CONSERVAR PATRIMÓNIO

ARP · Associação Profissional
de Conservadores-Restauradores
de Portugal
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de Portugal

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Editorial

Artigos Articles

Conservar Património: 20 anos a publicar

Conservar Património: 20 years publishing

ELIN FIGUEIREDO
Directora / Director
Editora-chefe / Editor-in-chief
ANA CLARO
SÍLVIA O. SEQUEIRA
Directoras adjuntas / Co-directors
Editoras-chefe / Editors-in-chief

Faz este ano 20 anos desde que a revista Conservar Património (CP) publicou o seu primeiro número (2005). Queremos assinalar esta data fazendo um pequeno resumo do percurso da revista, tanto a longo-termo como no passado mais recente e aproveitar para assinalar algumas novidades.

A CP soube desde a sua fundação adaptar-se e reinventar-se face às várias realidades de publicação científica dos últimos 20 anos (Figura 1). Iniciou-se com dois números por ano e com edição apenas em papel. Permaneceu assim até 2012, quando se tornou claro que teria de passar a digital para sobreviver num mundo cada vez mais digitalizado e interoperacional [1-2]. Já em formato totalmente digital e de livre acesso (2013), passou a publicar mais artigos por ano, passando de 80 artigos nos oito anos iniciais (2005 a 2012, todas as secções incluídas) para 90 em apenas seis anos (2013 a 2018). A partir de 2018 passou a publicar três números por ano, fazendo face à procura da revista por parte de autores nacionais e internacionais. De forma a agilizar a gestão editorial, no ano de 2021 passou também a implementar um novo processo de submissão de manuscritos através da plataforma OJS/PKP, a par da nova página oficial (https://conservarpatrimonio.pt) criada em 2020 e alojada na Fundação para a Computação Científica Nacional (FCCN) [3-4].

Desde a sua fundação, a revista sofreu também duas mudanças significativas na sua imagem gráfica. A primeira quando passou para o formato digital em 2013 e a segunda em 2018 quando se deu uma mudança na direcção da revista. A segunda mudança possibilitou a consolidação de uma identidade gráfica da revista, com uma imagem gráfica totalmente adaptada à publicação digital, a par da criação de um logótipo e o registo da marca no Instituto Nacional da Propriedade Industrial (INPI).

Apesar de algumas transformações, a revista tem mantido várias das suas características iniciais, algumas até em contraciclo com congéneres internacionais, como a publicação de artigos dedicados a intervenções (secção Intervenções). Entendemos tal secção fundamental para a comunidade de conservação e restauro. Decidiu-se também manter a possibilidade de publicar em mais do que uma língua, o que sem dúvida representa um esforço acrescido para a equipa editorial. Tal possibilidade favorece, no entanto, o desenvolvimento de nomenclatura na área da conservação e restauro em várias línguas.

Nos 20 anos de publicações da CP publicaram-se 334 artigos (incluindo as várias secções) e 31 editoriais, numa média de 27 artigos por ano só nos últimos sete anos (2018-2024) (Figura 2). Sem dúvida que o crescimento no número de artigos publicados ao longo dos 20 anos acompanha as tendências mundiais na publicação de artigos científicos, mas obriga também a um maior esforço por parte dos editores. A equipa editorial da CP tem por isso sofrido um aumento significativo, primeiro com a constituição de um Conselho Editorial em 2009 [5] e mais recentemente com o aumento do número de Editores Associados [6].

Além da publicação dos números regulares (decorrentes de artigos espontaneamente submetidos para publicação pelos seus autores ao longo do ano), nestes 20 anos foram publicados quatro números temáticos (decorrentes de convites lançados a autores para submeterem artigos no âmbito de um tema concreto) e 11 números dedicados a trabalhos apresentados em conferências (Figura 3). Vários destes números especiais contaram com Editores Convidados.

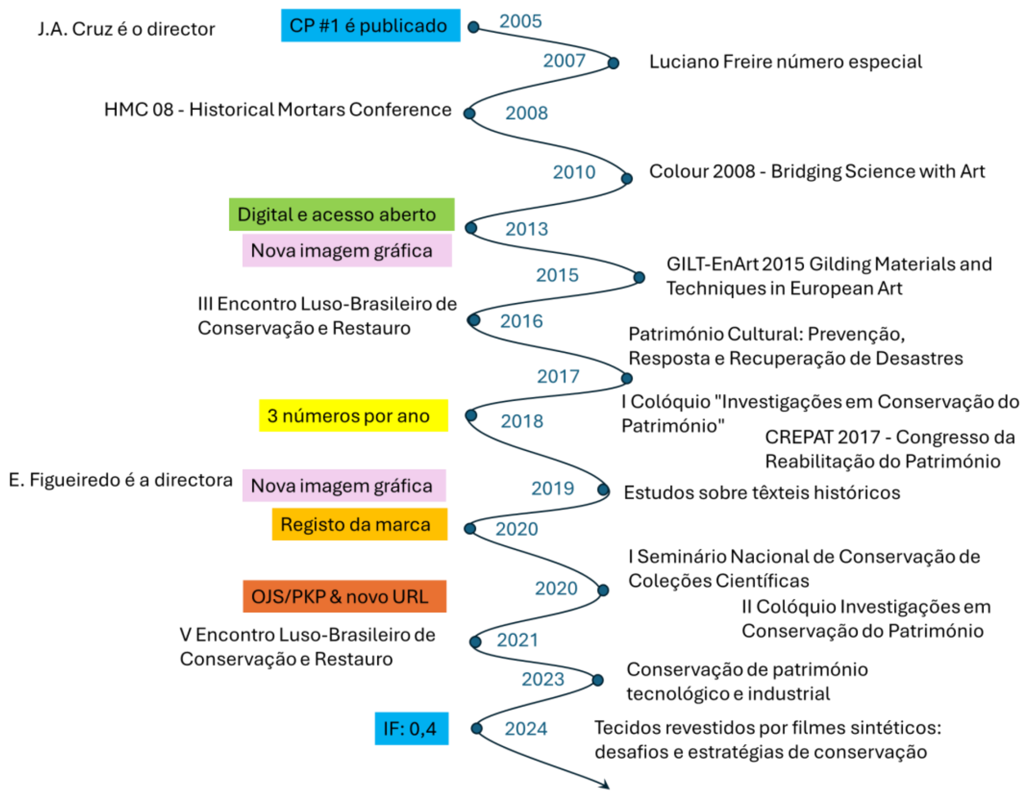

Figura 1. Esquema sumário do percurso da revista nos últimos 20 anos, com alguns acontecimentos destacados a cor e com a menção dos vários números temáticos e actas de conferencia publicados.

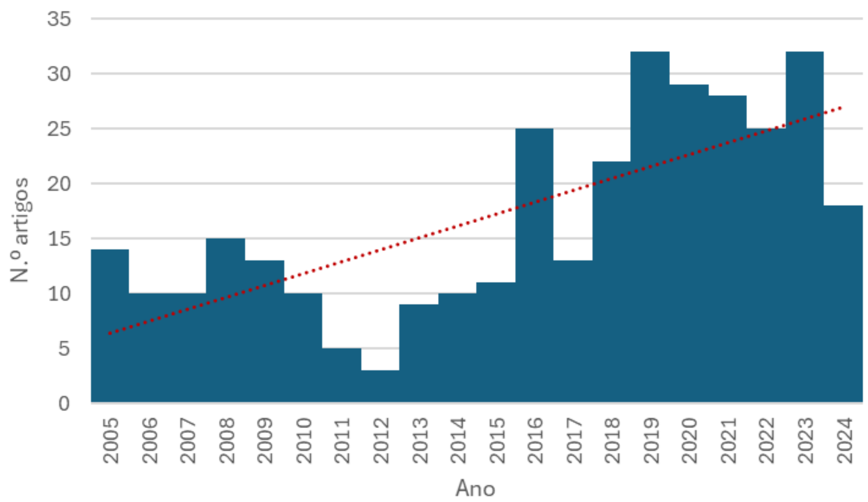

Figura 2. Número de artigos publicados (inclui todas as secções) durante os 20 anos da CP. A tendência linear crescente (a vermelho) marca o aumento generalizado no número de artigos publicados durante o período.

Quanto à temática dos artigos publicados na CP, e considerando as 19 categorias (ou sub-áreas) definidas em 2020 e implementadas no sistema de gestão editorial OJS/PKP, podemos observar que os artigos se encontram distribuídos por todas as áreas, mas de forma desigual (Figura 4). Tendo em conta o conjunto de artigos publicados no intervalo dos números 29 (2018) ao presente 47 (2025) (representando a totalidade dos artigos que se encontram categorizados à presente data), as categorias com mais publicações são Edifícios históricos e áreas urbanas (33), Pintura, escultura e policromia (32) e Coleções Científicas, Históricas e Etnográficas (32) seguidas de Conservação preventiva (26), Têxteis (24) e Materiais de património edificado (23). Para tal contam alguns números temáticos que incorporaram vários artigos, tais como o 44 (2023) (Conservação de património tecnológico e industrial) e o 31 (2019) (Estudos sobre têxteis históricos). As categorias com menos artigos são Documentos gráficos (6), Educação e formação em conservação (6) e Filmes e material fotográfico (3 artigos durante o período contabilizado).

A revista tem, desde a sua incorporação nas várias bases de dados internacionais, seguido uma trajetória constante de qualidade, encontrando-se normalmente nos Q1 e Q2 das áreas de Conservação e Museologia (*SCImago Journal & Country Rank*). A incorporação da revista no *Emerging Sources Citation Index* da *Web of Science* resultou recentemente na atribuição de um factor de impacto (*impact factor* (IF)). A CP tem assim desde 2023 um IF associado, que neste momento é de 0,4. Reconhecendo de que a existência de um IF nas revistas científicas é importante para certos autores, congratulamo-nos com mais esta conquista.

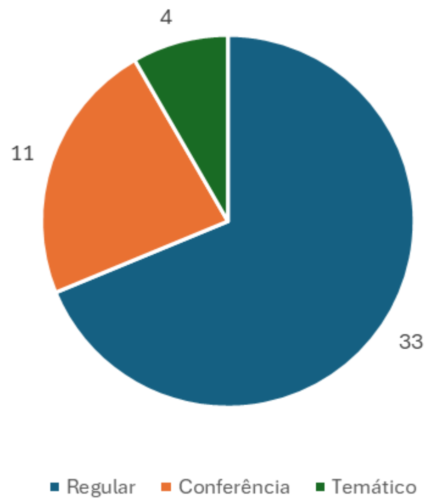

Figura 3. Distribuição dos números da revista ao longo dos últimos 20 anos relativamente à publicação de números regulares (11), números referentes a actas de conferencia (11) e números temáticos (4).

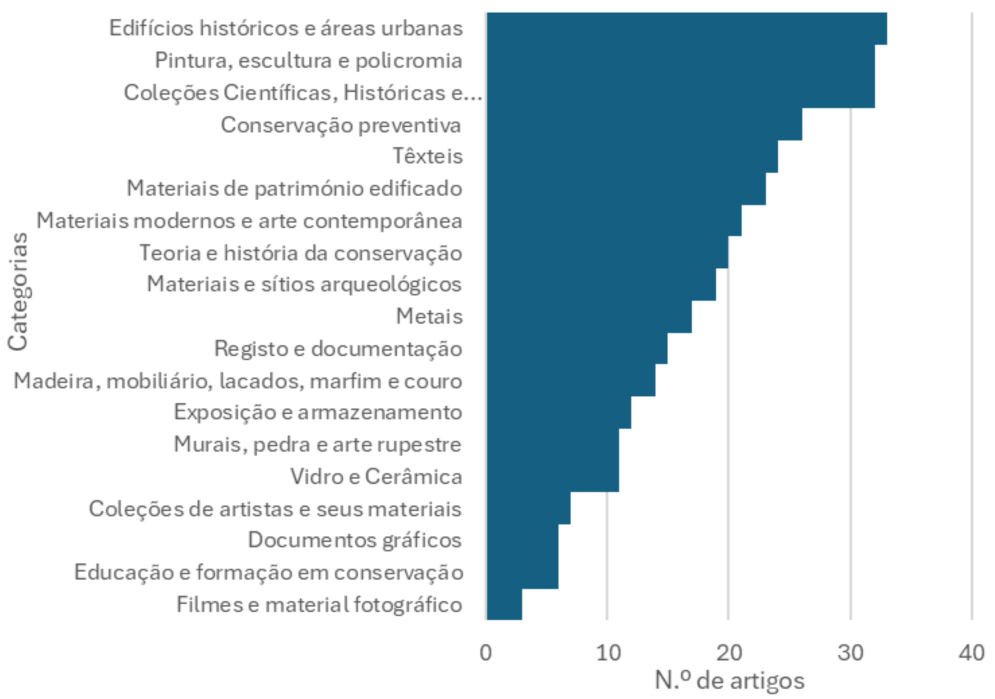

Figura 4. Categorias temáticas dos artigos publicados desde o número 29 (2018) ao presente 48 (2025). A publicação de números temáticos e decorrentes de conferencias durante este período resulta num maior número de artigos nalgumas categorias.

Celebrar 20 anos da revista CP é celebrar a colaboração e o compromisso de uma comunidade dedicada à salvaguarda e valorização do Património Cultural. Agradecemos a todos os autores, revisores, editores e leitores que contribuíram para este percurso. Olhando para o futuro, reafirmamos o nosso compromisso em continuar a fornecer uma plataforma de qualidade para a divulgação da investigação e intervenção em conservação e restauro. Convidamos todos a participar nesta jornada.

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This year marks 20 years since Conservar Património (CP) published its first issue (2005). We want to celebrate this date by giving a short summary of the journal's journey, both in the long term and in the more recent past and take the opportunity to point out some new achievements.

Since its foundation, CP has been able to adapt and reinvent itself in the face of the various realities of scientific publishing over the last 20 years (Figure 1). It began with two issues per year and a paper edition only. This format continued until 2012, when it became clear that it would have to switch to digital to survive in an increasingly digitised and interoperable world [1-2]. Once fully digital and open access (2013), it began publishing more articles per year, going from 80 articles in the initial eight years (2005 to 2012, all sections included) to 90 in just six years (2013 to 2018). From 2018 onwards, it began publishing three issues per year, meeting the demand from both national and international authors. To optimise editorial management, in 2021 a new manuscript submission process was implemented via the OJS/PKP platform, along with a new official website (https://conservarpatrimonio.pt) created in 2020 and hosted at the Portuguese Foundation for Scientific Computing (FCCN) [3-4].

Since its foundation, the journal has undergone two significant changes in its layout. The first, when it went digital in 2013, and the second in 2018 occurring with a change in the directory board. The second change enabled the consolidation of the journal's graphical identity, with the development of a page design fully adapted to digital publication, along with the creation of a logotype and trademark registration at the Portuguese Institute of Industrial Property (INPI).

Despite some transformations, the journal has maintained several of its initial characteristics, some even in counter-cycle with international counterparts, such as the publication of articles dedicated to interventions (Interventions section). We consider this fundamental for the conservation and restoration community. It was also decided to maintain the possibility of publishing in more than one language, which undoubtedly represents an added effort for the editorial team. This possibility, however, fosters the development of terminology in the field of conservation and restoration in various languages.

In its 20 years of publications, CP has published 334 articles (including the various sections) and 31 editorials, an average of 27 articles per year in the last seven years (2018-2024) (Figure 2). There's no doubt that the growth in the number of articles published during these 20 years follows global trends in scientific publishing, but it also implies a greater effort by the editors. The editorial team at CP has therefore grown significantly, first with the creation of an Editorial Board in 2009 [5] and more recently with the increase in the number of Associate Editors [6].

In addition to the publication of regular issues (resulting from articles spontaneously submitted for publication by their authors throughout the year), four thematic issues (which are the result of invitations to authors to submit articles on a specific theme) and 11 issues dedicated to papers presented at conferences have been published over the last 20 years (Figure 3). Several of these special issues featured Guest Editors.

