. These projects utilize a combination of contact digitizers, Rhinoceros3D, and Orca3D. While digitizers allow for detailed documentation and, more importantly, thorough analysis, Rhinoceros3D, a powerful software specifically designed for representing curves and surfaces, helps create solid models of ship timbers and enables control and fairing of the hull shape. On the other hand, Orca3D, a plug-in software for Rhinoceros 3D, allows for the assessment of hydrostatic properties, stability, weight, and speed of the reconstructed vessels. The integration of these software packages in nautical archaeology undoubtedly provides a

more precise and comprehensive approach to timber recording, as well as a deeper understanding of shipbuilding techniques and the behaviour of the ships and individuals who built them. (Nayling & Jones, 2013; Jones, Nayling, Tanner, 2013; Tanner, 2013; Tanner, 2020).

4. Conservation and display

Archaeological ship timbers often become waterlogged due to surrounding wet environment, requiring conservation treatment with various chemicals to achieve stabilization. Conservation is needed for their long-term preservation, as well as facilitating storage and display. The methods of conservation involve a prolonged impregnation process, which provides structural support and enhances the mechanical strength of the ship timbers. The initial attempts to conserve waterlogged wood date back to the 19th century when water was exchanged within the wood using aluminium potassium sulphate (alum). In the 1930s, extensive research in the United States introduced the use of polyethylene glycol (PEG), which has since become a widely recognized and commonly employed method. The drying of conserved wood poses another significant challenge. Instead of traditional air-drying, conservators increasingly prefer the freeze-drying technique following PEG impregnation. This method eliminates capillary tension and minimizes shrinkage more effectively than air drying (Unger et al. 2001, Grattan & Clarke, 1987).

Even after undergoing the conservation treatment, waterlogged ship timbers, whether on display or in storage, require ongoing monitoring by conservators to assess structural and microstructural changes and ensure long-term preservation. In recent years, digital methodologies have emerged as valuable tools for conservators in the monitoring process. As an example, a combination of structured light 3D scanning and micro-computed tomography were used to monitor and analyse the dimensional stability of wood samples selected from the reference collection held at Römisch-Germanisches Zentralmuseum (RGZM) and Leibniz Research Institute for Archaeology. Samples were collected from various sites, including wooden objects of different types and varying degrees of degradation. Conservation methods such as alcohol-ether-resin, melamine-formaldehyde, lactitol/trehalose, saccharose, silicone oil, and PEG with subsequent freeze-drying (with varying molecular weights) were employed. This systematic collection of samples and digital monitoring offered a unique opportunity to compare the structural differences in the wood before and after conservation. The study highlights the significance of digital monitoring in assessing the effectiveness of conservation efforts (Stelzner et al. 2022).

The ships displayed in museums are typically placed on support structures known as ship cradles (Figure 6). These cradles are specifically designed to provide stable and secure support

for the ships while they are exhibited. The primary purpose of ship cradles is to distribute the weight of the ship evenly, preventing any excessive stress or strain on specific areas of the hull. The majority of the supports are made of stainless steel, a preventive measure taken against oxidation, which is the most formidable enemy of wood conserved with PEG. In addition to corrosion resistance, the cradles are expected to possess flexibility, rigidity, and durability (Fix 2015; Stein 2017). They should also be reversible, easily accessible to aid in preventive conservation, and visually appealing for visitors. Although designers of ship exhibitions take these factors into consideration, most ships in museums are susceptible to deformation and experience a noticeable reduction in strength and resistance to creep over time. As a result, monitoring of ship hulls on display is crucial to detect any geometrical changes and implement appropriate solutions to prevent further deterioration. Several museums, including Vasa, Mary Rose, Arles Rhone 3, Oseberg, and Bremen Cog, have embarked on long-term maintenance projects for their ships and have implemented digital monitoring techniques to identify and track structural changes. Spatial monitoring, which requires high precision, has been implemented through the installation of Total stations, 3D scanners, and photogrammetry in various museums. These technologies enable accurate measurement and monitoring of ship exhibits (Colson et al.,2022; Colson et.al. 2022). One such example is the Vasa Museum, where spatial monitoring has been instrumental in identifying structural issues and the obtained results have dictated the need for the renewal of support structures. The design of new support structures can now be pre-designed through models and tested using digital technologies, unlike their predecessors.



Figure 6. Serçe Limanı Shipwreck in Bodrum Museum of Underwater Archaeology
(Photo. E. Türkmenoğlu).

Digital recording technologies offer precise measurements, detailed documentation, and the ability to achieve full reconstructions of ships. By capturing three-dimensional data of the ship timbers, digital tools provide enhanced control over the reconstruction process, allowing researchers to visualize and analyse the evolving shapes with greater precision. Advanced software enables the manipulation, refinement, and adjustment of digital models, facilitating comprehensive reconstructions that closely resemble the original form of the ship. This digital approach empowers archaeologists and researchers to overcome the challenges associated with complex ship shapes and achieve more reliable and comprehensive reconstructions. Digital technologies also enable conservators to monitor and analyse the condition of ship timbers over time. By comparing digital models at different stages, any changes or deterioration can be detected early, allowing for timely interventions and preservation efforts. In recent decades the field of nautical archaeology has undoubtedly made a significant progress in accurately understanding and preserving the nature of archaeological ship structures through the utilization of digital recording techniques.

References

- Bass, G. (1975). *Archaeology Beneath the Sea: A Personal Account*. New York: Walker and Co.
- Colson, A., Hauer, D., Gamstedt E.K., Schofield, E. (2022). Keeping an Eye on Conserved Ships, Why Implement Long-term Monitoring. *ICOM-CC WOAM*, 276-280.
- Colson A., Hastedt, H., Luhmann, T., Hess, M. (2022). The Role of Conservators in the Implementation of Surveying Techniques-Reflections on the Bremen Cog Monitoring Project. *ICOM-CC WOAM*, 276-281-286.
- Crumlin-Pedersen, O. (2002). Documentation, Analyses and Dating. In O. Crumlin-Pedersen & O. Olsen (Eds.), *The Skuldelev Ships I: Topography, Archaeology, History, Conservation and Display* (pp. 49–68). Viking Ship Museum, Roskilde.
- Fix, P.D. (2015). *Archaeological Watercraft: A Review and Critical Analysis of the Practice*. Doctoral Dissertation, Texas A&M University).
- Grattan D.W., Clarke, R.W. (1987). Conservation of Waterlogged Wood. In C. Pearson (Ed.) *Conservation of Marine Archaeological Objects*, Butterworth & Co. Ltd.
- Hocker, F. (2003). *Three-dimensional documentation of ship timbers using the FaroArm*. Copenhagen: National Museum of Denmark.
- Hocker, F. (2004). Shipbuilding: Philosophy, Practice and Research. In F. Hocker & C.A. Ward (Eds.), *The Philosophy of Shipbuilding: Conceptual Approaches to the Study of Wooden Ships*, (pp.1-11). College Station: Texas A&M University Press.
- Jones, T. (2015). *Three-Dimensional Digital Recording and Modelling Methodologies for Documentation and Reconstruction of the Newport Medieval Ship* (Doctoral Dissertation, University of Wales Trinity Saint David).
- Jones, T., Nayling, N., Tanner, P. (2013). Digitally Reconstructing the Newport Medieval Ship: 3D Designs and Dynamic Visualisations for Recreating the Original Hull Form, Loading Factors, Displacement, and Sailing Characteristics. *Underwater Archaeology Proceedings*, 123-130.
- Kocabaş, U. (2015). The Yenikapı Byzantine-Era Shipwrecks, Istanbul, Turkey: A Preliminary Report and Inventory of the 27 Wrecks Studied by Istanbul University. *International Journal of Nautical Archaeology*, 44 (1), 5-38.

- Maarleveld, Th.J. (1997). Nautical Archaeology in the Netherlands: Developments and Cultural Appraisal. In: W.J.H. Willems, H. Kars & D.P. Hallewas (Eds.), *Archaeological Heritage Management in the Netherlands, Fifty Years State Service for Archaeological Investigations*, (pp. 35-57). Assen/Amersfoort,
- Muckelroy, K. (1978). *Maritime Archaeology*. Cambridge University Press.
- Nayling, N., Jones, T. (2013). The Newport Medieval Ship, Wales, United Kingdom, *International Journal of Nautical Archaeology*, 43, 239-278.
- Özsait-Kocabaş, I. (2008). Belgeleme: Ahşabı Okumak. U. Kocabaş (Ed.), *Yenikapı Batıkları Cilt 1: Yenikapı'nın Eski Gemileri*, (pp.37-72). İstanbul: Ege Yayınları.
- Pulak, C., Ingram, R., Jones, M., (2015). Eight Byzantine Shipwrecks from the Theodosian Harbour Excavations at Yenikapı in Istanbul, Turkey: an introduction. *International Journal of Nautical Archaeology*, 44 (1), 39-73.
- Rule, N. (1989). The Direct Survey Method of underwater survey, and its application underwater. *International Journal of Nautical Archaeology*, 18 (2), 157-162.
- Steffy, J. R. (1994). *Wooden Shipbuilding and the Interpretation of Shipwrecks*, College Station: Texas A&M University Press.
- Stein, E. (2017). Design and analysis of a cradle structure for the Newport Medieval Ship. (Report, Swansea University).
- Stelzner, J., Stelzner, I., Martines-Garcia, J., Gwerder, D., Wittköpper, M., Muskalla, W., Cramer, A., Heinz, G., Egg, M., Schuetz, P. (2022). Stabilisation of waterlogged archaeological wood: the application of structured-light scanning and micro computed tomography for analysing dimensional changes. *Heritage Science*, 10 (60), 1-25.
- Tanner, P. (2013). 3D Laser Scanning for the Digital Reconstruction and Analysis of a 16th-Century Clinker Built Sailing Vessel. *Underwater Archaeology Proceedings*, 137-149.
- Tanner, P. (2020). The Reconstruction and Analysis of Archaeological Boats and Ships. (Doctoral Dissertation, University of Southampton).
- Unger, A., Schniewind, A.P., Unger, W. (2001). *Conservation of Wood Artifacts A Handbook*. Springer.
- Van Damme, T., Auer, J., Ditta, M., Grabowski M., Couwenberg, M. (2020). The 3D Annotated Scans Method: A new approach to ship timber recording. *Heritage Science*, 8 (75), 1-18.