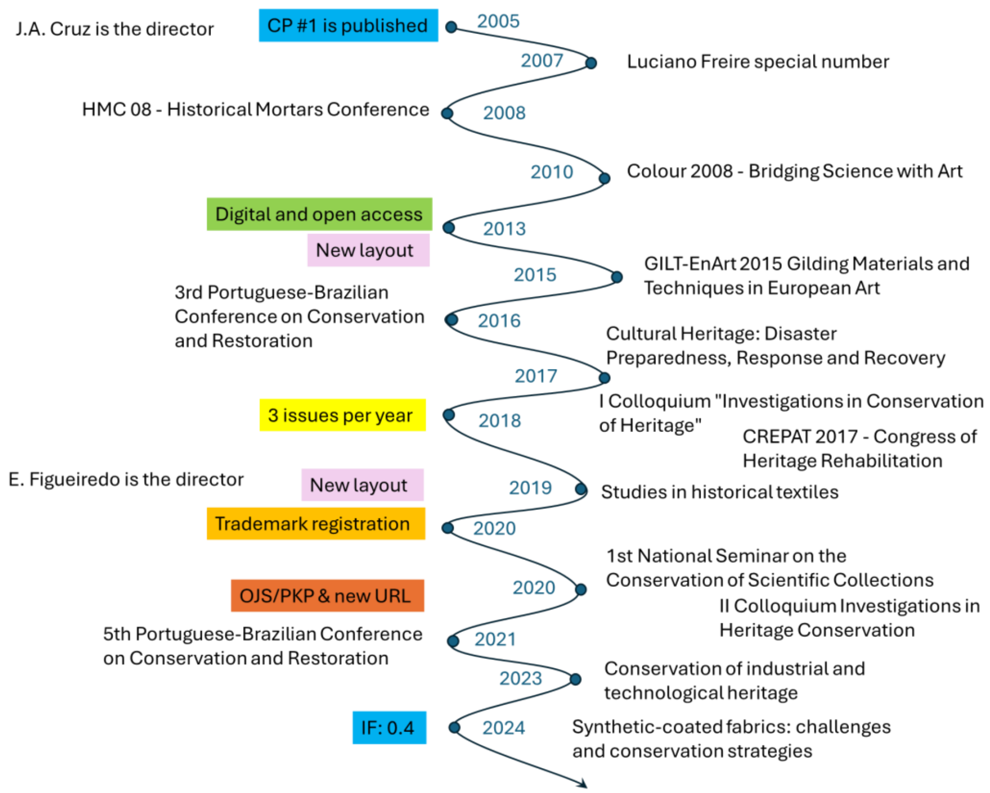

Figure 1. Summary diagram of the journal's history over the last 20 years, with some events highlighted in colour and the various special and conference issues published.

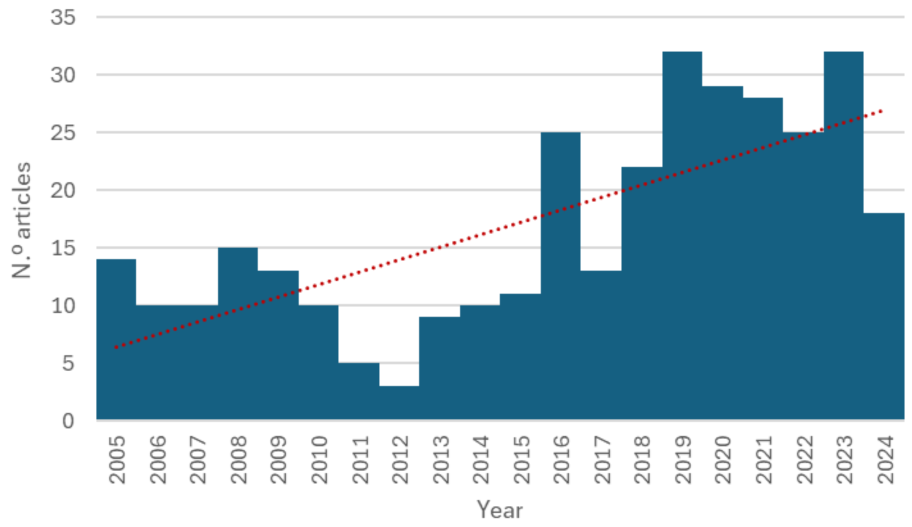

Figure 2. Number of published articles (all sections considered) during the 20 years of CP. A linear trend (in red) shows that the number of articles published along the period tended to increase.

As for the thematic area of the articles published in CP, and considering the 19 categories (or sub-areas) defined in 2020 and implemented in the OJS/PKP editorial management system, we can note that the articles are distributed across all areas, but unevenly (Figure 4). Considering the articles published between issues 29 (2018) and 47 (2025) (representing all articles that have been categorised at present date), the categories with the most publications are Historic buildings and urban settlements (33), Paintings, sculpture and polycrome (32) and Scientific, Historic and Ethnographic collections (32), followed by Preventive Conservation (26), Textiles (24) and Building materials (23). These results are influenced by some thematic issues that incorporated several articles, such as issue 44 (2023) (Conservation of industrial and technological heritage) and 31 (2019) (Studies in historical textiles). The categories with the fewest articles are Graphic documents (6), Education and training in conservation (6) and Film and photographic materials (3 articles during the period considered).

Since its inclusion in various international databases, the journal has followed a consistent trajectory of quality, being usually ranked Q1 and Q2 in the areas of Conservation and Museology (SCImago Journal & Country Rank). The journal's inclusion in the Web of Science's Emerging Sources Citation Index has recently resulted in the attribution of an impact factor (IF). Thus, since 2023, CP has an associated IF, which currently stands at 0.4. Recognising the importance of an IF in scientific journals to certain authors, we are very pleased with this achievement.

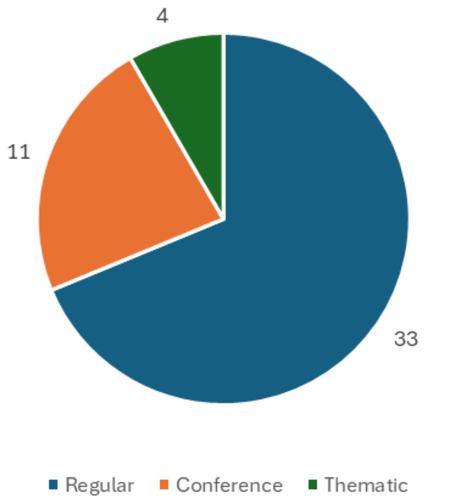

Figure 3. Distribution of the journal's issues over 20 years, by regular (11), conference proceedings (11) and thematic issues (4).

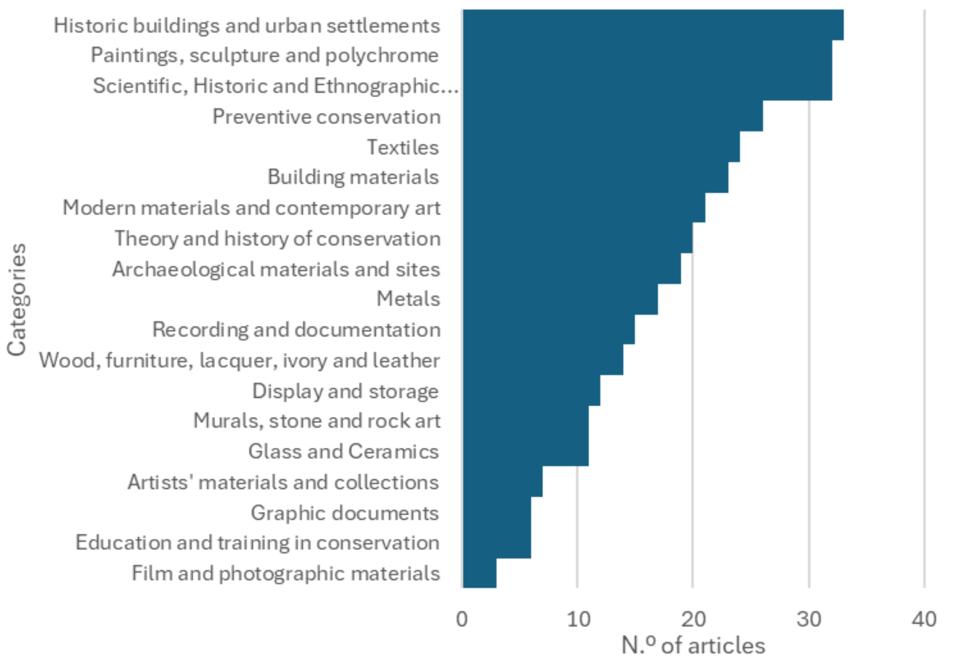

Figure 4. Thematic categories of published articles from issue 29 (2018) to the present issue 48 (2025). The publishing of thematic and conference issues during this period resulted in a higher number of articles in some categories.

Celebrating 20 years of CP journal means celebrating the collaboration and commitment of a community dedicated to the safeguarding and valorisation of Cultural Heritage. We would like to thank all the authors, reviewers, editors and readers who have contributed to this journey. Looking to the future, we reaffirm our commitment to continue providing a high-quality platform for the dissemination of research and interventions in conservation and restoration. We invite everyone to join us on this journey.

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CONSERVAR PATRIMÓNIO

ARTIGO / ARTICLE

Levantamento documental sobre a vida e obras de pintura mural da artista brasileira Gilda Neuberger (1911-2011)

Documentary survey on the life and mural painting works of Brazilian artist Gilda Neuberger (1911-2011)

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Resumo

Gilda Gelmini Neuberger (1911-2011), com mais de 60 anos de carreira, foi uma das raras artistas a produzir afrescos no Brasil durante o século XX. Também foi provavelmente a única artista brasileira a experimentar essa técnica em suportes não convencionais, assim como falso afrescos cujo significado é ainda ambíguo na comunidade artística. No Brasil, a artista foi pupila de Cândido Portinari e de Edson Motta e, em Itália, de Bruno Saetti. Este artigo baseia-se em pesquisas de fontes primárias e secundárias, incluindo depoimentos orais de pessoas que conviveram com Gilda Neuberger ou conheceram o seu trabalho. O objetivo é dar a conhecer a sua trajetória artistica e aferir potenciais influências de seus pares nas suas obras. O artigo também apresenta detalhes do processo de execução e destaca a originalidade dos seus afrescos em variados suportes, que serão futuramente investigados do ponto de vista analítico.

PALAVRAS-CHAVE
Gilda Gelmini Neuberger
Percurso artístico
Pintura mural
Afresco em suportes móveis
Falso afresco

Abstract

Gilda Gelmini Neuberger (1911-2011), with a career spanning more than 60 years, was one of the rare artists to produce frescoes in Brazil during the 20th century. She was probably also the only Brazilian artist to experiment this technique on unconventional supports, as well as false frescoes with a still ambiguous meaning for the artistic community. In Brazil, the artist was a pupil of Cândido Portinari and Edson Motta and, in Italy, of Bruno Saetti. This article is based on research of primary and secondary sources, including oral testimonies from people who lived with Gilda Neuberger or knew her work. The aim is to reveal her artistic career and evaluate the potential influences of her peers in her work. The article also details the execution process and highlights the originality of her frescoes in various media, which will be analytically investigated in the future.

KEYWORDS
Gilda Gelmini Neuberger
Artistic career
Mural painting
Fresco in movable supports
Fake *fresco*

Introdução

Gilda Neuberger (GN) foi uma artista plástica brasileira que atuou no século XX durante o modernismo e sucessivos movimentos artísticos contemporâneos no seu país. Detentora de uma carreira com mais de 60 anos, GN realizou obras em cerâmica e tapeçaria e experimentou diversas técnicas de pintura como o óleo, guache, aquarelas e afrescos [1]. Mas foi na área dos afrescos que a artista revelou a sua maior originalidade. GN pintava não só em paredes, mas também em diversos suportes móveis, em particular telas, sendo considerada a única mulher praticante dessa técnica no Brasil [2]. Adicionalmente, a artista é também conhecida por ter utilizado a técnica do falso afresco [1], ainda hoje ambígua no meio artístico pelas dúvidas que levanta sobre os materiais e métodos empregues.

Começando na década de 1930, e intensificando-se nas décadas de 1950 e 1960, a arquitectura brasileira estava alinhada com padrões internacionais em termos construtivos e decorativos. As obras murais de cariz decorativo eram produzidas em pastilhas de vidro, azulejos, cerâmica e pinturas murais [3]. Neste contexto, destacam-se nomes de artistas como Cândido Portinari (1903-1962) [4], Emiliano Di Cavalcanti (1897-1976) [5], Fulvio Pennacchi (1905-1992) [6], Clóvis Graciano (1907-1988) [7], Eugênio de Proença Sigaud (1899-1979) [8] e Edson Motta (1910-1981) [9]. Gilda Neuberger criou os seus afrescos na mesma época, mas, ao contrário de muito dos seus contemporâneos, a sua obra ainda é pouco conhecida no Brasil e nada foi ainda publicado sobre a artista e sua produção.

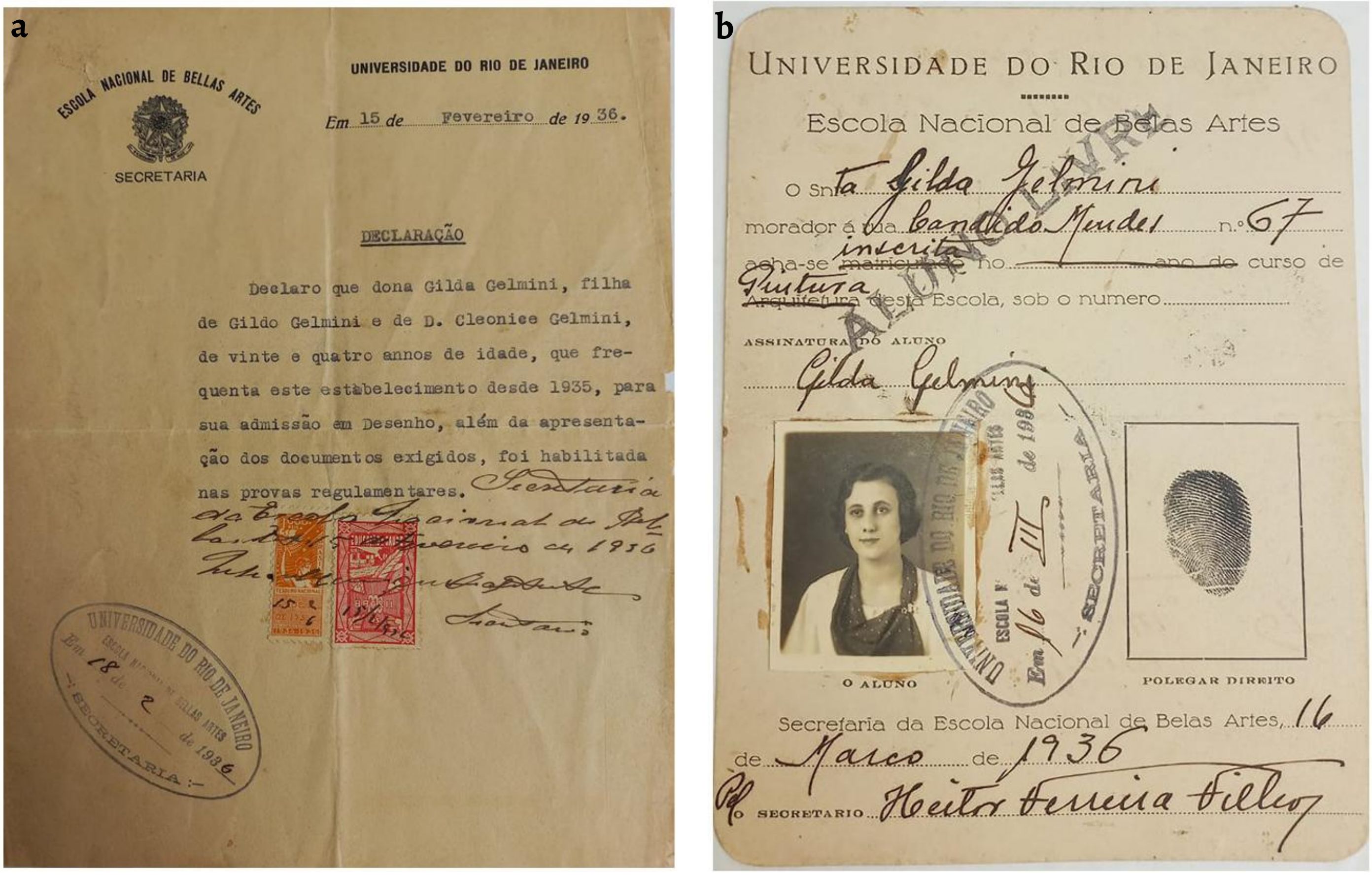
Este texto apresenta os primeiros resultados de um estudo iniciado em 2021, com base em diferentes tipos de fontes [10]. A pesquisa foi realizada em três níveis. No primeiro, examinaram-se fontes primárias e secundárias existentes no acervo da família, no sítio Web dedicado à artista e em sítios Web institucionais. No segundo nível, constam os depoimentos orais obtidos em entrevistas realizadas com Hilda Neuberger, filha de GN, bem como com especialistas que conviveram com a artista durante a criação das suas obras. O terceiro, e último nível, contém os dados adquiridos do primeiro contato direto com as obras de afresco e falso afresco que ela criou.

O objetivo dos diferentes levantamentos foi reunir os dados biográficos mais relevantes de GN e sobre a sua trajetória artística, relacionados com a produção de afrescos, afrescos sobre suporte móvel e falso afresco. Procurou-se também obter informação sobre materiais e métodos de trabalho de GN na construção de suas obras e, ao mesmo tempo, definir o conjunto de pinturas que irá ser objeto de um estudo integrado posterior.

Dados biográficos

Gilda Gelmini Neuberger nasceu em 1911 na cidade de Amparo, em São Paulo, filha de Cleonice e Gildo Gelmini, ambos imigrantes italianos. Gilda descende de uma família de artistas. Seu pai e seu tio, Gildo e Gustavo Gelmini, eram músicos, e Gildo chegou a ser maestro da orquestra de Amparo. GN orgulhava-se tanto do seu pai que gostava de ser chamada de forma a explicitar o sobrenome Gelmini. Ambos tiveram um profundo impacto na vocação artística de GN [1].

Ainda criança, Gilda Neuberger demonstrava peculiar destreza em desenhar, despertando aos 13 anos de idade a atenção de sua professora ginasial que a incentivou a seguir os caminhos da arte [1]. Em 1933, GN teve a oportunidade de ir para o Rio de Janeiro (RJ) o que lhe permitiu, dois anos mais tarde, com 24 anos, ingressar na Escola Nacional de Belas Artes da Universidade daquela cidade (Figura 1) [1, 11]. Nessa academia, GN aprendeu as técnicas de pintura a óleo, guache, aquarela e acrílico sobre cartão pelas diretrizes de afamados artistas brasileiros, como Georgina Albuquerque (1885-1962) e Henrique Cavalleiro (1892-1975) [12-13].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ESCOLA NACIONAL DE BELLAS ARTES
SECRETARIA

UNIVERSIDADE DO RIO DE JANEIRO

Em 15 de Fevereiro de 1936.

DECLARAÇÃO

Declaro que dona Gilda Gelmini, filha de Gildo Gelmini e de D. Cleonice Gelmini, de vinte e quatro annos de idade, que frequenta este estabelecimento desde 1935, para sua admissão em Desenho, além da apresentação dos documentos exigidos, foi habilitada nas provas regulamentares.

UNIVERSIDADE DO RIO DE JANEIRO
Em 18 de 2 de 1936
SECRETARIA

b

UNIVERSIDADE DO RIO DE JANEIRO
Escola Nacional de Belas Artes

O Snta Gilda Gelmini
morador á rua Candido Mendes n.º 67
acha-se inscrita no curso de Pintura desta Escola, sob o numero

ASSINATURA DO ALUNO
Gilda Gelmini

O ALUNO
POLEGAR DIREITO

Secretaria da Escola Nacional de Belas Artes, 16 de Março de 1936

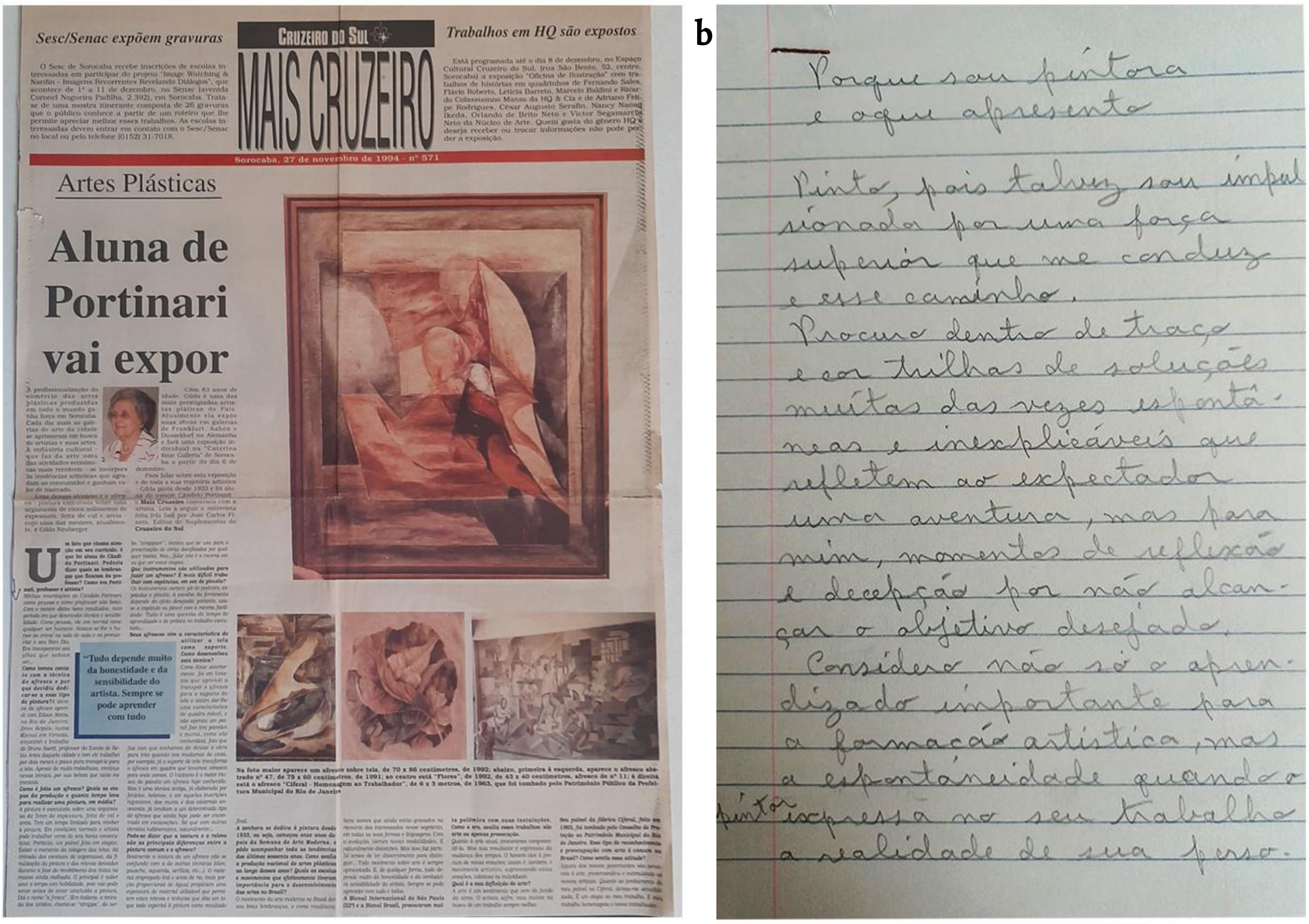
O SECRETARIO Heitor Ferreira Filho

Figura 1. Documentos escolares de Gilda Neuberger na Escola Nacional de Belas Artes: *a)* Declaração de inscrição (15 de fevereiro de 1936); *b)* Inscrição como aluna livre no curso de pintura (16 de março de 1936) (Fonte: Acervo familiar).

Em 1936, um ano após iniciar seus estudos acadêmicos em artes, Gilda Neuberger tornou-se aluna de Cândido Portinari (1903-1962) [14, p.45, 15-18]. Portinari foi um dos maiores expoentes da pintura mural moderna no Brasil, tendo projetado internacionalmente a arte brasileira com as suas obras monumentais e emblemáticas. Exemplos notáveis incluem os murais da Biblioteca do Congresso em Washington D.C., Estados Unidos (1941), e *Guerra e Paz* (1956), estes últimos encomendados pelo governo brasileiro para a sede da Organização das Nações Unidas (ONU) em Nova York [19]. Já em solo brasileiro, destacam-se os afrescos *Ciclos Econômicos* (1944), realizados para o Ministério da Educação e Saúde no Rio de Janeiro sob encomenda do ministro Gustavo Capanema [16]. No contexto da pesquisa em causa não se encontrou, porém, até o momento, detalhes sobre o conteúdo da aprendizagem de Gilda Neuberger com Portinari. É conhecido apenas o impacto que este artista teve em GN através de uma entrevista dada ao jornal *Cruzeiro do Sul* de 1994: “Com o mestre obtive bons resultados num período em que desenvolvi técnica e sensibilidade (...)” [20, p.8] (Figura 2a).

GN continuou ainda, em jeito de confidência ao mesmo jornal, de que terá sido com o seu amigo pintor e conservador-restaurador, Edson Motta (1910-1981), que a artista aprendeu a técnica do afresco aquando do convite para fazer o curso “Técnica e valores da pintura” por ele lecionado no Instituto Ghirlandaio História das Artes em 1961 [1, 20, p.8, 22, p.15,23].

a b



Sesc/Senac expõem gravuras

O Sesc de Sorocaba recebe inscrições de escolas interessadas em participar do projeto "Image Watching & Nardin - Imagens Recorrentes Revelando Diálogos", que acontece de 1º a 11 de dezembro, no Senac (avenida Coronel Nogueira Padilha, 2.392), em Sorocaba. Trata-se de uma mostra itinerante composta de 26 gravuras que o público conhece a partir de um roteiro que lhe permite apreciar melhor esses trabalhos. As escolas interessadas devem entrar em contato com o Sesc/Senac no local ou pelo telefone (0152) 31-7018.

CRUZEIRO DO SUL

MAIS CRUZEIRO

Trabalhos em HQ são expostos

Está programada até o dia 8 de dezembro, no Espaço Cultural Cruzeiro do Sul, (rua São Bento, 52, centro, Sorocaba) a exposição "Oficina de Ilustração" com trabalhos de histórias em quadrinhos de Fernando Sales, Flávio Roberto, Letícia Barreto, Marcelo Baldini e Ricardo Colassuonno Manso da HQ & Cia e de Adriano Felipe Rodrigues, César Augusto Serafin, Nancy Naomi Ikeda, Orlando de Brito Neto e Victor Segamarchi Neto da Núcleo de Arte. Quem gosta do gênero HQ e deseja receber ou trocar informações não pode perder a exposição.

Sorocaba, 27 de novembro de 1994 - nº 571

Artes Plásticas

Aluna de Portinari vai expor

"Tudo depende muito da honestidade e da sensibilidade do artista. Sempre se pode aprender com tudo"

Porque sou pintora
e aqui apresento

Pinto, pois talvez sou impulsionada por uma força superiór que me conduz e esse caminho.
Procuro dentro de traço e cor trilhas de soluções muitas das vezes espontâneas e inexplicáveis que refletem ao expectador uma aventura, mas para mim, momentos de reflexão e decepção por não alcançar o objetivo desejado.
Considero não só o aprendizado importante para a formação artística, mas a espontáneidade quando o pintor expressa no seu trabalho a realidade de sua perso.

Figura 2. Características cruciais que um artista deve possuir: técnica e sensibilidade, mencionadas por Gilda Neuberger: *a)* na edição do jornal "Cruzeiro do Sul" [20, p.8] onde se refere a exposição de GN na Caterina Reze Galleria; *b)* numa carta manuscrita [21] (fonte: acervo familiar).

Edson Motta foi também um artista atuante na pintura mural moderna brasileira, produzindo afrescos na igreja matriz da cidade Dores do Turvo, em Minas Gerais, Brasil. A produção artística de Edson Motta remete aos seus estudos sobre técnicas de pintura em Itália, local onde aprendeu técnicas pouco difundidas no Brasil, como o afresco e a pintura a têmpera de ovo [23]. A notável atividade de Edson Motta está vinculada ao "Núcleo Bernardelli" (1931-1941) [23-24], do qual foi o primeiro presidente. Esse núcleo foi fundado pelos artistas descontentes com o ensino tradicional e promovia dois princípios básicos: a democratização do ensino da arte na Escola Nacional de Belas Artes (ENBA) da Universidade do Rio de Janeiro e a participação de novos artistas no Salão Nacional de Belas Artes [23]. Essas propostas eram fundamentadas nas conquistas trazidas pelo movimento modernista, nomeadamente, o confronto com os moldes acadêmicos tradicionais oferecidos pela ENBA. Edson Motta iniciou a sua prática como conservador-restaurador em 1944 ao ser convidado para trabalhar no Serviço do Patrimônio Histórico e Artístico Nacional (SPHAN) na área do restauro de pintura, talha e escultura [23]. Entre 1951 e 1981, Motta foi professor da Escola de Belas Artes (EBA) da Universidade do Brasil, no Rio de Janeiro. Em 1976, enquanto professor da EBA, Edson Motta, juntamente com Maria Luisa Guimarães Salgado, escreveu o livro *Iniciação à pintura*, onde retrata, entre outras, a técnica do afresco que aprendeu em Itália e que, possívelmente, influenciou Gilda Neuberger nas suas obras de pintura mural.

Em 1982, GN participa da Bienal de Veneza e se interessa pelas obras em afresco sobre tela do pintor Bruno Saetti (1902-1984) [1]. Bruno Saetti foi um pintor italiano que se formou na Academia de Bolonha, em 1924 e, quatro anos mais tarde, se estreou na Bienal de Veneza, onde expôs suas obras em outros momentos [25]. Saetti esteve também presente em várias edições da Quadrienal de Roma entre 1931 e 1972 [25]. O pintor tornou-se professor da Academia de

Belas Artes de Veneza em 1930, onde foi diretor de 1950 a 1956 [25]. Saetti é conhecido sobretudo como “o mestre do afresco”, técnica que passou a desenvolver após sua visita a Pompeia em 1935. Seus afrescos mais conhecidos são *A Sagrada Família*, de 1958, na Universidade de Pádua e *Colóquio com o anjo*, de 1974, afresco sobre tela na Galleria d'Arte Moderna de Bolonha [25]. Seus afrescos sobre tela despertaram o interesse de vários artistas que o procuraram para aprender essa técnica [25-26]. Entre eles encontrava-se GN que permaneceu no ateliê do pintor em Itália (Figura 3) por um período de pouco mais de dois meses com o objetivo de aprender o afresco sobre tela conforme a artista declarou [20, p.8] (Figura 2a).

De regresso ao Brasil, GN executou a quantidade surpreendente de mais de duas centenas de obras pela técnica que aprendeu com Bruno Saetti. Essas obras foram produzidas entre 1982 e 1999. Os temas mais abordados em suas criações, como declarado pela própria artista ao jornal *O Globo*, em 1991 [14, p.45], foram “o abstracionismo, tanto o que oscila para o informal quanto para o geométrico”, pintando também paisagens e naturezas mortas. A maioria das pinturas de GN, em afresco sobre tela, seguiam assim uma linguagem contemporânea, em oposição aos afrescos tradicionais produzidos em paredes por seus pares, de que são exemplo o mural de Edson Motta na igreja matriz da cidade Dores do Turvo, voltado para a temática religiosa, ou os produzidos por Cândido Portinari para o Palácio Capanema, no Rio de Janeiro, e que versam sobre temas socio econômicos.

As obras de Gilda Neuberger foram apreciadas em 14 exposições nacionais e cinco exposições internacionais, no período compreendido entre 1937 e 1999, tendo o reconhecimento do seu trabalho granjeado à artista 11 prêmios (Tabela 1).

Figura 3. Gilda Neuberger com Bruno Saetti no ateliê do pintor em Itália (fonte: acervo familiar).

Tabela 1. Prêmios e exposições de Gilda Neuberger (compilados a partir da documentação constante no acervo familiar da artista).