CHAPTER 22

A PRELIMINARY STUDY COMPARING THE CONSTRUCTION FEATURES OF YENIKAPI SHIPWRECKS WITH THE NORTHWEST EUROPEAN CONTEMPORARIES: THE CASE OF YK20

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Abstract

The subject of this study involves a technical comparison of the shipwreck Yenikapı 20 (YK20) that was unearthed during the Yenikapı salvage excavations in Theodosius Harbor, which was used between the 5th-11th centuries, with Northwest European early Medieval-era shipwrecks that had been made using the clinker-built technique. In this context, the introduction briefly presents the evolution of water transport in the two regions, as well as the harbor's history and the 9 years of excavations that took place there before explaining the documentation and analysis of the YK20 shipwreck. The ship's construction features have been identified by studying its hull members and comparing these with Northwestern European ships dated to the same era. Northern Europe became an important center for shipbuilding in the early Middle Ages, and the clinker construction method was the technique the Vikings in Northern Europe mostly used. However, when looking at shipbuilding techniques further south after the Middle Ages, the carvel construction method is seen to have been used in the region covering the lands of the Netherlands and Germany, as well as in large parts of the Baltic countries. One of the biggest differences between Viking boats and Mediterranean ships is that they prefer a rectangular sail system and use long boats that can move both through rowing as well as under sail power. As such, Viking ships appear to be a mix of their contemporaries in the Mediterranean, warships, and cargo vessels. In other words, the Vikings used these ships for both trading and raids. The importance of ships in Viking culture is indisputable, and the fact that they used their ships for burials have allowed the wrecks to be discovered on land and excavated even as recent as 100 years ago.

Keywords: Maritime archaeology, Byzantine seamanship, Yenikapı, Theodosian Harbour, shipwreck, shipbuilding, Mediterranean, Middle Ages, clinker built, Nordic seamanship

1. Introduction

When encountering a ship find, marine archaeologists first measure important structural details such as plank thickness, frame spacing, and fastening methods. Based on these details, attempts are made to group boats and ships into a “traditions” classification system. This study will discuss the boat from the Yenikapı Shipwrecks, Yenikapı 20 (YK20), and compare it with some selected shipwrecks from its Northern European contemporaries. However, firstly making a brief introduction of the birth and development of plank boats would be useful.

2. The Evolution of water transport up to plank boats in northwestern europe and the mediterranean

One of the earliest steps in the history of seamanship must have been the transition from a single log to a buoyant platform made of bound logs or to reed-bundle rafts, especially in the Eastern Mediterranean (Casson, 1971, p. 3). No evidence has survived for the use of log rafts in prehistoric Europe, or is unrecognizable as such if it does. However, one can speculate on what is technologically feasible by considering similar manufacturing activities for which evidence has survived, and some scientists have identified the tools and techniques required to build the simplest of log rafts (McGrail, 2014, p. 53).

According to McGrail (2014: p. 53), log rafts could not have been built before the technological state equivalent to that of the Upper Paleolithic. The construction of such rafts may have been carried out in certain regions based on the availability of raw materials. Three types of shaping may have occurred regarding the ends of log rafts. The first type is categorized as shaping by reduction, which is done by using a controlled fire and/or scraper or a similar tool (e.g., axe). The second type is shaping by transformation, which generally consists of bending, where the ends of log rafts are bent by heating or soaking. The third type of shaping is fastening by treenails or mortise and tenon joints. In this type, mortise and tenons are carefully carved using hammers, knives, or chisels and fitted in an interlocking fashion. While McGrail suggested the Upper Paleolithic and Mesolithic periods for the first two techniques, he argued the third technique to not have existed prior to the Neolithic period (McGrail, 2014, p. 53). This indicates the earliest use of shell-based construction. These early rafts are thought to have been propelled by some sort of paddles. Although the earliest evidence of a sail has been dated to the 1st century BC (Casson, 1986, pp. 20–22), the earliest documented use of log rafts in Northwestern Europe dates back to the late Roman Republic. Julius Caesar mentioned how Celtic tribes used these kinds of vessels to cross rivers (McGrail, 2014, p. 54). While no archaeological evidence is found of early seamanship in Northwestern Europe, rafts and

an early form of plank boat had occupied the rivers of Mesopotamia and Egypt. Rafts called *kelek* were widely used in Mesopotamian rivers (Güler, 2006, p. 7). By the 4th millennium BC, however, the Egyptians had given these rafts a thin long shape and aligned both ends of the boat; they learned to steer with a rudder oar fixed with ropes and to float the boat quickly with side oars. Thus, reed/log rafts had developed and turned into reed/log boats. After all these developments, the Egyptians made a discovery that would become a milestone in the world maritime history: They'd learned to benefit from wind power, which is much cheaper and easier to use than human or animal power (Güler, 2006, p. 12). Stone reliefs, written sources, and ship models left as grave gifts provide information about the Egyptian maritime tradition. In addition to all these, though, the precisely sized boat found inside Giza's Cheops Pyramid dated to approximately 2,500 BC (i.e., the construction date of the pyramid) presents a unique example of the ship building tradition of that period (Güler, 2006; p. 13). Although very advanced maritime activities were found in Mesopotamia and Egypt, the world's oldest boat is the Pesse canoe (c. 8000 BC) found in Northern Europe (Verhagen, 2018, p. 89).

3. The construction features of wooden plank boats

Basically, two ways exist to construct a wooden plank boat. The most widely used form is skeleton-based, particularly in the West, and begins by setting up a sturdy skeleton of keel and frames, after which a smooth skin of planks are fastened to this skeleton. The other method is shell-based and favored by the Mediterranean regions, Southern Asia, and some parts of Northern Europe. This form is simply the reverse of the first technique: A sturdy shell of planks is erected first by pinning each plank to its neighbor, and then a certain amount of framing is inserted to strengthen the shell (Casson, 1986; p. 201). Classifying these two techniques regionally is highly controversial. Instead, a chronological classification appears to be more accurate. Archaeological finds have shown the shell-based form to be the oldest construction technique. Another feature of this technique is that planks are combined with pegged mortise and tenon joints, which go unpegged in later periods. These joints were used less and less over time, with the space between them widening and then disappearing completely once the skeleton-based technique began being fully used (see Figure 1; Güler, 2019; p. 87).

According to the Ole Crumlin-Pedersen (Hocker, 2004; p. 4), four basic types of ship construction exist from which he believed almost all Northern European ships had descended: the clinker-built Nordic vessels (Viking ships), the flat-bottomed vessels with stem and sternpost (cogs), the flat-bottomed vessels with square ends and vertical sides (barges/punts), and the rocker-hull with long parallel strakes and no true keel (hulks; Figure 2).

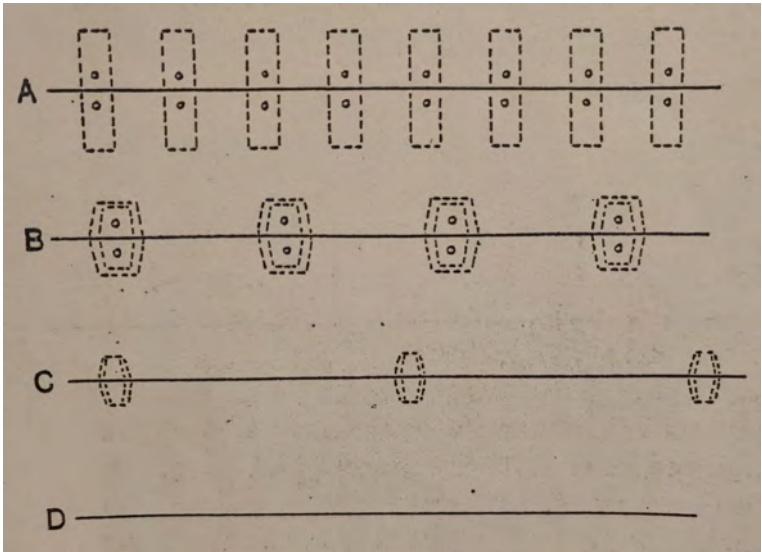


Figure 1. Transitions in mortise and tenon joinery: A) Kyrenia, B) Yassı Ada 2, C) Yassı Ada 1, D) Serçe Limanı (Steffy, 1994, p. 84).

The clinker-built tradition was the dominant shipbuilding method of the early Middle Ages in Northern Europe. It is a shell-based technique in which overlapping planks are riveted to each other (Figure 3). The diagnostic features of the carvel construction differ from the clinker construction. Some scientists have described these features by emphasizing assembly order and plank arrangement.

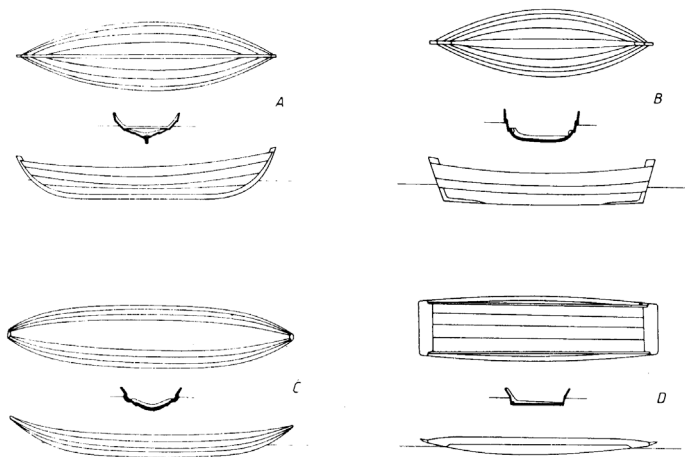


Figure 2. Basic structural characteristics of four ship types from early medieval-era Northern Europe. A) Nordic clinker type, B) cog type, C) hulk type, D) punt type (Van de Moortel, 1991, p. 14).

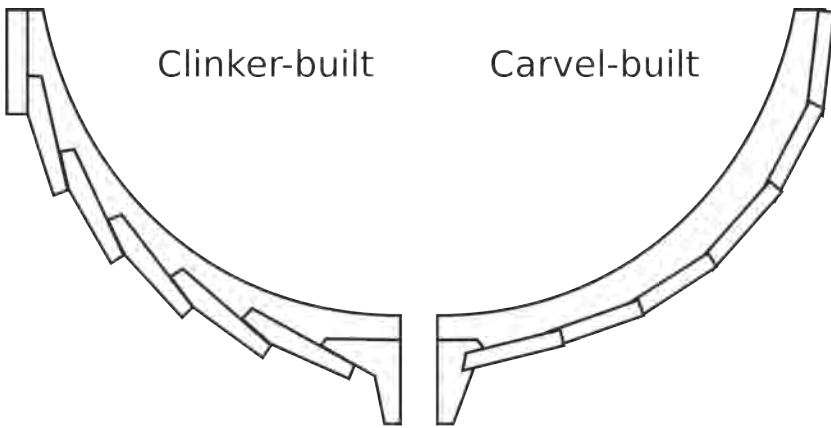


Figure 3. Clinker and carvel planking construction
 ([https://en.wikipedia.org/wiki/Cog_\(ship\)#/media/File:Clinker-carvel.svg](https://en.wikipedia.org/wiki/Cog_(ship)#/media/File:Clinker-carvel.svg)).

Shell-based construction was widely used in the ancient Mediterranean. Mostly two ways are found to build a shell-based ship: ships with the planking edge-joined using pegged mortise and tenon joints and ships whose planks are held together by pegged dowels (Hocker, 2004, p. 4).

According to skeleton-based construction, the ship's skeleton is built first with some or all of the frames being attached to the keel before building the ship's hull. After the frames are fixed to the keel at frequent regular intervals, the skeleton is strengthened with longitudinal support elements. The hull is completed by nailing the planks to the frames after the ship's skeleton has been partially or completely formed. The skeleton-based method was developed over time and used to construct large transoceanic ships. It is still preferred in traditional wooden boats produced today (Türkmenoğlu, 2017, p. 121).

Transition techniques, or mixed construction, have been mentioned several times as expressions that refer to the changes in the shipbuilding tradition and its techniques. Hasslöf (1963, p. 164) was the first to classify the shell-based and skeleton-based techniques for the ships that had first been examined in two basic groups (i.e., carvel-built common in the Mediterranean tradition and clinker-built as a technique unique to Northern Europe). Basch (as cited in Pomey et al., 2012, p. 235) introduced the concept of active and passive frames to explain the differences between the shell and skeleton techniques. He interpreted the frames of a shell-constructed hull as passive, functioning only as reinforcement, and those of a skeleton-based ship as active, giving the hull its shape and its primary strength. Passive frames

were not necessarily connected to the keel, whereas active frames were. Basch continued by introducing intermediary techniques, or mixed construction, as a term to describe active frames being employed together with passive frames in most hulls at different proportions.

4. Harbour of theodosius and the Yenikapı ships

Established in the 7th century BC and controlling the connection between the Black Sea and the Mediterranean with its location at the mouth of the Bosphorus, the city of Byzantium has been a very important commercial center for centuries due to its strategic location (Gyllius I, 1997, p. 1). The city began being called Constantinople after Constantine I moved the capital of the empire there in 330 CE and divided it into 14 administrative regions just like Rome. In addition, the city was made attractive in various ways, and its population started to increase rapidly. The construction of a new and larger port is said to have started during the reign of Emperor Julian (361-363 CE) in a bay on the south coast of the city facing the Marmara Sea, as the capacity of the old ports had begun to fall short in the face of the rapid population growth in the newly established city (Müller-Wiener, 1998, p. 8). Written in the 5th century CE, the *Notitia Urbis Constantinopolitanae* referred to another port as Portus Theodosianus (Magdalino, 2013, p. 14) and had probably been established by Theodosius I (379-395 CE) in a deep and wide bay in the 12th Region (Müller-Wiener, 1998, p. 8). This port, recorded as the Port of Theodosius, was most likely identified as the area where grain imported from Egypt was unloaded, as one of the warehouse buildings in the 9th Region on its eastern edge was named *Horrea Alexandriana* and the other *Horrea Theodosiana* (Müller-Wiener, 1998, pp. 8-9). Although different opinions exist about the name and when it was established, sources mention the Elefterius Port as being in the same region and as the likely predecessor of the Theodosius Port; its foundation date is thought to have been during the reign of Constantine I. During the excavations carried out by the Istanbul Archaeological Museums between 2004-2013, many archaeological finds were discovered, enriching Istanbul's cultural history and including the remains of 37 ships sunk at different times over a period of 600 years in the fill layers formed by silting (Özsait-Kocabaş, 2019, p. 326).

The Yenikapı shipwrecks are divided into two main groups according to their general construction features and purposes. Accordingly, the first group consists of cargo ships used for commercial purposes, and the second group consists of oars ships or galley type ships, which were probably used in the Byzantine navy (Kocabaş, 2015b, p. 49). A total of 31 Yenikapı shipwrecks have been evaluated as possible cargo ships. At least three of these were found with their cargo, while the others were found without their cargo or any equipment (e.g., rigging, anchors). Some of the ships, especially those with their cargo, are thought to have

sunk in the port as a result of a natural disaster such as a severe storm, while the others are thought to have reached the end of their work life and been abandoned in the port.

The results from studies on the cargo ships have determined the Yenikapı shipwrecks to have been built using three different construction techniques. The first are the ships with doweled edge joints up to the waterline. This group of ships have flat bottoms, a curved hull turn in the cross sections, and diagonal and S-shaped scarfs used in the joints of the outer planking (Kocabaş, 2015b, p. 49). The second group have no edge joints used in planking. These ships have a flat top the cross sections of the floor timbers with a twisting curve that increases as the size grows larger and more diagonal; Z- and butt-shaped scarfs were used in the joints of the outer planking. The third group includes the earliest period shipwrecks found in the excavation area. The common feature of these ships is that their cross sections are in the form of wine glasses. Another feature of these shipwrecks, which have diagonal and S-shaped scarfs, is that their outer planks are quite thick (Kocabaş, 2015b, pp. 49–51).

5. Construction features of Yenikapı 20 (YK20)

YK20 is a medium-sized cargo ship according to the standard size of the Yenikapı shipwrecks; it has round bilges and S-shaped diagonal scarfs and edge dowels up to the first wale. Radiocarbon analysis has dated YK20 to approximately the early 10th century CE.

The keel and stem-stern posts were clearly erected first on YK20, and according to the arrangement of the side dowels, some frames just after the garboards, as well as a few planks perhaps, had been placed before others. In the case of YK20, the edge joints were transformed into small dowels, as in many mixed or transitional technique ships at Yenikapı, with the purpose being to align them as they were built, as well as to connect the planks together. The hull planking was attached to the framing system using both wood and iron nails. This arguably constitutes the final stage of a hybrid shipbuilding technique representing the transition from the shell-based to the skeleton-based method. With this in mind, the existence of certain aspects of both methods may serve as proof of the use of a hybrid method for the vessel. As mentioned above, the outer planking had been edge-fastened using dowels and S-shaped scarf joints (Figure 4).

When looking at the ship's curves, some of the frames had likely been preassembled to shape the hull just prior to the construction of the planking. This idea of molded frames was first introduced by L. Basch (1972). One of the ideas Basch put forth was how molded frames play a concrete role on the ship (Basch, 1972, p. 35). Namely, molded frames are not removed later but remain a part of the ship; perhaps they may have been applied to YK20. As

seen in Figure 5, some frames of the ship were attached to the keel with only an iron nail and no wooden nails. Some frames and planks must have been placed up to the first wale during construction. The remaining frames are estimated to have then been nailed to strengthen the structure, after which the upper structure was formed (Güler, 2019, p. 96).



Figure 4. An example of S-shaped scarfs on planking from YK20 (Yenikapı Shipwrecks Project Archive).

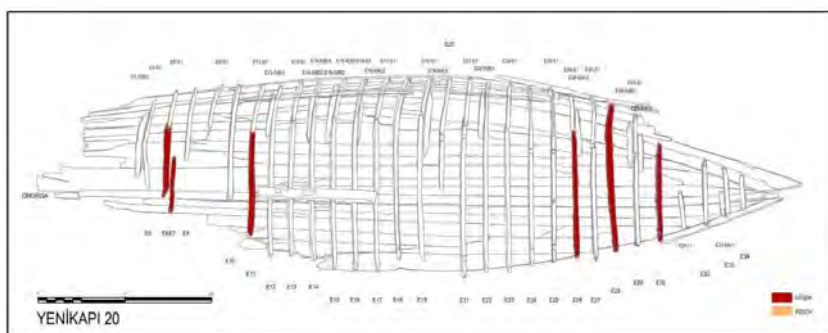


Figure 5. Frames attached to the keel with iron nails, likely molded frames? (Drawing: Ayşegül Çetiner, Digitalized by Hilal Güler).

YK20 is among the group of shipwrecks that have a very important place among the Yenikapı Collection; it has doweled edge joinery and was built with a mixed construction technique (Figure 6). This group of ships gives important information about the transition from shell-based to skeleton-based construction, and although they all give the same information (mixed/transitional technique), aspects such as construction sequence differ from each other in

terms of their characteristics. In other words, although these shipwrecks have similar features, the differences detected in the construction order and stages define the missing links one by one in the transition between techniques.