Data	Evento	Prêmio	Fonte
1937	43ª Exposição no Salão Nacional de Belas Artes (SNBA), Rio de Janeiro, Brasil (RJ-BR)	-	Folder da exposição na Caterina Reze Galleria
1940	46ª exposição SNBA, Divisão Geral, RJ-BR	-	[27, p.25]
1941	47ª exposição SNBA, Divisão Geral, RJ-BR	-	[28, p.41, 29, p.28]
1942	8º Salão Paulista de Belas Artes (SPBA), São Paulo, Brasil (SP-BR)	Menção honrosa	Diploma de premiação 1942
	48ª exposição SNBA, Divisão Geral, RJ-BR		[29, p. 42, 30, p.33]
1943	49ª exposição SNBA, Divisão Geral, SP-BR	Medalha de bronze	Certificado de premiação e [29, p. 32, 31, p.27]
1944	50ª exposição SNBA, Divisão Moderna, RJ-BR		Certificado de premiação e [29, p. 36, 32, p.109]
1945	51ª exposição SNBA, Divisão Moderna, RJ-BR		[33, p.98]
1947	52ª exposição SNBA, Divisão Moderna, RJ-BR*		[34 , p.114]
1949	1º Salão Municipal de Belas Artes, RJ-BR	Medalha de prata	[35, p.19]
1986	2ª Mostra Coletiva da Mulher nas Artes Plásticas, RJ-BR	Menção honrosa	Placa de homenagem concedida pela Rede Manchete Radio e TV, RJ
1988	Exposição *Novíssimo* na galeria do Instituto Brasil Estados Unidos - IBEU, RJ-BR	-	[36-38]
	Mostra de Arte Brasil-Israel/Associação brasileira de desenhos e artes visuais, RJ-BR	Medalha de prata	Certificado de premiação
1989	Exposição individual simultânea com o escultor Araryr Ferrari e o pintor Carlos Junqueira, Espaço Cultural Banco Central do Brasil, RJ-BR	-	Certificado de participação e [39-42]
	Exposição no 20º Salão da Arte Contemporânea, SP-BR	-	[43, p.46]
	Participação com *Geométrico III* no 5º Salão Armando Viana da Associação dos artistas plásticos profissionais da Academia Brasileira de Letras, RJ-BR	-	Certificado de participação
	Associação dos Artistas Plásticos Profissionais do Rio de Janeiro	Medalha de prata	Diploma de premiação
1990	Exposição individual na Ornatus, RJ-BR	-	[44]
1991	Exposição individual no Scotton Bar e Restaurante (Gruppo Disegno), RJ-BR	-	[45-46]
	Exposição individual no Espaço Barro Oco, RJ-BR	-	[47]
1992	Exposição individual no Serviço Social do Comércio - SESC Tijuca, RJ	-	[48]
	Exposição individual na Pinacoteca Municipal Dr. Constâncio, Visão Geral, Amparo, SP-BR	-	Certificado de participação e [49]
	Díptico no 1º MD - Municípios em Destaque, Nova Friburgo, RJ-BR	Medalha de ouro	Certificado de premiação e [50]
1993	Exposição individual na Deutsch Ibero Amerikonische Gesellschatt (DIAG), Frankfurt, Alemanha	-	[51]
	Exposição na Art-Gallery Sheraton Frankfurt Hotel, Alemanha	-	Carta da assessora da exposição, Myriam Bräunig a GN
1994	Exposição coletiva na Deutsch Ibero Amerikonische Gesellschatt em Frankfurt, Aachen e Düsseldorf, Alemanha	-	Folder da exposição na Caterina Reze Galleria
	Exposição individual na Caterina Reze Galleria, Sorocaba, SP-BR	-	[20, p.8]
	Classificação do mural *Homenagem aos trabalhadores* da empresa Ciferal pelo Governo Municipal do RJ-BR	-	[52]
1999	Exposição de Pintura e Escultura no Espaço Barro Oco, *A Representação dos 500 anos na Arte Brasileira e Inauguração da Calçada da Fama*, RJ-Br	-	Convite da exposição

*Contrariamente à informação constante no Catálogo da 52ª exposição do SNBA, datada de 1947 e referente à atribuição de uma Medalha de Bronze, foi encontrado um certificado que refere a premiação de GN com a Medalha de Prata da Divisão Moderna no 52ª SNBA, RJ-BR, com data de 1948.

Entre os prémios recebidos destacam-se a medalha de prata atribuída à artista em 1949, no 1º Salão Municipal de Belas Artes, assim como o reconhecimento do seu trabalho com referência 12664 no Museu da Arte Moderna (MAM) do Rio de Janeiro, em 1981. Posteriormente, GN foi premiada na Mostra de Arte Brasil-Israel pela Associação Brasileira de Desenho e Artes Visuais e pela Associação dos Artistas Plásticos Profissionais do Rio de Janeiro em 1988 e 1989, respectivamente, o que lhe granjeou mais duas medalhas de prata. Dentre as várias exposições nacionais de GN salienta-se, ainda no ano de 1989, a realização da exposição no Espaço Cultural Banco Central do Brasil, onde expôs simultâneamente com o escultor Arayr Ferrari e com o pintor Carlos Junqueira. Nessa exposição, GN teve 80 % dos afrescos sobre tela vendidos antes da vernissage [42]. Outro importante prêmio com seu mérito reconhecido tratou-se da medalha de ouro que a pintora recebeu em 1992 com seu afresco *Díptico* na primeira exposição *Municípios em Destaque* na cidade de Nova Friburgo, RJ, Brasil. Ainda em 1994, GN teve seu imponente mural *Homenagem aos trabalhadores* classificado pelo prefeito do RJ como patrimônio cultural da cidade [52].

Fora do Brasil, GN fez a sua primeira exposição individual na Europa em 1993, na Sociedade Germano-Ibero-Americana, DIAG (Deutsch-Ibero-Amerikanische Gesellschaft e.V.), e a segunda exposição na Art Gallery do Hotel Sheraton, ambas em Frankfurt, Alemanha. Neste mesmo país, no ano seguinte, em 1994, GN expôs suas obras novamente na DIAG e nas cidades de Aachen e Düsseldorf e participou na exposição “Nova Visibilidade” em Frankfurt [20, p.8, 22, p.15]. Nessas exposições foram exibidas pelo menos 46 obras em afresco sobre tela, como comprova a informação incluída em lista feita pelas assessoras das exposições de Gilda Neuberger dentro do Brasil, Noêmia Maestrini, e no extrangeiro, Myriam Bräunig.

Em 1991, GN escreveu uma carta de próprio punho para os admiradores de suas obras onde relatou o porquê de ser pintora e o que pretendia mostrar nas suas criações (Figura 2b). A artista explica que pintava porque provavelmente se sentia conduzida a fazê-lo por uma força superior. Enfatiza que o pintor deve ser honesto e mostrar a sua personalidade na obra que produz e que, por isso, muitas das suas criações eram espontâneas. GN também escreveu que era primordial a sua busca pelo aprimoramento das técnicas que executava, principalmente a técnica do afresco. Técnica esta, segundo a artista, que a encantava pela textura. No que se refere ao afresco sobre tela, GN ressaltou que requer força, coragem e dedicação para executá-lo. E conclui: “Enfim, a pintura é a razão do meu viver” [21].

GN faleceu em 2011, aos 99 anos de idade, deixando um legado de quase 300 pinturas que se encontram entre colecionadores particulares, nacionais e estrangeiros, entidades institucionais e acervo familiar [1].

Tipologias artísticas realizas por Gilda Neuberger

No texto que se segue, apresentam-se os dados levantados entre 2021 e 2022 sobre a produção de afrescos, afrescos sobre suportes móveis e técnica do falso afresco produzidos pela artista.

Afresco

O termo afresco refere-se a um tipo de pintura mural que é realizado enquanto o reboco de suporte está ainda húmido. O reboco tradicional nesta técnica pictórica consiste em uma ou mais camadas de argamassa à base de cal apagada (hidróxido de cálcio) e agregados de natureza variada [53]. A camada cromática é obtida a partir de pigmentos misturados com água (técnica também conhecida como *buon fresco*) ou com leite de cal (afresco a cal). A água é apenas o meio de transporte dos pigmentos, enquanto o leite de cal, quimicamente uma suspensão de hidróxido de cálcio, atua também como ligante. Os pigmentos são fixos na técnica do afresco pela reação de carbonatação que ocorre entre o hidróxido de cálcio contido na argamassa de suporte ainda húmida e o dióxido de carbono presente na atmosfera [54]. Esta reação inicia-se na superfície pintada e depois ocorre gradualmente em toda a espessura da pintura e camada de suporte. Os cristais de carbonato de cálcio produzidos durante a reação formam uma matriz cristalina que incorpora as partículas dos pigmentos, fixando-as ao suporte [54].

Gilda Neuberger fez apenas três pinturas com esta técnica em parede: o afresco *Fundo do mar*, de 1955, *Homenagem aos trabalhadores*, de 1963 e, por ultimo, *Libertas*, de 1993. A primeira pintura mural, com uma dimensão de 3,0 × 2,4 m, foi executada numa parede da sua residência no Rio de Janeiro [1]. Deste mural, destruido uns anos mais tarde pelos novos proprietários do imóvel, sabe-se apenas que foi alvo de uma breve menção em 1993 por Vicente de Pércia, então vice-presidente e membro, respetivamente da Associação Brasileira e da Associação Internacional de Críticos da Arte [55]. Ele relataria que GN “Em 1955 trabalha seu primeiro mural, coerente com seus antigos mestres e a influência dos muralistas mexicanos. Cria *Fundo do Mar*, onde o traçado geometrizante predomina" [1].

O seu segundo afresco é o mais emblemático e o único que sobreviveu até hoje (Figura 4) [1]. *Homenagem aos trabalhadores*, medindo 3 × 6 m, também foi pintado na cidade do Rio, no hall da antiga fabrica metalúrgica *Ciferal*, hoje sede da empresa JSL (Júlio Simões Transportes e Serviços). Inspirado na rotina de trabalho dos operadores na década de 60, o afresco foi símbolo da valorização da classe operária. Para protegê-lo e preservá-lo, o Munícipio do Rio de Janeiro classifica-o como Patrimônio Cultural do RJ em 1994 [52].

O terceiro afresco, entitulado *Libertas*, foi pintado no hall de entrada do novo apartamento de GN na cidade de S. Paulo, para onde a artista se mudou em 1993. Media 1,7 × 2,7 m e sofreria o mesmo destino trágico do primeiro.

A classificação de afresco nos três murais é dada pela própria artista. Este gênero de pintura, pelas particularidades técnicas referidas acima, possui uma série de preceitos que eram seguidos pelos seus executantes antes e durante a sua criação. Desses preceitos, a descendente de GN apenas refere que o método que a sua mãe mais usava para transpor os desenhos para a parede era o da incisão indireta [56]. Esta consiste na passagem do desenho por decalque, sendo este facilmente reconhecido pelo sulco arredondado que deixa na argamassa fresca. Com o desenho já traçado, a artista reforçava os contornos incisos com o auxílio de um pincel embebido em pigmento.

A mestria de GN na arte do fresco seria no entanto elogiada por alguns dos seus pares. Na documentação consultada, destacam-se a este nível dois comentários feitos em 1992 pelo critico de arte Ferreira Gullar [57] e pelo artista plástico Maurício Magalhães [58]. O primeiro foi publicado em *A Tribuna*, jornal de maior circulação na cidade de Amparo, São Paulo [59]: "Suas tintas casam-se, integram-se adequadamente ao afresco, e tanto mais ele pode ser reconhecido e apreciado quanto mais simplificado for o tema dentro das abstrações procuradas e expressas por Gilda" [1]. O segundo consta numa carta dirigida a Noêmia Maestrini (assessora de exposições de GN) e realça o quanto a artista era a única "afresquista" em atividade, uma vez que eram poucos os artistas no Brasil adeptos desse tipo de pintura [1].

Figura 4. Gilda Neuberguer em frente ao seu mural *Homenagem aos trabalhadores* (fonte: acervo familiar).

Gilda Neuberger pertence a um grupo restrito de artistas que produziu afrescos no Brasil e uma das raras mulheres executantes desta técnica, ainda hoje pouco difundida e ameaçada de extinção em território brasileiro [60]. Realça-se os esforços da Casa de Oswaldo Cruz (Fiocruz) no Rio de Janeiro na revitalização desta técnica artística com o curso de pintura tradicional *A arte e a técnica do afresco* [60-61]. O curso foi ministrado de 2013 a 2016 e estruturou-se em quatro módulos que tiveram o intuito de dar a conhecer os princípios da técnica, a história da sua utilização e os seus materiais. O quarto, e último módulo, consistiu na produção de afrescos em edifícios de uso público sitos nos territórios em que a Fundação Oswaldo Cruz está presente na cidade. Os locais selecionados foram os de maior visibilidade entre a população, como um museu, uma biblioteca e três igrejas [60]. No total foram feitos treze afrescos na cidade litorânea. Este curso contou com o pintor Lydio Bandeira de Mello (1929-2023), outro dos grandes nomes de renome neste gênero de pintura no Brasil, na estruturação, concepção, e como principal formador da técnica do afresco [62].

Afrescos sobre suporte móveis

Como referido anteriormente, Gilda Neuberger produziu mais de 200 afrescos em suportes móveis. Na posse da família, encontrou-se um protótipo didático feito pela artista e uma descrição das etapas do processo que aprendera em 1982 com Bruno Saetti em Itália. Na Figura 5 consta o prótotipo e, abaixo, a transcrição do método seguido.

> *Sobre uma tábua ou cimento, ou outro suporte em que a argamassa não agarre. Espalhar a massa de afresco na espessura mais ou menos de 5 milimetros, na proporção de 1 de cal para 2 de areia. Depois do quadro pintado e bem seco, colar sobre a pintura um pano ralo e fino com cola de madeira (titan) bem quente. Depois de bem seca, colar por cima do primeiro pano, outro, sendo mais resistente, assim como um canhâmo. Isso será feito com a mesma cola da primeira aplicação. Depois da cola estar bem seca, retirar o afresco do suporte onde foi pintado. O que deve sair com facilidade. O quadro deve ser virado com a face pintada sobre uma superficie plana. Feito isto, com uma ferramenta, deve-se raspar a massa caso não esteja completamente lisa. Isso é feito também para diminuir a espessura da massa. Feita essa operação, que alías, é trabalhosa, cola-se desse lado um pano fino e ralo com cola acrilica, não dissolvente em água. Depois de bem seca essa operação, com a mesma cola aplicar outro tecido, porém mais resistente. Pode ser canhâmo. Naturalmente quando este lado estiver bem seco, vira-se o quadro, ficando o lado da pintura para cima. Isto sobre a mesa. Com água bem quente, aplicar sobre os panos colados sobre a pintura . Assim eles se desprenderão. Retirar o excesso da cola. Etapa final: Esticar a tela sobre um chassi*. [63]

O protótipo e a descrição parecem revelar a adoção de um procedimento de restauro recorrente na época para destacar pinturas murais do seu suporte murário, conhecido como *stacco*. Num *stacco*, a pintura é retirada do muro com o reboco superficial, que é de seguida nivelado e fixo numa base móvel. O processo termina com a remoção dos tecidos colados na camada cromática para proteção. A uníca diferença é que GN, ao invés de pintar sobre um muro e proceder ao destacamento da pintura, criava o afresco desde o início sobre um suporte móvel, como a madeira ou o cimento, sendo este posteriormente substítuido por uma tela.

Segundo Edson Motta Jr. (também conservador-restaurador como o seu pai), a artista foi até agora a uníca no Brasil que fez afrescos dessa forma [2]. Fato que GN afirma em 1991, em entrevista ao jornal *O Globo* [47], e que parece ser confirmado no contexto desta pesquisa. Foram apenas encontradas até ao momento, duas referências sobre pintural mural afresco em suporte móvel, sendo que uma diz respeito a um afresco realizado sobre eucatex em contexto acadêmico por Edson Motta e seus estudantes [64]; a outra, é uma breve nota acerca do método seguido por um artista plástico de nome Cavani Roças para transpor as suas obras murais para suportes móveis: "Zé Cláudio tinha um método: pegava tecidos enormes com goma, encostava nos painéis [pinturas murais], puxava e saía tudo. Depois, passava cola em alguma madeira do mesmo tamanho dos painéis, passava água no pano que tinha goma, tirava, e os painéis ficavam" [65].

Tal como a sua produção em paredes, os afrescos em suportes móveis de Gilda Neuberger foram também tema de admiração pelos seus pares e críticos da época. Cite-se Noêmia Maestrini em 1989: "o afresco sobre tela de que trata a obra de Gilda Neuberger é tão misterioso e tão enigmático, quanto forte, envolvente, atraente e lúdico" [1], e Vicente de Pércia em 1993: "Gilda faz a passagem do afresco para a tela numa técnica primorosa, inventiva onde seu conhecimento exprime obra segura (...) tornando-se uma especialista no assunto em que os estudiosos da arte e principalmente a crítica não podem deixar de citar" [1]. Edson Motta Jr., em 1992, também exprime espanto após ter conhecido as obras da artista, pela forma surpreendente como GN utilizou seus materiais plásticos para reproduzir a milenar técnica do afresco sobre suportes móveis [1].

Figura 5. Protótipo de Gilda Neuberger referente à realização de afrescos sobre suporte móvel (fonte: acervo familiar).

Na Figura 6 estão patentes os dois afrescos sobre suporte móvel selecionados para investigação futura sobre a técnica e materiais empregues. O afresco, com data de 1963 (Figura 6a), foi produzido antes de GN estudar a técnica do *stacco* com Bruno Saetti. O de 1990 (Figura 6b), após essa aprendizagem. Com o auxílio de técnicas analíticas não invasivas e de microanálise em amostras recolhidas em ambas as obras, pretende-se averiguar as mudanças no modo de atuar da artista.

Figura 6. Vista geral dos dois afrescos sobre suporte móvel selecionados para investigação: *a)* Afresco sobre madeira (gn-283) de 1963 e com 95 × 133 cm; *b)* Afresco sobre tela (gn-121) de 1990 e com 70 × 54 cm. As referências gn-283 e gn-121 são as que constam no catálogo da artista em posse da família.

Falso afresco

Falso afresco é um gênero de pintura que ainda hoje é ambígua e não reune consenso entre os especialistas da temática, por ainda suscitar uma série de questões do ponto de vista técnico e material. Disso são exemplo as duas referências bibliograficas consultadas que descrevem dois procedimentos díspares [66-67]. Para Morales A.F., [66], falso afresco é uma pintura a cal, ou seja, uma pintura feita com pigmentos previamente misturados em um leite de cal, que são aplicados no reboco de cal já seco. Para Santos A.O. [67], o falso afresco é, por sua vez, obtido com uma tinta produzida com pigmentos e cola animal, sendo a pintura executada sobre um suporte de gesso ou um reboco seco de cal e areia.

A dúvida mantém-se nos falsos afresco de Gilda pois não foram até o momento encontrados registros explícitos sobre o procedimento. Em 2022, na primeira análise visual das obras assim catalogadas, notou-se apenas que estas pinturas aparentam ser menos espessas (Figura 7b-c) que as realizadas na técnica do afrescos sobre suportes móveis (Figura 7a). A impressão que fica é de que GN, nos falsos afrescos, pintava diretamente sobre uma tela com recurso a uma camada de preparação com agregados na sua composição. No acervo familar consta uma receita com a inscrição "telas tipo afresco" com os seguintes ingredientes: cola "Totain", areia grossa de construção lavada e "gesso cré". Seriam estes os ingredientes empregues por GN na produção dos falsos afrescos? Para tentar responder a esta questão, duas obras de falso afresco da artista (gn-215 e gn-306) foram selecionadas para uma análise técnica e material comparativa que pretende no futuro dar resposta às duvidas existentes (Figura 8).

Figura 7. Pormenores na gama do visivel das camadas cromáticas e seus suportes das obras catalogadas: *a)* afresco sobre tela (gn-121); *b e c)* falso afresco sobre tela (gn-215).

Figura 8. Vista geral em luz visível das obras de falso afresco sobre tela: *a)* gn-215; *b)* gn-306.

Os materiais de cor na obra de Gilda Neuberger

A paleta de cor de Gilda Neuberger é variada, desde cores vibrantes a tons mais suaves que lembram pastéis. Contudo, nada se sabe sobre os materiais de cor empregues nem sobre o método de preparação para pintura. Pela observação das obras em 2022, levanta-se a hipótese de GN ter recorrido a pigmentos naturais tradicionalmente empregues na técnica do afresco (exemplo dos ocres) e a pigmentos sintéticos modernos, tal como fizeram artistas congêneres fora do Brasil. Este é um ponto importante tendo em conta as recentes descobertas de pigmentos de cádmio (Cd) em pinturas murais da autoria de Almada Negreiros (1893-1970), uma das figuras-chave da primeira geração do modernismo em Portugal [68]. Este fato é particularmente relevante, uma vez que a estabilidade deste tipo de pigmento na técnica do afresco era questionável na época. Disso faz prova Edson Motta no seu tratado *Iniciação à pintura*, no qual defende o uso de amarelo de cádmio como uma alternativa aos ocres: (...) "atualmente os artistas já contam com os cádmios, que a despeito de preconceitos existentes, têm resistido sem alterações, a ação da cal" [69]. Para além destes pigmentos, Edson Motta refere ainda o uso de outros pigmentos sintéticos, tais como o verde e o azul de ftalocianina, disponíveis no comércio brasileiro desde 1935 [70]. Gilda Neuberger foi aluna de Edson Mota, sendo possível que tenha empregue alguns destes materiais nas suas obras. Hilda Neuberger, filha da artista também confirma o recurso a pigmentos da marca *Xadrez*, produzidos pela empresa alemã Lanxess [71-72]. De acordo com as fichas técnicas entretanto obtidas, foi possível verificar que o pigmento de cor azul da marca referida é a ftalocianina de cobre, enquanto outras cores, tais como amarelo, castanho e vermelho, são pigmentos sintéticos à base de ferro [72].

Considerações finais

Este artigo apresenta pela primeira vez o estudo biográfico sobre o percurso artístico de Gilda Neuberger e revela a notável singularidade da pintora na utilização da técnica do afresco em suporte fixo e móvel e do falso afresco. A importância da sua produção mural é atestada pela classificação do seu único mural remanescente na cidade do Rio de Janeiro, assim como pelos elogios tecidos pelos seus pares e pelos prêmios granjeados durante a sua carreira.

Ao considerar a relação entre as características específicas da pintora, sua formação artística e suas produções, é possível afirmar que GN foi uma experimentalista. Afirmação essa que se fundamenta no perfil dinâmico de GN na busca do conhecimento, conforme descrito pela própria pintora em uma carta manuscrita. Além disso, é reforçada na formação adquirida pela artista ao passar pelo clássico ensino na Escola Nacional de Belas Artes no RJ até aos ateliês de Cândido Portinari, Edson Motta e Bruno Saetti. Sua abordagem inovadora também se comprova pela produção de afrescos sobre vários tipos de suporte móvel, antecedendo seus estudos com Saetti. GN é reconhecida pelos seus pares como a única artista que produziu essa técnica no Brasil. Os documentos consultados permitiram também apurar dados relevantes sobre a metodologia de trabalho empregue e constituirão a base de investigações futuras, de índole analítica, nas obras selecionadas para estudo.

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CONSERVAR PATRIMÓNIO

ARTICLE / ARTIGO

Non-destructive electrochemical evaluation of corrosion protection systems subjected to accelerated ageing tests: a strategy for the conservation of colonial Mexican metal alloys

Avaliação eletroquímica não destrutiva de sistemas de proteção contra corrosão submetidos a ensaios de envelhecimento acelerado: uma estratégia para a conservação de ligas metálicas do México colonial

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Abstract

In this study we used Electrochemical Impedance Spectroscopy (EIS) to assess the protective capacity of different conservation treatments: benzotriazole, tannic acid and a polyurethane coating. They were applied on corroded coupons that replicate colonial Mexican brass and cast-iron alloys which were subjected to an accelerated ageing process under UVB/condensation exposure cycles. Electrochemical analysis was complemented with colorimetric measurements and FTIR analysis for information on the structural level before and after ageing. EIS results indicate that although the inhibitor systems prevent corrosion in early stages of the ageing, after 600 h they degrade, and corrosion products are formed resulting in low protective capacities. The selected polyurethane coating provided high protective capacities measured by EIS and agreed with no chemical degradation registered by FTIR and colour aspect. This investigation was performed with a methodology that can be replicated on site since it is non-destructive and the data can be employed for planning conservation strategies.

KEYWORDS

Protective coatings
Brass
Cast iron
EIS
FTIR
SEM

Resumo

Neste estudo utilizamos a Espectroscopia de Impedância Eletroquímica (EIS) para avaliar a capacidade protetora de diferentes tratamentos de conservação, nomeadamente: benzotriazol, ácido tânico e revestimento de poliuretano. Os tratamentos foram aplicados em provetes corroídos que replicam latão colonial mexicano e ligas de ferro fundido submetidas a um processo de envelhecimento acelerado sob ciclos de exposição UVB/condensação. A análise eletroquímica foi complementada com medidas colorimétricas e FTIR para obter informações sobre o nível estrutural antes e após o envelhecimento. Os resultados do EIS indicam que, embora os sistemas inibidores previnam a corrosão nos estágios iniciais do envelhecimento, após 600 h os inibidores degradam-se e os produtos do processo de corrosão são formados, resultando numa baixa capacidade de proteção. O revestimento de poliuretano selecionado proporcionou grande capacidade de proteção (EIS), coincidente com os resultados obtidos por FTIR, por não apresentar degradação química ou mudanças na coloração. Esta investigação foi realizada com uma metodologia que pode ser replicada no local por ser não destrutiva, e os dados obtidos podem ser empregues para o planeamento de estratégias de conservação.

PALAVRAS-CHAVE

Revestimentos protetores
Latão
Ferro fundido
EIS
FTIR
SEM

Introduction

For thousands of years, mankind explored materials from beneath the earth's surface and transformed them into spearheads, rudimentary tools and ornamental metal objects that have since corroded and can still be admired today. This legacy, left by our ancestors throughout history, are material goods that help us to define and understand cultural identities [1]. Hence, the interest in preserving this heritage in the best conditions and passing it on to future generations with the best guarantees of survival [2], even against the natural tendency of metals to corrode [3-4].

Historically, the conservation of metallic artefacts has followed rudimentary schemes that have evolved and become systematised over time. In recent decades, this has included both the maintenance of artefacts in controlled environments [5-6] and the use of oxide inhibitors, converters and anticorrosive coatings [7-12]. Benzotriazole (BTA) and tannic acid are the most widely used oxide inhibitors and converters, for copper [13-16] and iron alloys respectively [17-19]. BTA inhibitory action is explained by a physical barrier effect, which happens by the formation of a polymeric surface complex between the copper alloy corrosion products and BTA, due to the union of the triazole ring with the less noble metal of the alloy [13-14]. Several studies of BTA in aqueous solution showed that it induced a long-lasting prevention against corrosion, however, in outdoor environments, the protective capacity of BTA is lower [20-25]. In the case of tannic acid, it reacts with rust components, mainly iron oxides and oxyhydroxides, forming iron phosphates and tannates that induce the formation of surface layers with protective capabilities that prevent the corrosion progress [17]. However, the formation of these complexes provides a blue-black colour on the treated surfaces and their life period becomes short in outdoor environments [18-19]. In recent years, studies reported that the use of aliphatic polyurethane coatings provides strong dielectric layers that prevent current flow and combines good chemical and weather resistance with the possibility of selecting a matte, gloss, or colour finish accordingly. Therefore, polyurethanes are good candidates for applications on metallic heritage artifacts in order to obtain a better appearance and protection against corrosion but the efficiency is very dependent on the application method and coatings thickness [26-27].

On the other hand, to evaluate the behaviour of applied protection systems on metallic artifacts, it is very important the use of non-invasive and non-destructive techniques to avoid permanent damage on their physical, chemical and aesthetic properties. In this order, Electrochemical Impedance Spectroscopy (EIS) is an electrochemical technique that has been widely used in the evaluation of industrial paints and coatings. Recently, EIS has been implemented to study metallic heritage, because it has the advantage of applying a sinusoidal potential signal of 10-20 mV, small enough to avoid the alteration of the studied surface [28-33], and to measure the sinusoidal current response of the system with the same frequency, but of different amplitude and phase angle. In the same context, Fourier Transform Infrared Spectroscopy (FTIR), is an extremely useful spectroscopic technique for the interpretation of both organic and inorganic molecular structures. The infrared spectrum of a sample is obtained by recording the amount of energy absorbed at each wavelength of the incident infrared radiation [34-35, 36, pp. 137-196, 37]. This is achieved by scanning the spectrum with a monochromatic light that changes in wavelength over a time interval or by using a Fourier transform to measure all wavelengths at the same time. Thus, a spectrum of transmittance or absorbance can be traced, allowing the identification of bonds through the infrared energy absorbed by the sample [38-40].

In Mexico, metal heritage from the colonial period (seventeenth and eighteenth centuries) is abundant in outdoor environments such as cannonry and bells [41, pp. 37-39, 42]. These historic artefacts can be found in urban environments but the most degraded are on coastal cities subjected also to saline environments. In Mexico, conservators commonly employ corrosion inhibitors as the ones mentioned before, and the application of a polyurethane coating commonly employed on industrial cases still needs to be evaluated for heritage artifacts.

Therefore, it was considered relevant to study the efficiency of different corrosion protection systems currently in use in Mexico by conservators with a specific reproducible methodology both in laboratory and directly on metal objects. This research evaluates the electrochemical behaviour of three protective systems on mockup coupons based on the colonial period alloys in Mexico: tannic acid for cast-iron, BTA for brass and a polyurethane coating was applied on both brass and cast-iron before and after an UV/condensation ageing period. In particular, the selected polyurethane coating is an industrial product that has the characteristic that can be applied directly to the metal without a primer or surface abrasion, no reversibility studies have been reported so far on this material.

Experimental

Preparation of the metal alloys coupons

In this study, representative cast-iron and brass coupons were manufactured considering the typical composition that these alloys had during the colonial period [43]. Table 1 shows the chemical composition (wt. %) of the 72 mockup coupons prepared (36 brass and 36 cast-iron) in comparison to the reported chemical compositions of brass and cast-iron during colonial period. For the experiment, coupons with dimensions of 1.5 × 2.0 × 0.5 cm for cast-iron, and 2.0 × 2.0 × 0.5 cm for brass were manufactured.

Table 1. Elemental composition obtained by SEM (wt. %) of brass and cast-iron coupons manufactured for this study, and typical composition of these alloys during the colonial period reported by Lopez-Garrido et al. [43].

Elemental content	Experimental brass coupons	Typical colonial brass alloy	Elemental content	Experimental cast iron coupons	Typical colonial cast-iron
Cu	67.8±0.4	72.3±0.5	Fe	90.1±0.6	85.0 ±0.6
Zn	22.0±0.2	20.3±0.3	C	4.3±0.8	5.6±0.2
C	5.4±0.3	3.1±0.1	Si	2.4±0.1	3.2±0.3
Sn	1.4±0.1	2.1±0.2	O	1.4±0.1	4.6±0.2
O	0.5±0.1	0.8±0.1	Mn	1.3±0.1	1.3±0.1

The coupons surface was progressively wet-ground to 1200 grit finish (SiC grit paper), washed with deionized water, and degreased using acetone. Then these coupons were oxidized. An artificial patina was grown on the brass samples by heating them up to 60 °C, then were immersed in a 2.0 wt. % K_2S solution, and after in a 1.0 wt. % $CuSO_4$ solution and left to dry in a heating plate [44-45]. The cast-iron coupons were corroded by exposing them to an ISO type 3 natural marine atmosphere for three months to simulate alteration in a coastal city [46].

Preparation of protective systems

The coupons were separated into two series, each series consists of 18 coupons for each alloy. The first series includes the inhibitor systems and the second series the polyurethane coating. The corroded coupons were prepared with the according protection system as presented in Table 2. For the first series of brass a 1 % of benzotriazole ethanolic solution was used (system 1). In the case of cast-iron, a 3 % tannic solution was prepared using ethanol, water and phosphoric acid to reach an acid pH (system 2) [47]. Both solutions were applied on the surface with a hand sprinkler.

The second series both brass and cast-iron coupons were treated with a commercial polyurethane coating Polylite 160-DTM prepared as the vendor indicated. An electrical low-pressure sprinkler was used for a homogeneous surface application (systems 3 and 4).

Table 2. Names and description of the applied protection system for each metal coupons.

Series	Base metal	Surface condition	Applied protection system	Name
1	Brass	Patinated	Benzotriazole (BTA)	System 1
	Cast-iron	Rusty	Tannic acid	System 2
2	Brass	Patinated	polyurethane coating	System 3
	Cast-iron	Rusty	polyurethane coating	System 4

Accelerated ageing tests

All the systems were exposed to accelerated ageing tests in an ATLAS UV/CON chamber. The chamber operated in 4 × 4 h UVB/condensation exposure cycles according to the ASTM G-154-06 Standard [48] during a maximum time of 600 hours.

Evaluation of the protection systems

For the materials characterization three coupons of each system before ageing (0 h) were considered control samples, then three coupons of each system were retired after 24, 96, 183, 384 and 600 hours of exposure for their analysis with the following techniques.

Fourier Transform Infrared spectroscopy (FTIR)

The FTIR analysis was carried out in an Alpha Reflectance Spectrophotometer (Bruker) in the middle infrared (500-4,000 cm^{-1}) at 24 scans min^{-1} and a spectral resolution of 4 cm^{-1}. The data was processed with the Opus Video 7 software. For the data treatment, the OriginPro 8 software was used. Spectral identification was carried out by using the RRUFF electronic data bases and own FTIR spectra collection. The analysis was performed coinciding with the withdrawal periods of the samples.

Appearance and colorimetric measurements

The appearance of the samples was observed under optical microscopy in order to evaluate their appearance by using a stereomicroscope Stemi 305 (Carl Zeiss) coupled to an Axicocam 105 Camera (Carl Zeiss), after 24, 96, 183, 384 and 600 hours of ageing test.