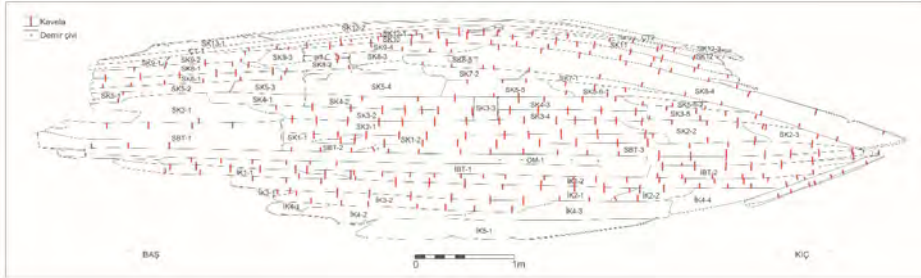


Figure 6. Edge fasteners on YK20 (Drawing: Ayşegül Çetiner, Digitalized by Çisil Şanlıgençler).

6. Yenikapı 20 and its contemporaries in northwestern Europe: A comparison

6.1. Utrecht type

One of four major medieval ship types of the Northwestern European era predating 1,200 CE is the Utrecht ship type (Van de Moortel, 2012, p. 296). Some scholars speculate the recent discovery of the Vleuten 1 wreck dendro-dated to approximately 734 CE has moved back this type of ship a little earlier. However, no consensus exists regarding the definition of cogs, so insufficient information is found for calling these cog ships. The distribution of these finds over Belgium and the Netherlands and even to maybe the German Rhineland proves that Northwestern Europe had been home to the Utrecht ship type (Figure 7; Van de Moortel, 2012, p. 296). Some experts believe the Utrecht ship type to have been an early form of the hulk¹ (Crumlin-Pedersen, 1978; Van de Moortel, 2012, p. 296). The possible connection between the Utrecht type and hulk type of historical ships is not universally accepted, and the issue will remain unresolved until the actual remains of a fully planked hulk are found (Van de Moortel, 2009, p. 333).

Crumlin-Pedersen (2010, pp. 60–66) observed that, before the Migration Period (c. 300–800 CE), two distinct boat-building traditions were found to the east and west of the Rhine. Southern Scandinavia and northwestern Germany had a tradition of building thin, light boats that had originated from the expanded log boat, with 60–70 expanded log boats having been found in this area (Crumlin-Pedersen, 2010, pp.65–66).

1 Or hulk. This was a type of medieval sea craft and a technological predecessor to the carrack and caravel types.

Such log boats have slender solid hulls carved from tree trunks and expanded with the help of fire and water. The expansion stretches the thin hull and gives it more strength while also providing more graceful curvatures, greater capacity, and more stability. To maintain its shape after expansion, the log boat should be reinforced with frames that lie symmetrically around the hull's center-line. The shipbuilders in this region can be said to have strengthened the thin and bendable trees by applying tension and in this way switched to fully planked ships (Van de Moortel, 2012, p. 297).

The term cog was used in late medieval texts to refer to a type of ship that included boats of various sizes, from small local boats to the largest seagoing ships of the time. Cogs were a type of round ship characterized by a flush-laid flat bottom amidships which gradually shifted to overlapped strakes near the posts. They were propelled by a single large rectangular sail. Cogs were apparently very effective vessels, and the Hanseatic League used these boats to dominate trade in northern and central Europe. Typical seagoing cogs ranged from about 15-25 meters in length with a beam of 5-8 meters. However, because almost all archaeological finds considered to be cogs are dated no earlier than the 12th century, examining the northern European clinker construction vessel, contemporary to YK20 would be a more appropriate comparison.

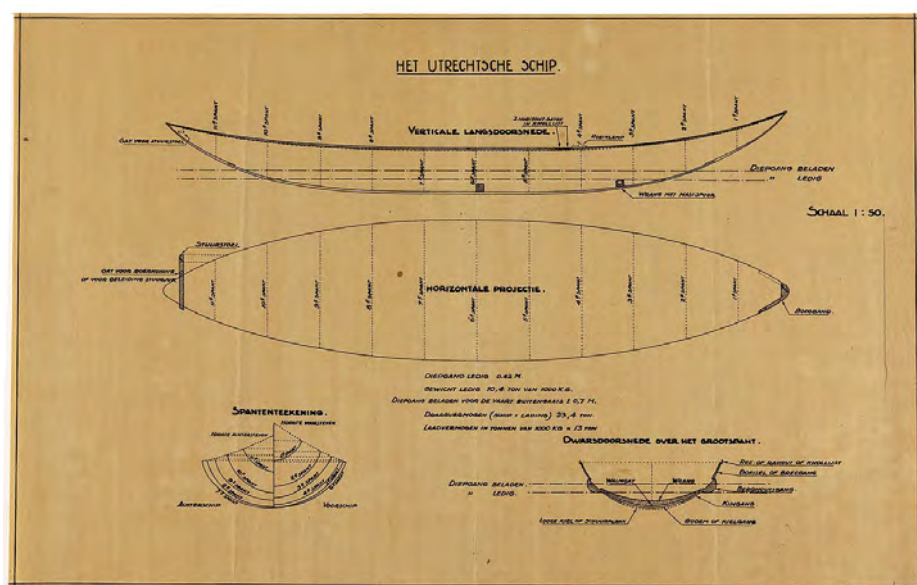


Figure 7. Plan and amidships cross-section of Utrecht 1 (https://en.wikipedia.org/wiki/Utrecht_ship#/media/File:HUA-214753_Plattegrondprojectie_doorsneden_en_spantekening_van_het_in_december_1930_opgegraven_schip_te_Utrecht_met_toelichting_en_aantekeningen.jpg)

As a result of the extensive maritime and river trade, Northern Europeans have been aware of the difference between clinker- and carvel-built vessels, but the difference was not just in planking methods. These two types of shipbuilding are referred to as the opposite in terms of construction technique. While clinker ships use planking as the primary element, carvel boats can be seen as more suitable for the skeleton-based technique, especially after the 1st millennium CE in which pre-erected frames gave the ship its shape. After northern Europeans adopted the carvel method in the 15th century CE, the clinker method completely lost its importance and tended to disappear, especially in the Low Countries (Hocker, 2004, p. 5).

In studies on Viking ships, some scholars have stated that molded frames may have been used at various points along the keel to determine the shape of the ship, as in YK20 (Crumlin-Pedersen, 2004, p. 40). One of the biggest differences between the YK20 and its northern European contemporaries is the absence of any examples in the Viking shipbuilding tradition where frames were attached to the keel (McGrail, 2014, p. 103). In this regard, making a comparison would be more appropriate with the Graveney boat, a contemporary of the YK20, and one of the ships built with the clinker construction.

6.2. Graveney boat

In September 1970, part of a clinker-built boat was discovered accidentally during the excavation of a large drainage channel in the Graveney Marshes (Figure 8). Most of the keel was found, as well as the sternpost and parts of eight strakes on each side. The total length surviving in the ground was 10 m, and the maximum surviving width was 3.40 m. Also, parts of nine frames were found in position. Later studies understood the ship to have had 10 frames with seven starboard and eight port-side planks (Ali, 2016, p. 2). This ship used both iron and treenails, which clearly resembles YK20.

Luting was used on both ships. While the content of the luting material on YK20 could not be definitively identified, cattle hair is estimated to have been used in the luting material on the Graveney ship. The iron clench-nails fastening the planks had almost completely rusted but left a clear impression of their shape on the timber (Figure 9), which is a huge distinction from YK20, which used edge fasteners as dowels (treenails). However, wedged treenails fastened the massive frames to the planking of the ship (Figure 10), just as in YK20. Although the butt scarfs used in the Graveney boat do not resemble the S-shaped and diagonal scarfs used in YK20, they do match some other Yenikapı shipwrecks (YK17, YK27; Kocabaş, 2015, p. 12). In addition to the luting used in both ships, a light brown resin was observed to have been used extensively on YK20, with the remains of a very hard grey-colored adhesive also found in some areas. However, researchers have mentioned the remains of a layer of clay

plowed under the Graveney ship to have provided waterproofing and held the planks together (Evans, 1971, p. 90). In contrast to the Graveney ship, which was determined to have been made entirely of oak, the use of different wood species in the construction of YK20 may have been the product of superior technical knowledge in addition to the diversity of regional flora.

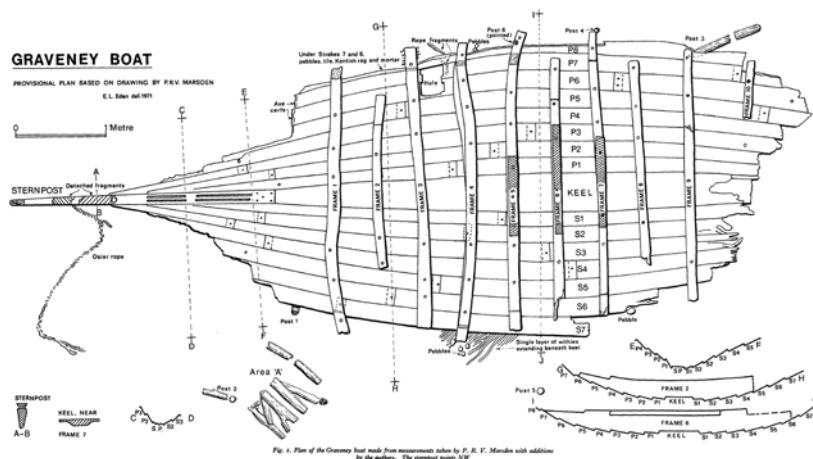


Figure 8. Plan of the Graveney boat made from measurements taken by P. R. V. Marsden with additions by the authors (Evans, 1971, pp. 91–92).



Figure 9. Luting of animal hair pierced by clench-nails (Evans, 1971, p. 114).



Figure 10. Field-recording: knobbed treenail projecting outside the boat (Evans, 1971, p. 111).

6.3. Skuldelev 3

The Skuldelev ships are five original Viking ships recovered from the waterway of Peberrenden in Skuldelev (c. 20 km north of Roskilde/Denmark). The remains of the shipwrecks were excavated in 1962 over the course of four months. The recovered pieces constitute five types of Viking ships and have all been dated to the 11th century. They are thought to have been an early form of blockship.² The numbering of the ships is slightly confusing, as when the remains were unearthed, they were thought to comprise six ships. However, after Skuldelev 2 and Skuldelev 4 were later discovered to be part of the same ship, the decision was made not to renumber the other vessels.

The Skuldelev 3 boat has been determined to be more appropriate for comparison, as it has suitable integrity and reconstruction. Skuldelev 3 was localized to the south of Wrecks 1 and 2 during the underwater examination in 1958, when part of the starboard side from keel to gunwale was uncovered and measured, as well as the keelson and parts of the internal timber amidships. She is the best preserved of all the ships in the blockage. The boat had settled against the southern side of the channel in a north/south orientation when it sank, with its stem across the deepest part of the channel and its stern jutting out of the water at the southern edge of the channel (Figure 11; Crumlin-Pedersen, 1967, pp. 118–120).

2 A blockship is a ship deliberately sunk to prevent a river, channel, or canal from being used as a waterway.

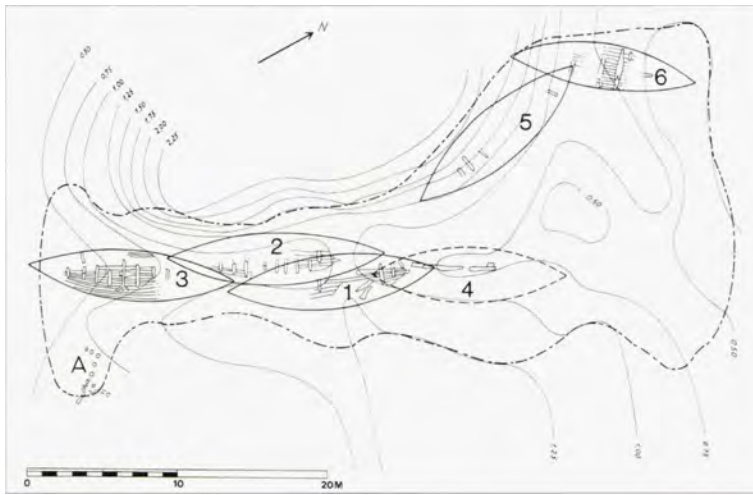


Figure 11. Skuldelev 1959. Contour plan showing the supposed position of six ships in the blockage (Crumlin-Pedersen, 1967: p. 75).

The pressure of the stones had loosened the planks of the starboard side from the stem, and these rested against the port side of Wreck 1's stern. However, the stem itself followed the planks to port and was found fully preserved below Wreck 2. The entire ship is made of oak, just like the Graveney boat. As mentioned before, although this preference was most likely a regional necessity, it can be technically interpreted as a more backward planning than YK20 and other Yenikapı Ships. Its 8.6 m keel, which is same as YK20, curves upward toward the ends with presumably a curve of 0.3-0.4 cm amidships. The full length of the keel must have been around 9-9.5 m. It has no rabbet, and the garboards are fastened to the sides of the keel amidships with iron rivets at intervals of around 15 cm and spikes at intervals of 14-19 cm toward the stem and stern (Crumlin-Pedersen, 1967, p. 121). Meanwhile, the YK20 used dowels (treenails) in the keel-garboard connections and was determined to have quite irregular distances between these treenails (Güler, 2019, p. 32).

Skuldelev 3 is clinker-built with eight planks to a side at an overlap of 3-4 cm fastened by round rivets 0.7-0.9 cm. in diameter at intervals of 12-16 cm. In the area along the bottom edge of each strake is a shallow groove containing the remains of a caulking of twisted animal hair and tar that had been inserted before the planks were nailed together. Some of the scarfs were also caulked with animal hair and tar (Crumlin-Pedersen, 1967, p. 122).

The strakes consisted originally of two or three planks 2.5-5.5 m in length, although planks of greater length were used in the two top strakes in order to strengthen the amidship area on each side (Figure 12). The plank lengths are generally longer compared to YK20 (Güler, 2019, pp. 37–40).

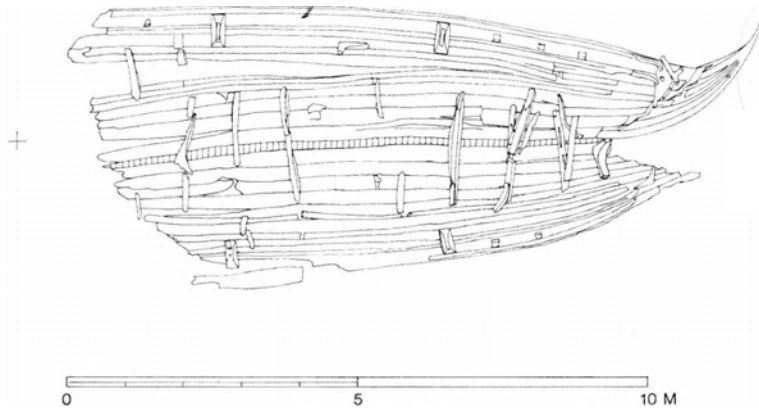


Figure 12. Skuldelev 1962. Wreck 3. Plan is at a 1:100 scale based on a photogrammetrical survey and aerial photographs (Crumlin-Pedersen, 1967, p. 120).

In both Skuldelev 3 and YK20, the original pattern of the scarfs in the lower rows is disrupted by subsequent repairs where short pieces of planks were used to replace damaged areas (Güler, 2019, p. 40; Crumlin-Pedersen, 1967, p. 123). In short, Skuldelev 3 had been constructed in the following order: the frames and keelson were situated after the keel, stem, stern, and at least the first five strakes had been assembled; the stringer on the fifth strake could not have been fitted before the sixth strake was placed, and the stringer on the sixth strake was not nailed into position until at least the seventh strake had been placed. Therefore, the shape of the hull had been fashioned solely on the basis of the planking and decided by the variations in the width of and angle between the planks (Crumlin-Pedersen, 1967, p. 132).

The types of fastenings used between clinker-built planks varied in the Middle Ages, with the oldest technique of sewn planks still used in Scandinavia, iron rivets used in Viking homelands, and pegged planking used toward the Baltic and Southeastern England, where iron rivets passing through wooden pegs were also used (Figures 13; Crumlin-Pedersen, 2004, pp. 47–48).

In the mid- and late Middle Ages, ships of several types not originating from the Nordic clinker tradition (e.g., cogs and hulks) had their upper planking built up of lapstrakes. For ships built according to the cog tradition, the part of the planking laid out as lapstrake were fastened with double-clenched nails. In these ships, a caulking of moss was driven into a wedge-shaped groove and held in position by thin laths fastened by iron staples, in contrast to true clinker boats that had either riveted planking in combination with inlaid caulking of animal hair or pegged (treenailed) planking with inlaid moss caulking (Figure 14; Crumlin-Pedersen, 2004, pp. 47–49).

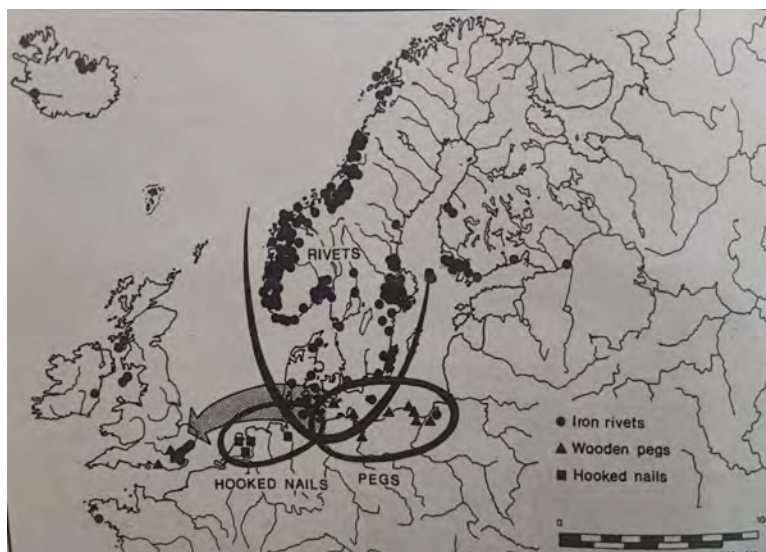


Figure 13. The distribution of various techniques for plank fastenings in clinker-built ships and boats in the seventh to thirteenth centuries according to P. Marsden (Crumlin-Pedersen, 2004: p. 48).

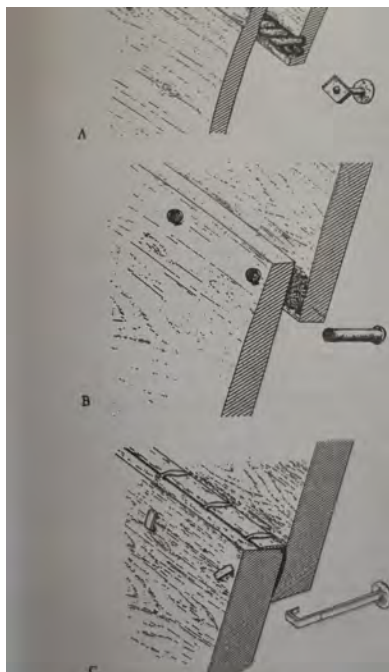


Figure 14. Lapstrake planks are assembled and made watertight in different ways within the various traditions: A) iron rivets and a string of wool as inlaid caulking in the Scandinavian clinker tradition, B) treenails and inlaid moss-caulking in the south Baltic tradition, or C) hooked nails and driven moss caulking held by a wooden lath fastened by iron cramps as employed in the cog tradition (Crumlin-Pedersen, 2004, p. 49).