Colour changes were measured by using a CM-700d spectrometer (Konica Minolta). It operated in the 400 to 700 nm visible range with a wavelength interval of 10 nm, spectral resolution of 0.01 % and an effective measure area of 3 mm. The data was analyzed by considering the CIELab colour system and the total colour change (ΔE^*_{ab}) before and after weathering was calculated by the following equation, defined by the Commission Internationale de L'Eclaraige [49]:

$$\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad \text{(eq.1)}$$

where: L^* indicates luminosity and variables a^* and b^* indicate the cartesian coordinates of the CIELab chromatic space. Δ represents the difference between the trial and the reference value of the corresponding variable.

Electrochemical impedance spectroscopy (EIS)

Impedance measurements were carried out by using a Solartron Analytical 1280C Electrochemical Test System (Figure 1a), which was controlled by a personal computer using Z-plot software to operate the system and gather data. During EIS spectra acquisition, samples were potentiostatically held at their open circuit potential (OCP), a sinusoidal perturbation of 10 mV was applied to systems 1 and 2, and 20 mV to systems 3 and 4. The impedance response was measured in a frequency range from 20 KHz to 50 mHz.

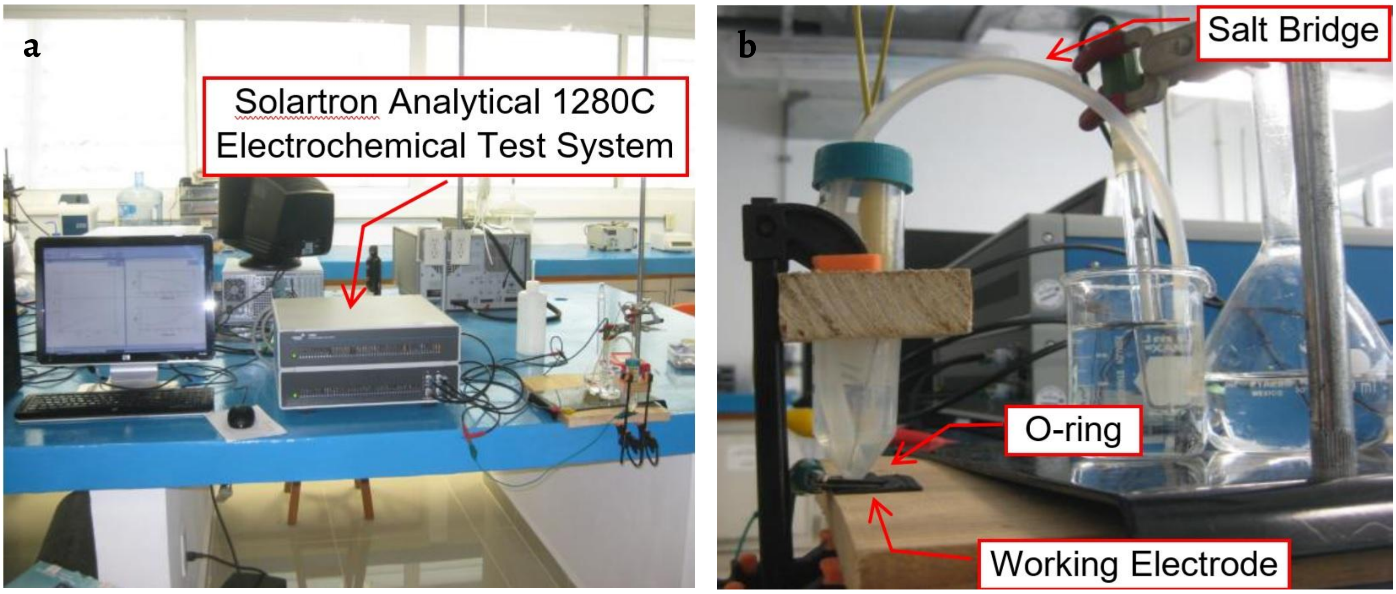

Figure 1. Experimental setup using: *a)* Solartron Analytical 1280C Electrochemical Test System and *b)* corrosion cell.

All electrochemical experiments were carried out in a neutral aerated 0.1 M Na_2SO_4 solution, at 25 ± 1 °C, using a three-electrode cell mounting (Figure 1b): the counter electrode was a platinum wire, an Ag/AgCl (KCl saturated) electrode was used as the reference electrode. The systems under study were the working electrodes. A rubber o-ring was used between the sample metallic and the cell to prevent solution leakage. The o-ring allowed a measurement area of 1 cm^2 to be exposed to the cell solution. To minimize the ohmic drop, the reference electrode was connected to the main cell compartment through of a salt bridge.

Results and discussion

Chemical and structural analysis

Figure 2 shows the FTIR spectra of the 1-2 and 3-4 systems, after 24, 96, 192, 384 and 600 h of accelerated ageing test. Control systems were included as well. Table 3 shows the corresponding FTIR absorption frequencies [50-56].

After 24, 96, 192, 384 and 600 hours of ageing, system 1 (Figure 2a and Table 3) showed a loss of the absorption signals corresponding to ν_{as}(N-N), δ_{oop}(C-C), ρ_{as}(C-H) and ν_{as}(C-H) bonds, as well as a decrease in the intensity of the absorption bands associated to σ_{as}(C-H) and σ_{as}(N=N) bonds. These structural changes suggest a photochemical degradation of the polymeric complex that causes the loss of the protective capabilities in the complex due to mechanical, electrical, and optical transformations [17-19, 58].

Regarding system 2 (Figure 2b), the FTIR spectrum obtained after 24 h of ageing showed characteristic signals akin to those of the control system. However, a decrease in the intensity of the absorption band located in the range of 3200-3600 cm^{-1} was also observed. This indicates the reduction of the free OH^- groups, which allows the tannic acid to chelate the Fe ion [57, 59, pp. 144-160]. The FTIR spectra obtained after 96 and 192 h of ageing, showed a decrease in the intensity of the ν_{as}(C-O), σ_{as}(C-H) and σ_{as}(C-C) bonds while, the corresponding spectra for the 384 and 600 h of ageing showed the loss of the signal corresponding to the ν_{as}(C-O), σ_{as}(C-C), σ_{as}(C-H) and δ_{oop}($FePO_4$) bonds, this as consequence of the structural changes in the tannic acid molecule due to photodegradation [57, 59, pp. 144-160, 60-61].

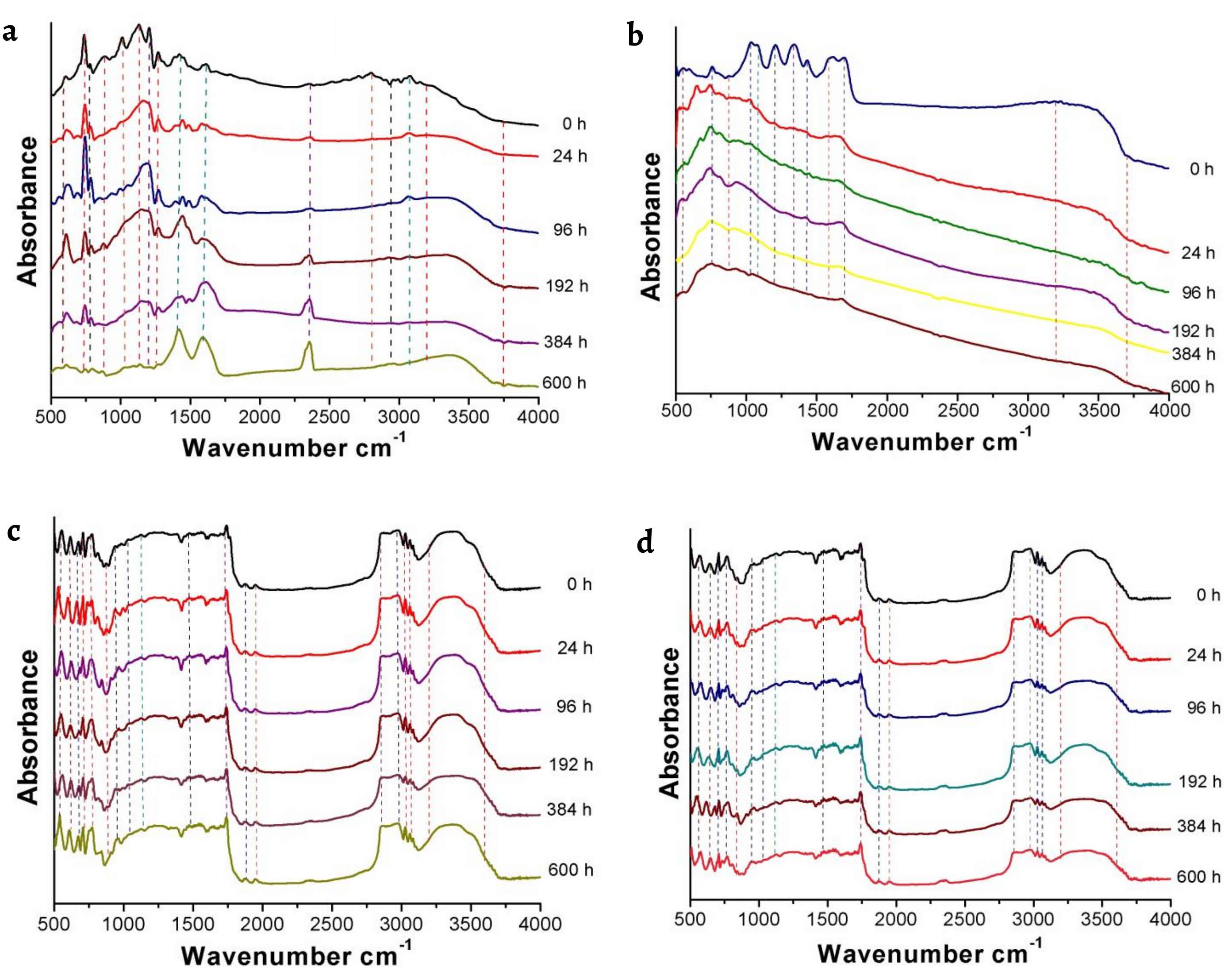

Figure 2. FTIR spectra of protective: *a)* system 1; *b)* system 2; *c)* system 3; *d)* system 4.

Figure 2c-d show the FTIR spectra after the ageing period of the systems 3 and 4 respectively. Not visible changes were observed in absorption intensities in comparison to the control system. This behaviour suggests that this coating conserves its structural stability after 600 h of ageing test, independently of the substrate where it was applied. This indicates that the polymer was not affected by exposure conditions. However, for longer exposure times, UV radiation could promote photo-oxidative degradation through a mechanism of free fall that starts when UV radiation is absorbed by the chromophore group causing the breakdown of the C-C bonds in the polymeric chain [62-67].

Table 3. FTIR absorption bands corresponding to the protective systems.

System 1				**System 2**			
Assigned signal	**Band (cm^{-1})**	**Vibration mode**	**Reference**	**Assigned signal**	**Band (cm^{-1})**	**Vibration mode**	**Reference**
Cu-O	606 (m)	ν_{as}	[50]	Fe-O	550 (s)	ν_s	[17]
C-H	740 (m)	σ_s	[51]	α Fe-O	760 (w)	ν_{as}	
C-C	781 (w)	δ_{oop}		α Fe-O	873 (w)	ν_{as}	
N-N	871 (m)	ν_s		γ Fe-O	1035 (s)	ν_{as}	
C-C	1007 (mw)	δ_{oop}	[52-53]	γ Fe-O	1080 (s)	ν_{as}	
C-H	1127 (s)	σ_s		C-O	1207 (m)	ν_{as}	[18-19]
N=N	1208 (m)	σ_s		C-H	1340 (w)	σ_{as}	
C-C	1246 (m)	ν_s		C-C	1435 (m)	ν_s	
C=C	1416 (m)	δ_{oop}	[51]	$FePO_4$	1620 (m)	δ_{oop}	[57]
C=C	1617 (m)	δ_{oop}		Fe (TH_3) [	1680 (m)	σ_s	
C-O	2353 (w)	ν_{as}	[54]	O-H	3200-3600 (m)	ν_{s+as}	[17]
C-H	2798 (m)	ρ_{as}	[51]				
C-H	2939 (w)	ρ_{as}					
C-H	3077 (s)	ν_s					
O-H	3200-3600 (m)	ν_{s+as}	[55-56]				
System 3				**System 4**			
Assigned signal	**Band (cm^{-1})**	**Vibration mode**	**Reference**	**Assigned signal**	**Band (cm^{-1})**	**Vibration mode**	**Reference**
C=C	555 (m)	δ_{iop}	[59, pp. 144-160]	C-C	1473(m)	ν_s	[60]
C=C	614 (m)	δ_{oop}		C=C	1741 (m)	δ_{oop}	[59, pp. 144-160]
N-H	674 (w)	ω_{as}		C=O	1877 (w)	ν_{as}	[60-62]
C-H	701 (w)	$\delta_{iop+oop}$	[60-61]	C=O	1951 (w)	ν_{as}	
C-H	779 (m)	$\delta_{iop+oop}$		CH_2	2850 (w)	ν_{as}	
C-H	875 (w)	σ_s	[60-62]	CH_2	2971 (m)	ν_{as}	
CH_2	941 (w)	δ_{oop}	[60]	CH_2	3024 (w)	ν_s	
C-H	1022 (s)	σ_s		C-H	3068 (m)	ρ_s	[60]
C-O	1120 (m)	ν_s	[60-62]	O-H	3200-3600 (m)	ν_{s+as}	[55]

*s – strong; m – medium; mw – medium weak; w – weak; vw – very weak

Appearance and colour evaluation

The appearance is an important aesthetic property to be considered in metallic artifacts corroded during its environmental interaction. Corrosion products aspect depends, of course, on the type of metal alloy, but also on the characteristic of the surrounding atmosphere (i.e. presence of sulphur dioxide, chloride, humidity, etc.), which also affects every preventive corrosion system applied over the artifact. Colour changes are one of the most important aspects to be evaluated in order to stablish the long-term behaviour of metallic artifacts under corrosive environments.

During this study, the system appearance was monitored by optical microscopy and colour measurements. Figure 3 shows a set of surfaces microscopical images corresponding the four treatments during the control measurements at 24, 96, 192, 384 and 600 hours of ageing test.

System 1, had in appearance a homogeneous distribution of BTA, but during the first 192 h of exposure, occurred the formation of surface groves associated to the gradual loss of BTA. According to Roberge [68], those groves are preferential zones to initiate the corrosion process.

With the advance of ageing, the system turns cracked, with visible colour changes, consequence of the photochemical degradation of BTA [58, 68]. In the case of treatment 3, after 600 h of ageing, it does not present perceptible surfaces changes. It is indicative of the stability of the coating system under experimental conditions.