7. Conclusion

The object of this study has involved a preliminary analysis of the Yenikapı shipwrecks, YK20 in particular, alongside their contemporaries found in Northwest Europe, including Viking ships and other medieval vessels. The analysis was based on archaeological records, historical documents, and scientific studies pertaining to ship construction techniques. The comparison focused on the materials used, hull shape, and construction design. The comparison has revealed the Yenikapı shipwrecks to have some similarities with their Northwest European contemporaries in terms of hull shape and design, as well as many differences. The biggest difference is the construction techniques, as the Yenikapı ships had been built using carvel planking and nailed construction, whereas their Northwest European counterparts had been built using clinker planking and riveted construction. The materials used in the Yenikapı ships also differ from their contemporaries by being built using locally sourced timber and not being fitted with iron clamps.

The Yenikapı Ships provide new insights into the ship construction techniques of the Byzantine Empire, and highlight the diversity and regional variations in shipbuilding during the Middle Ages. Further research is needed to explore the cultural, economic, and technological factors that influenced ship construction in different regions.

Linking the similarities between ships unique to the two regions precisely to interactions among shipbuilders may not be accurate, as Northern Europeans didn't begin to abandon clinker construction or become influenced by the Mediterranean shipbuilding technique of carvel construction until the 15th century. However, this preliminary study forms an important introduction to a detailed study of the Mediterranean and northern European shipbuilding features and their maritime interactions.

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References

- Ali, S. (2016). *A Digital Re-Examination of the Graveney Ship Find*. Master's thesis submitted to the Maritime Archaeology Department at the University of Southern Denmark.
- Basch, L. (1972). Ancient Wrecks and the Archaeology of Ships. *IJNA*, 1, 1-58.
- Casson, L. (1971). *Ships and Seamanship in the Ancient World*. Princeton.

- Crumlin-Pedersen, O., Olsen, O. (1967). The Skuldelev Ships. *Acta Archaeologica*, 38. Copenhagen: 73-176.
- Crumlin-Pedersen, O. (1978). The Ships of the Vikings. In: *The Vikings. Proceedings of the Symposium of the Faculty of Arts of Uppsala University, June 6-9, 1977*. Uppsala Universitet, Uppsala: 32-41.
- Crumlin-Pedersen, O. (2004). Nordic Clinker Construction. *The Philosophy of Shipbuilding: Conceptual Approaches to the Study of Wooden Ships*. Texas A&M University Press, College Station: 37-63.
- Crumlin-Pedersen, O. (2010). Archaeology and the Sea in Scandinavia and Britain. A personal account. *Maritime Culture of the North 3*. Viking Ship Museum, Roskilde.
- Evans, A.C., Fenwick, V.H. (1971). The Graveney Boat. *Antiquity*, 45: 89-104
- Güler, T. (2006). *Antik Çağ Doğu Akdeniz Ticareti ve Ticaret Gemileri*. Yayınlanmamış Yüksek Lisans Tezi, Selçuk Üniversitesi Sosyal Bilimler Enstitüsü.
- Güler, T. (2019). *Yenikapı 20 Batığının Konstrüksiyon Özellikleri ve Yapım Tekniği Önerisi*. Yayınlanmamış Doktora Tezi, İstanbul Üniversitesi Sosyal Bilimler Enstitüsü.
- Gyllius, P. (1997). *İstanbul'un Tarihi Eserleri*. Çev. Erendiz Özbayoğlu, Eren Yayıncılık, İstanbul.
- Hasslöf, O. (1963). Wrecks, Archives and Living Tradition. *Mariner's Mirror*, 49.3: 162-177.
- Hocker, M. F., Ward, C.A. (2004). Shipbuilding: Philosophy, Practice, and Research. *The Philosophy of Shipbuilding: Conceptual Approaches to the Study of Wooden Ships*. Texas A&M University Press, College Station: 1-12.
- Kocabaş, U. (2015a). The Yenikapı Byzantine-Era Shipwrecks, Istanbul, Turkey: A Preliminary Report and Inventory of the 27 Wrecks Studied by Istanbul University. *IJNA*, 44.1: 5-38.
- Kocabaş, U. (2015b). *Geçmişe Açılan Kapı: YENİKAPI BATIKLARI*, İstanbul.
- Magdalino, P. (2013). Bizans Dönemi Konstantinopolis Limanları. *Saklı Limandan Hikayeler: Yenikapı'nın Batıkları*, İstanbul, 11-15.
- McGrail, S. (2014). *Ancient Boats in North-West Europe*. Routledge, New York.
- Müller-Wiener, W. (1998). *Bizans'tan Osmanlı'ya İstanbul Limanları*. Çev. Erol Özbek, Tarih Vakfı Yurt Yayınları, İstanbul.
- Özsait-Kocabaş, I. (2018). The Yenikapı 12 Shipwreck, a 9th-Century Merchantman from the Theodosian Harbour in Istanbul, Turkey: construction and reconstruction. *IJNA*, 47.2: 357-390.
- Özsait-Kocabaş, I. (2019). Bir Bizans Teknesinin Anatomisi: Yenikapı 8 Batığı. *Art-Sanat*, 11: 325-338.
- Pomey, P., Kahanov, Y. & Rieth, E. (2012). Transition from Shell to Skeleton in Ancient Mediterranean Ship-Construction: Analysis, Problems and Future Research. *IJNA*, 41. 2: 235-314.
- Steffy, J. R. (1994). *Wooden Shipbuilding and the Interpretation of Shipwrecks*. College Station, Texas A&M University Press.
- Türkmenoğlu, E. (2017). *Yenikapı 27 Batığı: Konstrüksiyon Özellikleri ve Restitüsyon Önerisi*. Yayınlanmamış Doktora Tezi, İstanbul Üniversitesi Sosyal Bilimler Enstitüsü.
- Van de Moortel, A. (1991). *A Cog-like Vessel from the Netherlands*. Flevovericht Nr. 331.
- Van de Moortel, A. (2009). The Utrecht Ship Type, an Expanded Logboat Tradition in Its Historical Context. *Between The Seas Transfer and Exchange in Nautical Technology Proceedings of the Eleventh International Symposium On Boat and Ship Archaeology Mainz 2006*.
- Van de Moortel, A. (2012). The medieval Utrecht ship type. Blending boatbuilding traditions in the cultural landscape of Europe's early medieval Migration Period. *Ships and Maritime Landscapes. Proceedings of the Thirteenth International Symposium on Boat and Ship Archaeology, Amsterdam 2012*.
- Verhagen, S. (2018). Pesse Kanosu: Dünyanın En Eski Teknesi. *TINA*, 9: 88-91.

CHAPTER 23

THE WOODEN ANCHORS OF KARABURUN: DOCUMENTATION AND PRELIMINARY ASSESSMENTS

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Abstract

The subjects of this article are two wooden anchors that were found by fishermen in 2011 off the Black Sea coast in Karaburun Village, Istanbul. The waterlogged wooden anchors were delivered to Istanbul University's Conservation Laboratory for scientific analysis. Documentation studies carried out in the laboratory revealed the four pieces of the remains to belong to two different wooden anchors. The anchors are dated between 580-460 BC according to the C14 analyses. The waterlogged wooden anchors were stored wet, the desalination procedure was completed, and surface cleaning was carried out. After cleaning, photo-mosaics were completed of both sides of the anchors by combining approximately 25 photo-frames. Documentation was carried out using the 3D digitizer *FaroArm*; the technical details of the anchors, the data related to the manufacturing methods, and the elements such as nails, dowels, mortise and tenon joints are written on the drawing. Wood samples were taken from the anchors, and genus-species identifications as well as dendrochronological results are in the works.

Keywords: Anchor, Black Sea, Karaburun anchors, waterlogged wood, wooden anchor

1. Karaburun anchors: Discovery

In the winter of 2011, wooden pieces caught in fishermen's nets off the Black Sea coast in Karaburun village, Istanbul-Turkiye were delivered to Istanbul University's Department of Conservation of Marine Archaeological Objects for scientific analysis and conservation (Fig. 1). Preventive conservation was applied to the wooden anchors taken to laboratory, and the necessary conservation studies were initiated. The 1:1 scale drawings of the details, C14 analyses, and wood species identification have been done for these unique wooden anchors. The Karaburun anchors consist of four main parts. During the documentation studies carried out in the laboratory, the remains were understood to belong to two separate wooden anchors. Scientific investigations on the construction technique used for the anchors will be carried out by experts in our laboratory using the 3D digitizer *FaroArm*.



Figure 1. People who contributed to the rescue of the anchor, (from right to left) Haslet Soyöz and Selçuk Birinci.

2. Karaburun

The village settlement of ancient *Delkos* (Terkos) is located on the Black Sea coast approximately 40 km west of the northern entrance of the Bosphorus and 2 km northwest of the Durusu estuary (Fig. 2). Some researchers have stated that the ancient *Philea* settlement should be localized in this region. Historians think that *Philea* was not a city but a marketplace (*emporion*) of the *Delkos* settlement on the shore of Terkos Lake. All researchers agree that a lighthouse had existed in Karaburun in ancient times, similar to where one is today. Five votive inscriptions were found here, and the museum purchased these pieces in 1913 (Sayar, 2005, pp. 4–5; Gyuzelev, 2008, pp. 291–292). The inscriptions revealed the existence of a

local cult called *Heros Stomianos*. The adoration of *Heros Stomianos* in Karaburun shows that this cult was related to the safety of sailors traveling in the Black Sea. Although the location of the sanctuary of this cult in Karaburun and the traces of the *Philea* settlement have not yet been identified with archaeological finds, this place is probably located around the hill overlooking the Black Sea, where today's Karaburun Lighthouse is located, and under the present settlement.



Figure 2. The Delkos settlement and Karaburun.