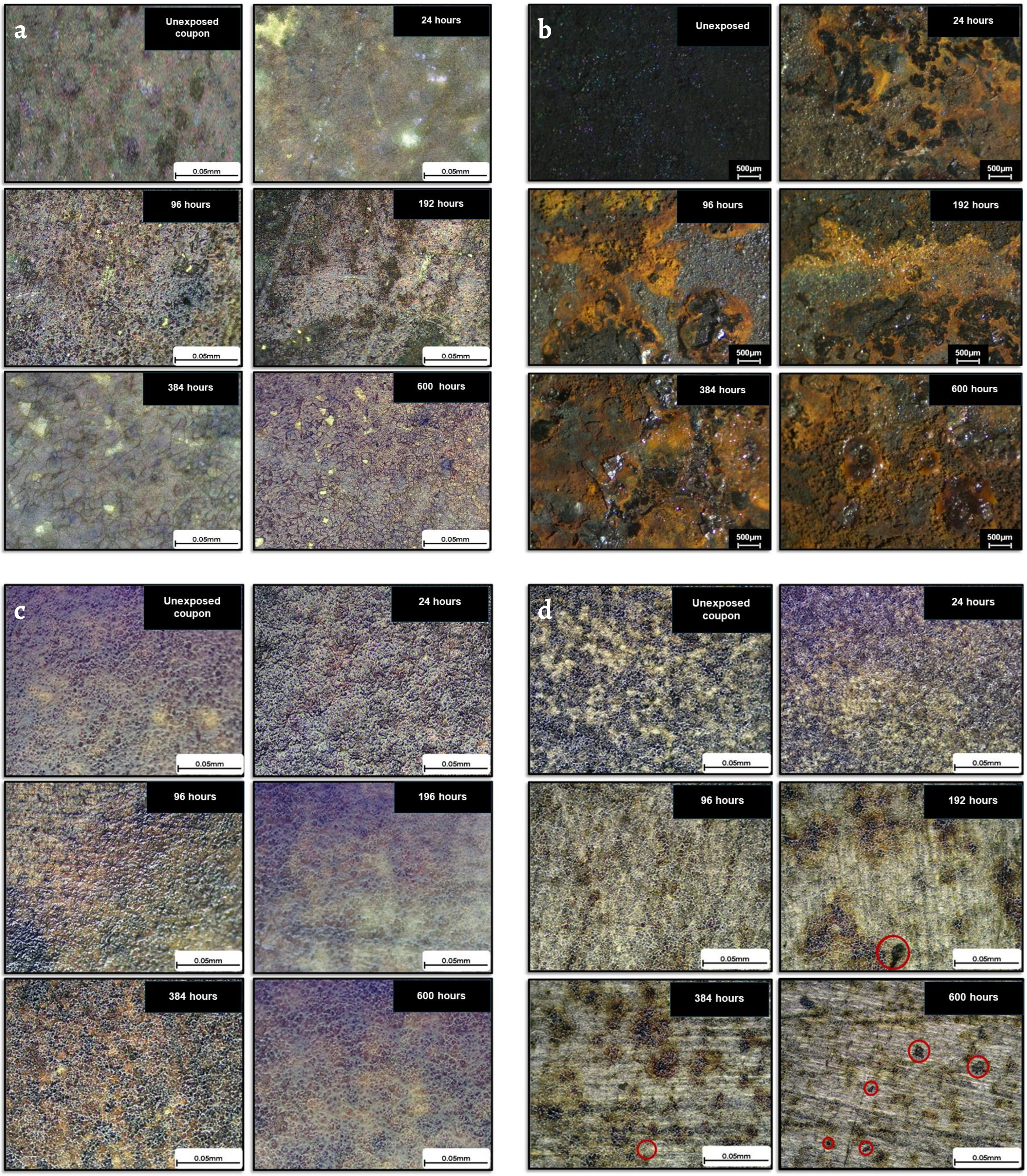

Figure 3. Evolution of the systems surface appearance registered by optical microscopy during the ageing test: *a)* system 1: *b)* system 2; *c)* system 3; *d)* system 4.

The images indicate that in apparency, the distribution of the coating systems applied over the iron coupon surface at the initiation of the experiment was homogeneous. After 24 h of ageing, the formation of blisters and the apparition of red to orange corrosion products result evident in system 3. After 96 h the formation and breakdown of blisters is frequent, resulting in the apparition of new corrosion products until the end of the experiment. It is known that the breakdown of blisters is cause of the increase of corrosion rate, although, certain iron corrosion phase can be more stable when interact with the remnant tannic acid.

On the other hand, system 4 showed a more stable behaviour during the first 96 test hours, without apparent change in the coating appearance. Nevertheless, after 192 h of test, some picks, probable associated to the formation of pores in the de coating due to the photodegradation of the polymeric film start to appear [69]. They increase until the end of the experiment, and can be associated to the formation of localized zones where corrosion is possible.

The changes in the aesthetical aspect of the test systems were quantified through the colour measurements according to the CIELab system. Figure 4 show the colour evolution of the ageing coupons during the experiment, while Figure 5, indicates the tendency of the colour difference (ΔE) during the experiment.

The brass alloy used as muck-ups had an initial value of L^* = 71.2±2.9, a^*= -7.1±0.9 and b^*= 60.5±2.0 corresponding to a brilliant yellow colour. After oxidation, these value change to L*= 22.1±1.2, a^*= -16.2±0.9 and b^*= 28.4±2.0 that corresponded to a dark brown colour. This colour changed when the system 1 was applied, diminishing its brightness and displacing to the red to- yellow zone. But when BTA was applied, the surface acquired whitish aspect. During ageing, surfaces changes induced by the continuous photodegradation of the inhibitor reach a ΔE of 31 colour units (Figure 5). These visual changes could be an indicative of changes in stability of the coating, associated to the apparition of corrosion cells on brass surface [13, 15, 70-71].

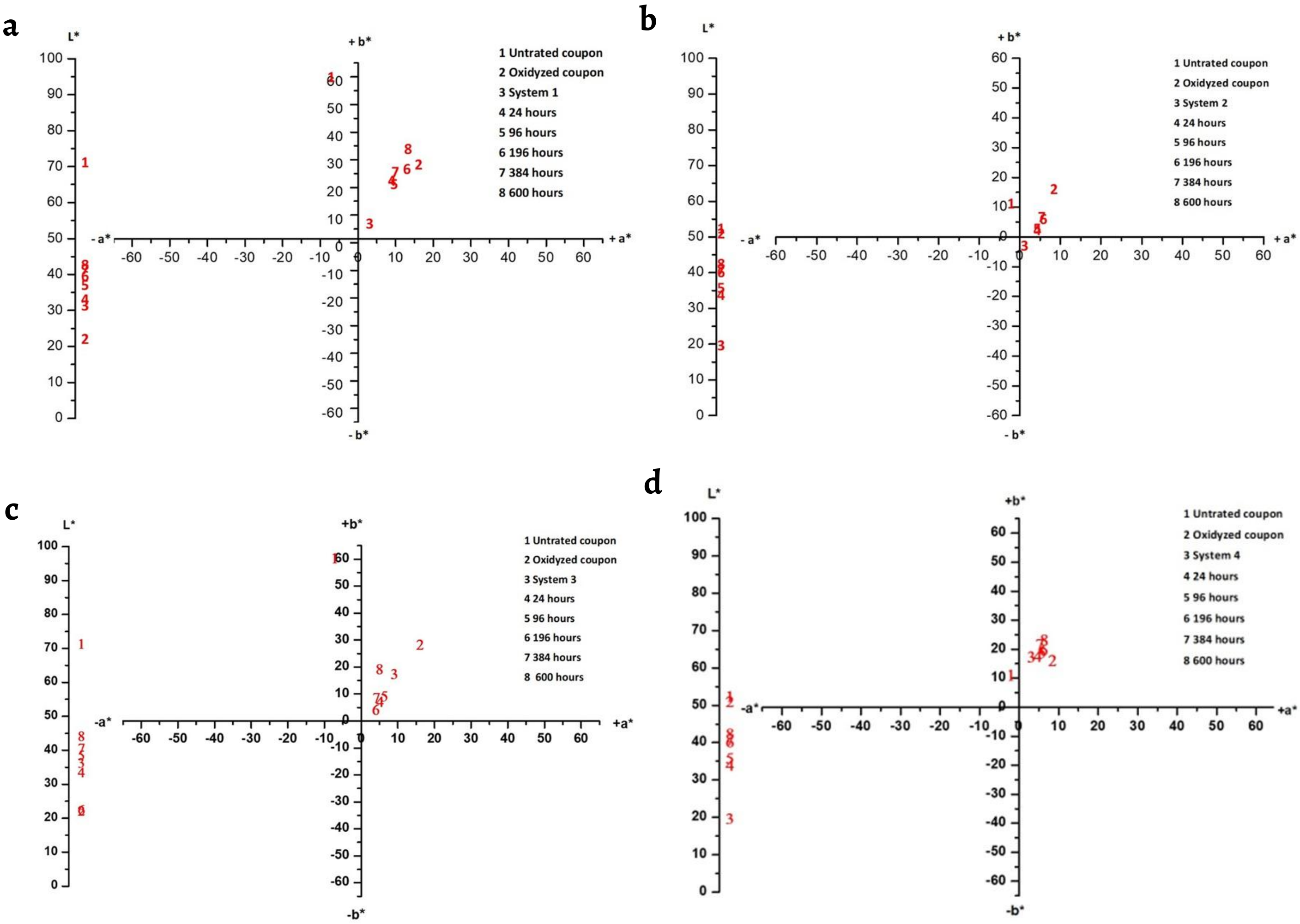

Figure 4. Colour coordinates for: *a)* system 1, *b)* system 2, *c)* system 3; *d)* system 4.

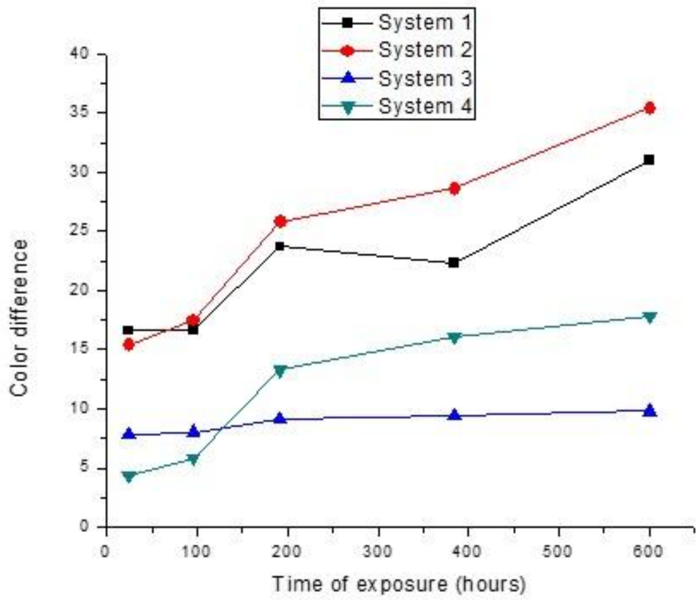

Figure 5. Evolution of colour change (ΔE) on the four test systems.

Cast iron muck ups showed initial L^*= 52.5 ± 2.7, a^*= -2.0±0.8 and b^*= 11.2 ± 1.1 corresponding to a grey colour produced by graphite flakes present in the alloy [72]. After the oxidation, colour coordinates move to L^*= 51.1 ± 1.7, a^*= -8.4 ± 0.3 and b^*= 16.2 ± 2.2, associated to the typical ochre colour of iron corrosion products (13). The application of tannic acid (system 3), scroll the colour to red to- blue with a lower luminosity, consequence of the formation of iron tannates. After ageing, the colour tends to the red to- yellow zone, with an increasing of luminosity. The system, reach a ΔE of 35.4 when the experiment is over. Rendón [73], indicates that the colours orange and yellow are associated to the formation of the corrosion phases lepidocrocite and goethite respectively. Eventually, UV radiation photodegraded the chemical structure of tannates, then it caused the reactivation of corrosion process over metal surface [74].

By the other hand, the application of the polymer to systems 2 and 4 cause small variation in the visual aspect of the coupons, but it tends to change with the advance of the experiment. System 3 showed an initial L^*= 36.4 ± 2.7, a^*= 9.2 ± 0.8 and b^*= 17.5 ± 0.01 values, in the red to-yellow region. At the end of the experiment, the difference of colour was 9.8, closer to the perception limit for human eye [75]. For the system 4, the colour coordinates were L^*= 48.9 ± 0.4, a^*= 3.1 ± 0.3 and b^*= 17.5 ± 0.7. At the end of the experiment, ΔE was 17.9 colour units. In this order, colour changes started to be perceptible around 192 h after the experiment start up. Photodegradation of organic coating starts with the loss of the brilliance in the surface, followed by its disintegration. It affects the capabilities of the coating to protect the metallic surface again corrosion.

Electrochemical analysis by EIS

Experimental impedance spectra of studies systems are presented in the form of Nyquist diagrams in Figure 6a, Figure 7a, Figure 8a and Figure 9a, as well as its respective Equivalent Circuit (EC). The impedance data were fitted using the Zview program.

System 1 (brass/patina/benzotriazole)

Figure 6a shows the Nyquist diagrams corresponding to system 1. There, two-time constants can be observed. The time constant at high frequencies is associated to the formation of the patina/BTA complex [16]. On the other hand, the time constant observed at low frequencies is attributed to the charge transfer caused by the corrosion process. It is associated to the presence of heterogeneities in the patina/BTA complex [14-15, 76]. The arc size of the time constant at low frequencies decreases in accordance to the aging period. This suggests the loss of its protective capabilities in the polymeric complex as a result of the structural changes caused by the photodegradation [14-16, 76]. This behaviour was also consistent with the structural changes observed during the FTIR analysis.

The equivalent circuit showed in Figure 6a was used to interpret the EIS spectra of a one-layer oxide film structure. The parameter R_{sol} represents the electrolyte resistance used; CPE_{pbs} corresponds to the protective properties of the patina/BTA complex with a non-ideal model behaviour due to the presence of system irregularities, such as the lack of uniformity of the inhibitor, roughness, non-homogeneous distribution of the current, etc. [77-79]. On the other hand, R_{pbs} is the resistance associated to the patina/BTA complex. CPE_{dl} represents the electrochemical double-layer capacitance and R_{ct} is the charge transfer resistance that occurs at the metal-patina/BTA complex interface [13, 80-81]. This EC suggests the presence of defects in the complex, that according to Haruyama et al. [81], facilitates the interaction of the electrolyte with the metallic interface. Figure 6a shows the experimental data, in the form of symbols, and the fitted data, in the form of lines. The quality of the fit can be judged by observing the difference between the experimental and fitted values.

Figure 6b shows the decrease in the R_{pbs} y R_{ct} values as a function of ageing time, which suggests the loss of protective capabilities in the system. This behaviour is consequence of the photochemical degradation of the BTA, as suggested by Haruyama et. al., and Ling et. al. [13, 81], who assessed the electrochemical behaviour of BTA in copper specimens using polarization curves and EIS, respectively.

The capacitance of an electrochemical system is related to the quantity of material that can be transformed through the electrochemical processes [82-83]. In this study, the effective capacitance (C_{eff}) associated to the CPE was calculated with equation 1, which is equivalent to that presented by Hsu and Mansfeld [84]:

$$C_{eff} = \left(Y_0 R_p^{1-n}\right)^{1/n} \qquad (1)$$

where n, Y_0 and R_p are the exponent, admittance constant of CPE and the parallel resistance associated to the faradaic process, respectively.

In Figure 6b, shows a progressive increase in the C_{pbs} y C_{dl} values, which suggests an increase in the corrosion rate. According to Fedrizzi et al. [83], the inhibitor photodegradation causes the appearance of defects that allow the continuous penetration of the electrolyte across the brass/patina interface, then an increase in corrosion rate occurs.

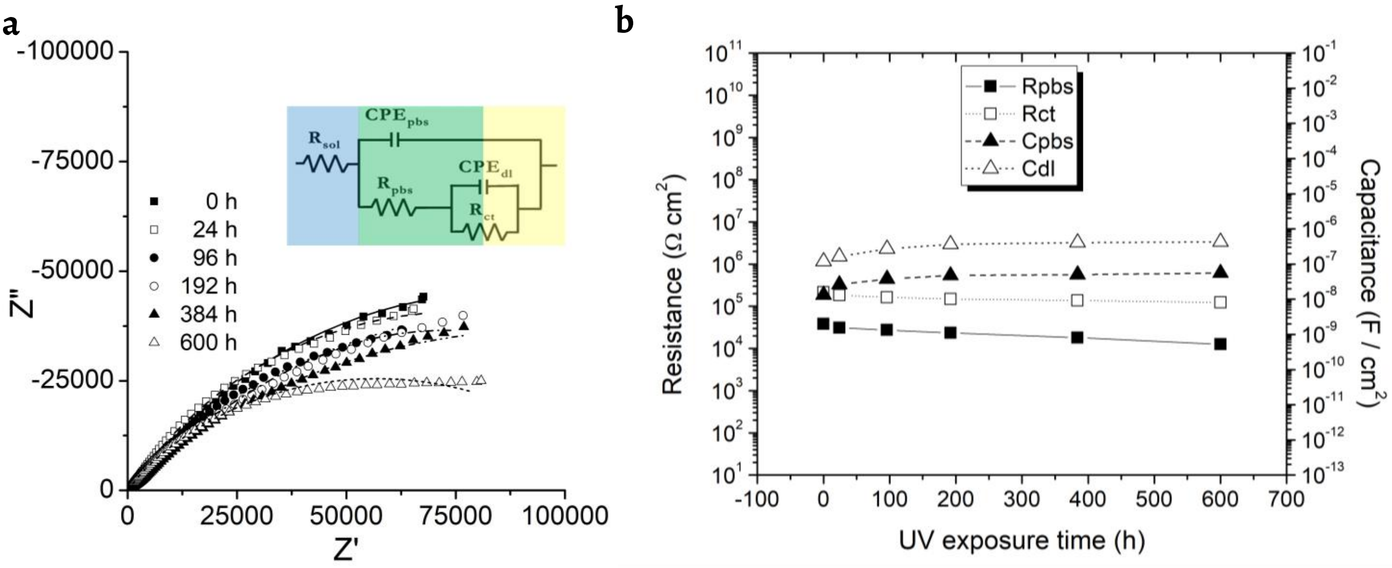

Figure 6. System 1: *a)* Nyquist plots and electrochemical circuit model used in fitting the experimental data, at different ageing times, exposed to 0.1 M Na_2SO_4 solution; *b)* R_{pbs}, R_{ct}, C_{pbs} y C_{dl} values at different ageing time.