3. Wooden Anchors

Anchors are equipment that keep floating vehicles in a particular position by countering the effects of wind, current, and waves.¹ Anchors that are lowered into the water with a rope, chain, or a combination of the two either cling to the bottom to ensure stability or create a large area to minimize drag under the boat, as used in open seas (Kocabaş, 2005, p.11). Anchors are one of the most critical pieces of equipment of a boat or ship today and undoubtedly had much more vital importance for ancient sailors who sailed only with the wind and oars.² While the first examples attempted to ensure the anchor was attached to

1 For general information about the history of anchors, see Curryer (1999).

2 The Greek poet Theognis, probably a seaman, in an article from 548-537, literally dwelled on the functions of anchors: "A young girl is not good for old man, for she does not follow the rudder as a ship does. She is not

the sea floor, this understanding developed in the direction of lightening anchors by having them attach to the bottom with sharp nails. This was achieved by constructing anchors using different materials (Fig. 3).

In the initial stages of their historical development, anchors were made of heavy stones. Homer used the word *ευναί* to express anchor stones in his *Odyssey* (Homeros, ix. 137); he also mentioned perforated stones to have been used as anchors in the *Iliad* (Homeros, i. 436; xiv. 77). The Greeks referred the anchors *ἄγκυρα* (ankyra), meaning hook. Sidonis (600 AD) wrote, “Ancora comes from the Greek...like a hand it grips sand and stone.” In the 5th century BC, Pindar described anchors as “bronze toothed” in his *Pythian Odes* (iv. 24), referring to a bronze nail attached to the end of the arms of a wooden anchor to prevent wear. Virgil stated that this type of anchor was still used by the Romans in the 1st century BC, using the expression “stubborn tooth” (Virgil, *Aeneid*, vi.4). Anchor teeth found in the Ma’agan Mikhael and Porticello shipwrecks, dating back to 400 BC, were made of copper and bronze (Rosloff, 1991, p. 223; Eise-man & Ridgway, 1987, pp. 19–21).

Plinius in his *Naturalis Historia* (vii. 57) mentioned that single-armed wooden anchors were used after stone anchors and that this discovery was attributed to Eupalamus. Strabo in his *Geographika* (vii. 303; 64 BC-25 AD) credited the invention of the double-armed anchor to the Scythian Anakharsis (600-590 BC). According to legend, King Midas of Phrygia founded the city of Ankyra (Ankara), where he discovered a ship anchor. Pausanias, in his *Descriptio Graeciae* (i. 4–5) stated that this anchor was still preserved in the temple of Zeus during his time (2nd century AD).

Stone anchors have been around since stones were used as anchors by the first sailors. Lead stock anchors were also developed based on a two-armed wooden anchor with a stone stock. The medieval and modern iron stock anchors were achieved based on the iron anchors used in tandem with wooden anchors. The unique dating and classification of ancient stone, wood, and especially iron anchors have been discussed in the article by German underwater archaeologist Gerhard Kapitan (1984) in the *International Journal of Nautical Archaeology* (IJNA). Kapitan’s article has been frequently repeated and used as a reference by researchers interested in this subject. However, since then, new research and discoveries in underwater archaeology have shown that Kapitan’s work should be updated with changes and additions (Haldane, 1986; Kocabaş, 2003; Votruba, 2014).

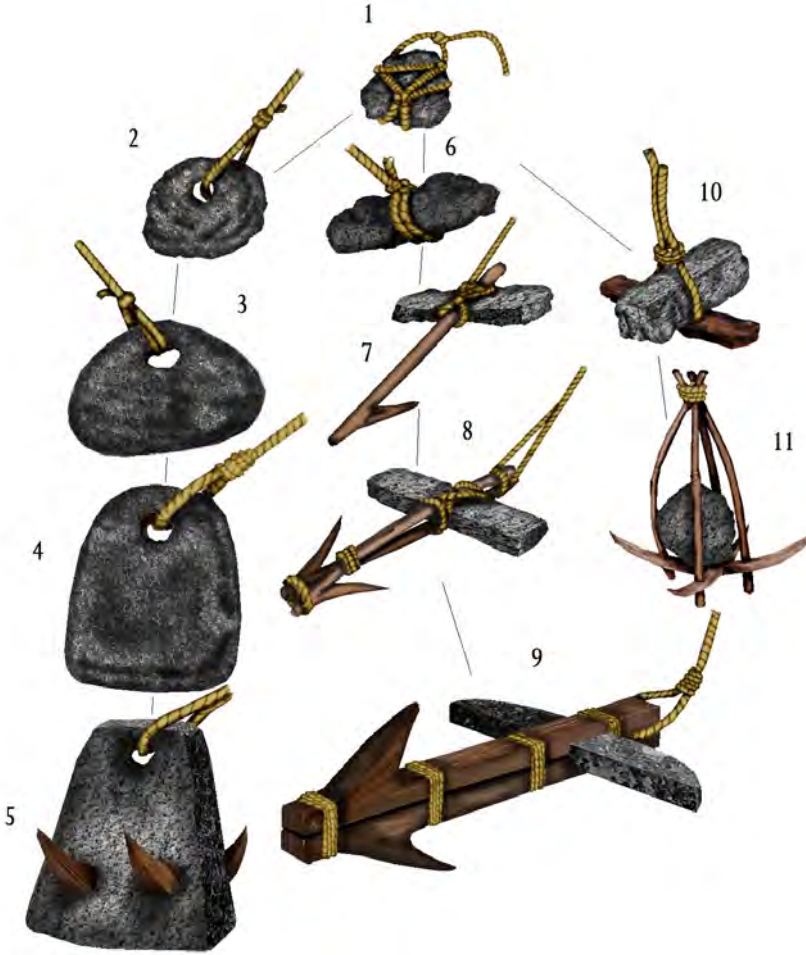


Figure 3. Diagram illustrating the development of ancient anchors (Kapitan, 1984, p. 34).
(With an illustration by Çağlar Çakır).

Wooden anchors as they are known today were first used at the end of the 7th century BC. Stone or lead stocks, bronze or iron nails, and lead support pieces were used on wooden anchors at the junction of the arm and the shank. When an anchor is lost underwater, the wood deteriorates, leaving metal, stone, and other anchor elements. Evaluations are also made according to these remains and the information from ancient sources, rarely from the wooden anchor itself. The classifications made so far have primarily been based on the stock material and the way it is attached to the wooden anchor (Kapitan, 1984; Haldane, 1984). Archaeological and written documents indicate that, stone or lead-filled wooden stocks appear to first have appeared in the 7th century BC. The first examples of stone stocks being in Cyprus, Punta della Ristola, and Metaponto. One example dating to

the second half of the 6th century BC was also found in the Dattier Shipwreck. In addition, wooden-anchor depictions first appeared on coins dating from 600-400 BC. Almost all of these depictions on coins strikingly show quite thick arms and a buoy ring on the stock and crown, which allows the anchor to be pulled up in case it gets stuck on the bottom or breaks. Depictions were first found on the coins of Apollonia Pontika³ (Fig. 4; Kapitan, 1990, p. 243; Paunov, 2017). However, when examining the descriptions of anchors on the coins recovered from *Apollonia Pontica*, the anchor body is understood to have contained two shanks and the arms to have been composed of pieces adjacent to this body shank. These shanks were probably cut from a large tree with one or two branches. Until the discovery of the Karaburun Anchors, how these two pieces that make up the wooden anchor were put together had remained unknown.



Figure 4. Depictions of wooden anchors with stock on *Apollonia Pontica* coins (Paunov, 2017, p. 84).

4. Preventive conservation

How much time elapsed from when the fishermen had retrieved the wooden pieces underwater to when they were delivered to us is not known precisely. The first examinations determined that deep cracks had occurred on the artifact, which had been found in a waterlogged state due to the drying that had occurred while exposed to the air. This occurring in winter

3 Apollonia was founded as a Miletus colony in Thrace on the Black Sea coast in the 6th century BC. Today, the settlement within the borders of Bulgaria was named Sozopol.

prevented the formation of irreversible damage to the works to some extent. The waterlogged wooden artifacts were stored wet in the laboratory. By the dimensions of the objects, a wooden chest was made for storing them in water. Thus, the wooden anchors could be stored wet during the entire study. The procedure for desalinating the objects was also carried out in the same crates. Due to the low salinity of the Black Sea (1.8%), the objects were placed directly into freshwater and measured using a conductometer tester periodically; the salinity was reduced to around 350 ppm in approximately four months through the water changes. Work in the laboratory started with the mechanical cleaning of the anchors. The cleaning removes inorganic dirt and organic formations such as mud, clay, sand, and grit residues on the pieces in order to reveal the details. The surfaces of the objects were thoroughly cleaned using soft brushes, water, and dental tools.

5. Documentation

After cleaning, photo shoots were made for a photo-mosaic. First, the photo-mosaic works on both sides of the anchor were completed by combining approximately 25 photo frames. The images were combined in the program Adobe Photoshop to obtain a single high-resolution image. Next, three-dimensional drawings of the objects were made by expert Ayşegül Çetiner-Dinçer using the 3D digitizer FaroArm. This was used to determine the elements of the anchor, such as nails, dowels, and mortise and tenon joints. The documentation work was completed by storing the documentation reports in the laboratory once the detail photos had been taken (Figs. 5a, 5b). The investigations on the wooden anchor were completed by Ayşegül Çetiner-Dinçer at Istanbul University Yenikapı Shipwrecks Application and Research Laboratory.

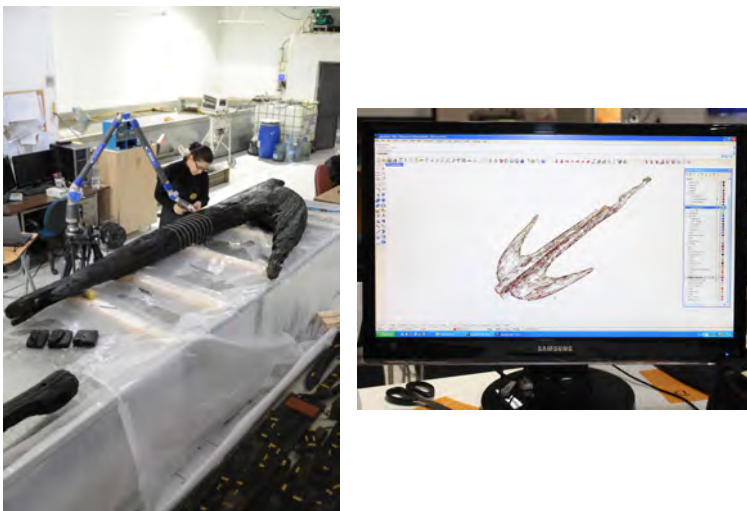


Figure 5. (a) Photo and (b) 3D drawing of wooden anchors.

5.1. Karaburun Anchor 1 (KA1)

A general description of the find reveals a double-armed anchor that is considered whole with its shank and arms; it is composed of two equal parts formed by dividing it into two along the axis of symmetry. In short, each part has one arm and half of the shank axis. These parts are named KA1-1 and KA1-2. KA1-1 was found intact with the shank, arm, and head parts; the length of the piece measures 460.5 cm. KA1-2, on the other hand, was broken at a point very close to the beginning of the stock-aperture, and most of its head was missing. The current length of the piece up to the fracture is 315.7 cm. Apart from these, no other element that could belong to this anchor was found.

The wood from both parts is rugged and robust. However, the most extensive damage to the pieces occurred in the form of deep cracks from the outside to the core due to being exposed to rapid moisture loss, especially on the faces of the anchor pieces taken from the sea. Apart from this, surface losses are found in the form of scorching due to occasional wear and excessive drying on the surfaces.

These two anchor pieces are joined by four mortise and tenon joints on the body parts, and the tenons are fixed in place with the peg that act as a lock on both sides. In addition, three more mortises on the head part of the anchor are seen to pass through the piece in the horizontal direction.



Figure 6. Karaburun Anchor 1 photo-mosaic.

5.2. Karaburun Anchor 2 (KA2)

If identifying the find is necessary, one can start with Karaburun Anchor 1, which has a similar structure and from which more data can be obtained. The anchor can be described as

double-armed anchor, which is considered as a whole with its body and arms, and is composed of two equal parts formed by dividing it in half along the axis of symmetry. In short, each part has one arm and half of the trunk axis. As seen from the drawing, these parts are named KA2-1 and KA2-2. Of these, only part of the body of KA2-1 is present. The head, arms, and crown have not survived. The current length of the piece is 247 cm. We also have the head of KA2-2, which unlike KA2-1 was found broken in three pieces. Its current length is 483 cm. Apart from these, no other element was found that might belong to this anchor.

The wood of both parts is rugged and robust. Apart from the losses, they have a few cracks and occasional wear on the surface. When evaluating the existing parts of these two anchor pieces, six mortises are seen to open from the body parts and to be joined with a tenon, and the pegs to be fixed in place act as a lock on both sides. However, not much care is understood to have been taken while opening the mortise. The mortise holes were not centered while drilling but were drilled closer to the second surface. One of the holes is seen to open too close to the edge (second surface) and to extend beyond the edge line, thus ceasing its function as a mortise socket. The makers were seen to have resolved this problem caused by careless calculations during the construction by shaving the mortise edges and the surface and using it in that form. It was probably hammered into the joint and visible from the outside, but it has not survived.

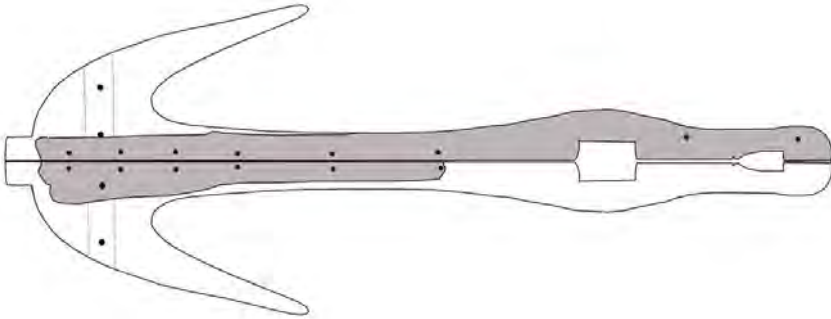


Figure 7. Karaburun Anchor 2's estimated reconstruction based on KA 1.
(Drawing by Ayşegül Çetiner).

6. Conclusion

The focus of underwater archaeology studies in the Black Sea in recent years have identified many well-preserved shipwrecks as a result of various deep-sea research (Ward & Ballard, 2004; Batchvarov, 2021). These shipwrecks have been dated to different centuries and are accepted as an indicator of intense trade in the Black Sea.

The unique Karaburun Wooden anchors can be considered proof of this wealth of underwater archaeology in the Black Sea and have been examined in detail regarding their construction techniques. In particular, the high level of preservation for KA1 and the fact that the two essential parts constituting the anchor were recovered with very little incompleteness increased the accuracy of the work carried out on them.

The preserved length of the Karaburun Anchor 1 (KA1) is 460.5 cm, and the arm width of the anchor is 184.5 cm from end to end. The Karaburun Anchor 2 (KA2) has features similar to that of the KA1 anchor but has fewer preserved parts. The mortise and tenon joint was used to connect both anchors.

Looking at the finds, no clear statement can be easily made about the material of the stock that had been lost. Therefore, the anchor may conceivably had a stone, lead, or lead-wood composite stock. However, the stock-aperture measurements of the Karaburun anchors help us infer the type of stock used in the anchor's construction. Accordingly, it can be suggested that stone stocks were used for Karaburun anchors.

Based on the C14 analysis results of samples taken from KA1 and KA2, the anchors date back to the period of 580-460 BC.

The underwater survey we will carry out in front of the Karaburun lighthouse in the spring of 2024 will perhaps help unearth the shipwreck to which the wooden anchors belong.

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References

- Batchvarov, K. (2021). A Byzantine period merchant ship from the Black Sea. *Archaeonautica*, 21: pp. 176–179.
- Curryer, B.N. (1999). *Anchors: The Illustrated History*. Annapolis-Maryland: Naval Institute Press.
- Eiseman, C. J. and Ridgway, B. S. (1987). *The Porticello Shipwreck: A Mediterranean Merchant Vessel of 415–385 BC*. College Station, Texas.
- Gyuzeev, M. (2008). *The West Pontic Coast: Between Emine Cape and Byzantion During the First Millenium BC*. Burgas.

- Haldane, D.D. (1986). Wooden Anchor Arm Construction. *International Journal of Nautical Archaeology*. 15.2: 163–166.
- Homer. (1984). *İlyada*. Trans. A. Erhat, A. Kadir. İstanbul: Can Yayınları
- Homer. (1984). *Odysseia*. Trans. A. Erhat, A. Kadir. İstanbul: Can Yayınları.
- Haldane, D.D. (1984). The Wooden Anchor, Texas A&M University (Unpublished master's thesis). Texas.
- Kapitan, G. (1990). Ancient Two-Armed Stone-Stocked Wooden Anchors-Chinese and Greek. *International Journal of Nautical Archaeology*. 19.3: 243–245.
- Kapitan, G. (1984). Ancient Anchors-Technology and Classification. *International Journal of Nautical Archaeology*. 13.1: 33–44.
- Kocabaş, U. (2005). Çamaltı Burnu I Batığı Demir Çapalarının Tarihsel İncelenmesi, Koruma, Onarım ve Tıpkıyapım Çalışmaları. (Unpublished doctoral thesis). İstanbul Üniversitesi Sosyal Bilimler Enstitüsü.
- Sayar, M. H. (2005). Roma İmparatorluk Devrinde İstanbul Boğazı ve Çevresinde Denizcilik Hakkında Bazı Notlar. *Tarih Boyunca Dünyada ve Türklerde Denizcilik Semineri Bildiriler Kitabı*, pp. 1–6. İstanbul: Globus Dünya Basımevi.
- Paunov, E. (2017). The Tetradrachm Coinage of Apollonia Pontica: Iconography, Issues and Magistrates. Ed. D. Boteva. *Studies in Ancient Numismatics in Honour of Dimitar Draganov*, pp. 59–87.
- Pausanias. (1964). *Descriptio Graeciae*. Ed. W.H.S. Jones. London: Loeb.
- Plinius. (1947). *Naturalis Historia*. Ed. H.R. Rackham. London: Loeb.
- Pindar. (1997). *Pythian Odes*. Ed. W.H. Rieu. Loeb.
- Rosloff, J.P. (1991). A One-Armed Anchor of c.400 BCE from the Ma'agan Michael Vessel, Israel. A Preliminary Report. *International Journal of Nautical Archaeology*, 20.3: 223–226.
- Stephanus Byzantius. (1984). *Ethnicorum quae Supersunt*, Ed. A. Meineke. Berlin.
- Strabon. (1987). *Geographika*, (Coğrafya). Trans. A. Pekman, İstanbul: Arkeoloji ve Sanat Yayınları.
- Virgil. (1956). *Aeneid*. Ed. W.F.J. Knight. Penguin Classics.
- Votruba, G. F. (2014). Iron Anchors and Mooring in the Ancient Mediterranean (until ca. 1500 CE). Unpublished Ph.D. Thesis. Oxford University.
- Votruba G. F. and Artzy, M. (2016). An Archaic Anchor Arm from Liman Tepe/Klazomenai, Turkey. *International Journal of Nautical Archaeology*, 45:2, 450–456.
- Ward, C. and Ballard, R. D. (2004). Deep-water Archaeological Survey in the Black Sea: 2000 Season. *International Journal of Nautical Archaeology*, 33.1: 2–13.