System 2 (cast-iron/corrosion products/tannic acid)

During this study, all specimens of the system 2 presented one-time constant from high to intermediate frequencies (Figure 7a). That was associated to the formation of complexes formation between tannic acid and the substrate (phosphates and iron tannates) [18, 85].

At low frequencies, control specimens unexposed to ageing, tend to form a straight line with a slope of 45° (Figure 7a), which is typical of diffusion processes [18]. The experimental results obtained after 24 h of ageing showed the formation of a slope lower than 45°, with a tendency to form an arc. It can be associated to a change of diffusion to charge transfer processes caused by the metal/electrolyte interaction [85].

In the Nyquist diagrams, Figure 7a, can be observed that the impedance spectra start at different Z' values as function of ageing time; i.e., there is an increase in the electrolyte resistance. According to Orazem [86], this behaviour can be associated to the inhibitory effect produced by the substance that is deposited on the converted layer, which in contact with the electrolyte is solubilized, increasing the resistance of the medium due to the inhibitory ohmic effect of the active compound.

The arc size from the time constant at high frequencies increased as function of ageing time, probably due to the stability of the phases that were initially present as magnetite, goethite and lepidocrocite, which were observed during the FTIR characterization (Figure 2b). Those phases protect the base metal [87].

Figure 7a shows the EC model used to evaluate the impedance spectra for the unexposed system, where CPE_{co} and R_{co} are the capacitance and resistance associated with the layer of converted oxides, respectively [18, 50]. The use of Warburg impedance (Z_w) suggests that the kinetics of the overall corrosion process of the studied system is controlled by the diffusion process, across the superficial porosities. Al-Mayouf [88], showed that the application of tannic acid on oxidized iron, allows the formation of a porous iron tannates layer, which is dependent on the moisture content. Figure 7a shows the EC model used to evaluate the impedance spectra when the system is under charge transfer control (for 24 – 600 hours exposure). These diagrams showed a good relation between experimental and fitted data using proposed models.

Figure 7b shows the increase in the R_{co} y R_{ct} values as function of ageing time, in contrast to the C_{co} and C_{dl} values which decreased. According to Favre [74], and Pantoja [89], these behaviours can be associated to the presence of a stable iron oxides phases of such as magnetite, goethite and lepidocrocite that provide good protective capabilities to the system.

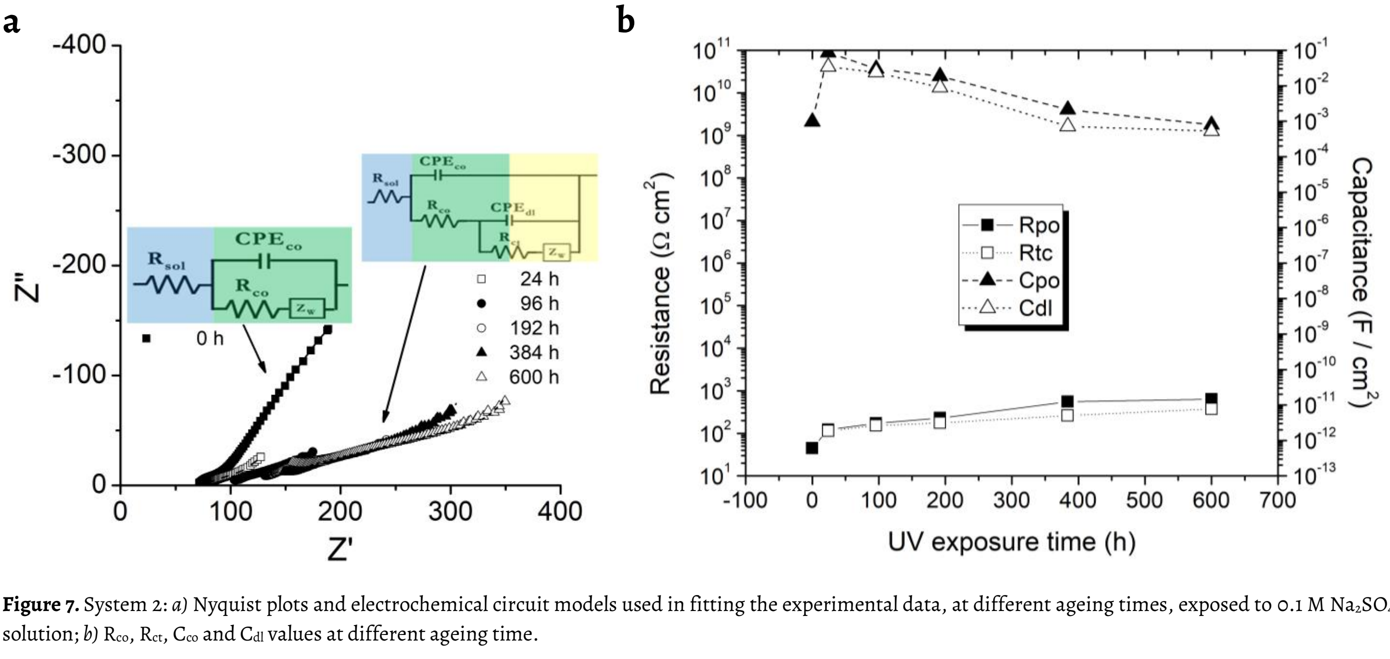

Figure 7. System 2: *a)* Nyquist plots and electrochemical circuit models used in fitting the experimental data, at different ageing times, exposed to 0.1 M Na_2SO_4 solution; *b)* R_{co}, R_{ct}, C_{co} and C_{dl} values at different ageing time.

System 3 (brass/patina/polyurethane coating)

The experimental results of EIS for system 3 (Figure 8a), shows a tendency toward the formation of a very big semicircle to high frequencies, from 20 KHz to 300 Hz. At lower frequencies scattered results were obtained, which are not presented in this study. This behaviour can be consequence of the formation of a homogeneous coating film which acts as an ideal capacitor that acts such as protective physical barrier of the metal surface, i.e., as an insulator, therefore, no charge transfer occurs [90-91]. Also, this behaviour is attributed to the lack of interactions between the electrolyte and the metal surface, hence the absence of a second or third time constant [92-93].

Figure 8a, presents the EC model used to evaluate the impedance spectra for system 3. The properties of the coating were evaluated by the pore resistance (R_{po}) and a CPE_{po} that represents the capacitive properties of the protective layer formed by the polyurethane coating, as a consequence of its dielectric properties [94]. According to that, the protective mechanism of the polyurethane coating is barrier type, therefore, only one time constant was observed in the diagrams of Nyquist. The EC is similar to that used by Hu et al. [93], when organic coatings were evaluated at room temperature by using EIS.

Figure 8b shows the R_{po} and C_{po} values as a function ageing time. R_{po} values of coating decrease when the exposure time is increased. That suggests a reduction of the protective capacity of coating. However, the R_{po} are in the order of 10^7 Ω-cm^2, so according to Lee et. al. [95], this coating is in the range of medium protection. On the other hand, C_{po} values increased as a function ageing time. According to Martin et al. [92], it is possible that the degradation of coating allows the interaction of the metallic substrate with the electrolyte, causing the formation of preferential sites where corrosion can occur.

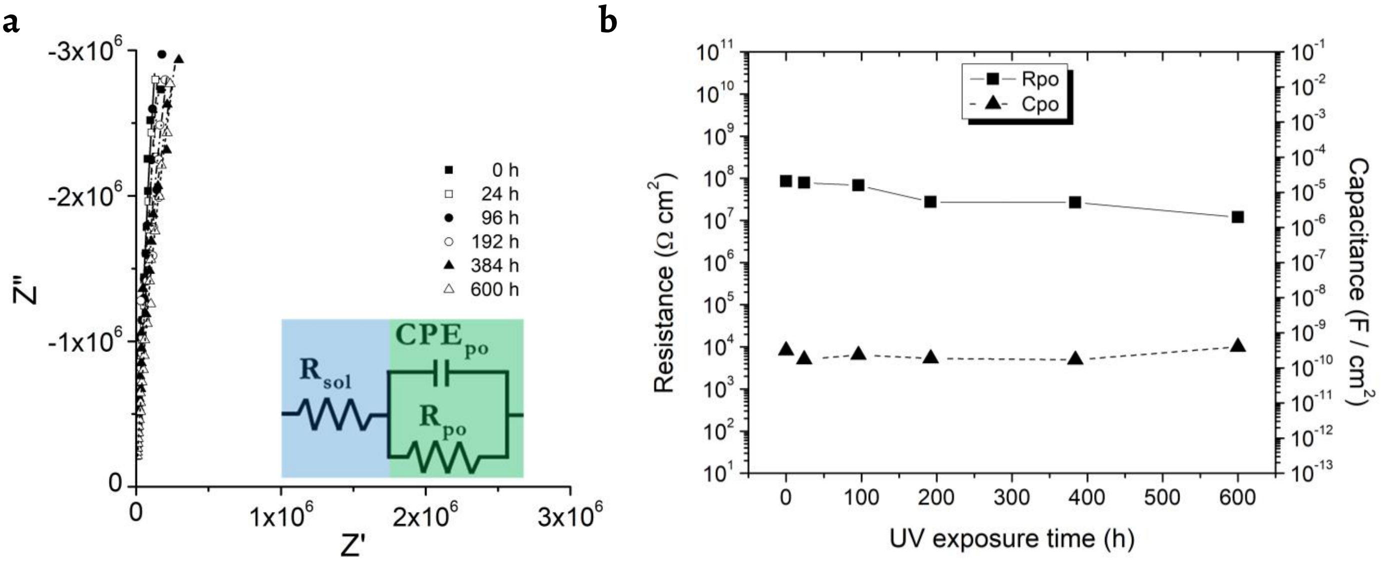

Figure 8. System 3: *a)* Nyquist plots and electrochemical circuit model used in fitting the experimental data, at different aging times, exposed to 0.1 M Na_2SO_4 solution; *b)* R_{po} and C_{po} values for system 3 at different ageing time.

System 4 (cast-iron/corrosion products/polyurethane coating)

In the Nyquist diagrams corresponding to system 4 (Figure 9a), two different behaviours can be observed. At high frequencies, the unexposed specimens and those with 24 and 96 h of ageing, shown a tendency to form a very large capacitive arc, similar to the observed in system 3 (Figure 8a), but as occurred with the system 3, the scattered results are not presented. The behaviour described, can be associated to the formation of a physical barrier that provides high values of dielectric resistance, directly related to good protection, as was previously observed in the Brass/Patina/POL system.

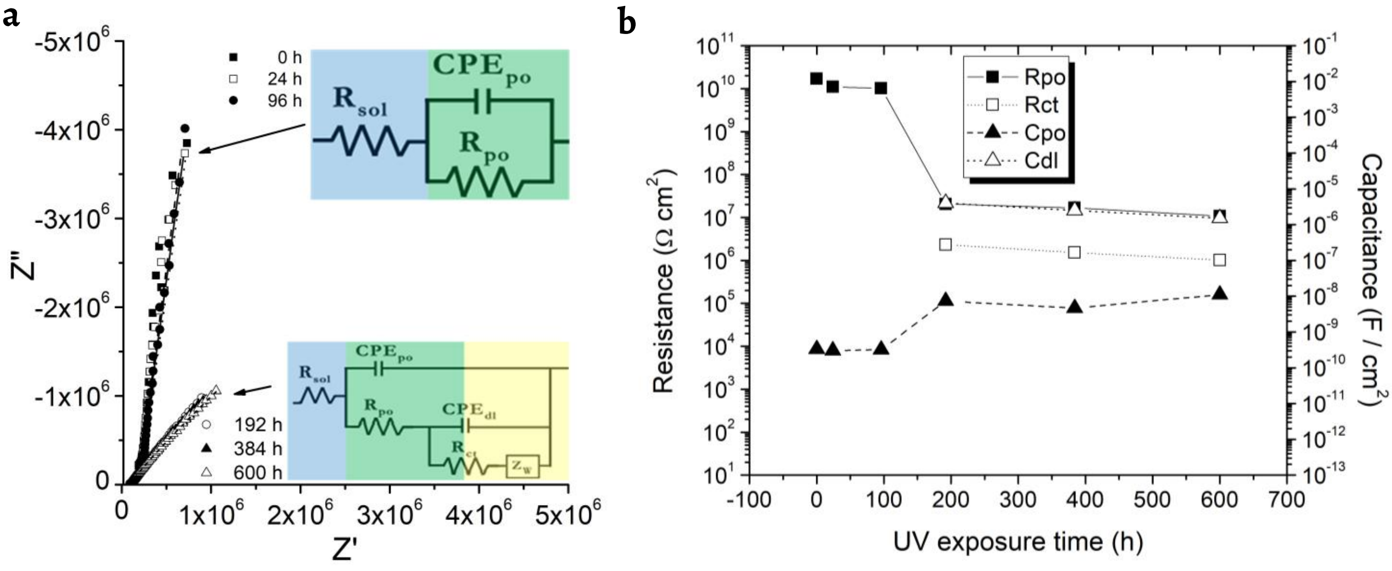

Figure 9. System 4: *a)* Nyquist plots and electrochemical circuit models used in fitting the experimental data , at different aging times, exposed to 0.1 M Na_2SO_4 solution; *b)* R_{po}, R_{ct}, C_{po} and C_{dl} values for system 4 at different ageing time.

On the other hand, the experimental results obtained at 192, 384 and 600 h of ageing, shown a tendency to form an arc, of smaller size than that observed at initial times (Figure 9a). Vesga, indicates that this behaviour is associated to the appearance of coating defects such as pores, cracks or change of thickness, which allow apparition of diffusion process [96].

A Randles circuit [16] (Figure 9a) was used to analyze the impedance spectra for unexposed and exposed specimens after 24 and 96 h (very large capacitive arc). There R_{po} is the pore resistance and CPE_{po} represents the capacitive properties of polyurethane coating protective layer due to its dielectric properties [95-96].

To evaluate the impedance spectra that showed a decrease in the size of the arc (192, 384 and 600 h), associated with the coating failure, the circuit proposed by Haruyama et al. [81], was used (Figure 9a). Where CPE_{po}, at high frequencies, represents the dielectric properties of the coating that represent the non-ideal behaviours consequence of system irregularities such as lack of coating uniformity, roughness, non-homogeneous distributions of the current, etc. R_{po} is the resistance that provides the coating. CPE_{dl} is associated to the capacitance of the double layer, R_{ct} is the charge transfer resistance occurring in the metal-electrolyte interface [16] and Z_w is the Warburg impedance, used to adapt diffusional processes [96-97]. According to Itagaki et al. [77, 81], when a coating fails, corrosion occurred due to the combination of the following factors:

- diffusion of electrolyte ions toward the substrate through areas of the coating that present weak bonds;
- diffusion of the electrolyte by defects of the coatings such as air bubbles, craters, pores, etc. Then, the entry of oxygen induces the formation of anodic and cathodic sites in the substrate, in consequence corrosion reactions accelerate and a pH decrease occurs. This process can induce the loss of adhesion of the coating and metal surface.

Figure 9b shows the values of C_{po}, R_{po}, C_{dl} and R_{ct} as a function ageing time. At initial aging times, up to 96 h, the R_{po} values are in the order of 10^9 Ω cm^2. From 192 h and until the end of aging, a decrease of 3 orders of magnitude was presented in the R_{po} values. Such a decrease can be associated to the appearance of defects in the coating, which allow the interaction of the electrolyte with the base metal resulting in the presence of a second arc in the Nyquist diagram, that corresponds to the corrosion process. The R_{ct} values also showed a tendency to decrease as the aging time increased as a result of the corrosion process. On the other hand, the C_{po} values increased by around two magnitude orders from 192 h compared to those obtained at initial aging times. The C_{dl} values (associated to the R_{ct}), increased when the exposure time increased.

According to Fedrizzi et al. [83], the increase in capacitance values (C_{po} y C_{dl}) and the decrease in resistance values (R_{po} y R_{ct}), are influenced by the appearance of defects in the coating that allow the formation of preferential sites where the corrosion process is carried out, suggesting an increase in the corrosion rate [83, 97-98].

Conclusions

This study employed an electrochemical impedance spectroscopy analysis complemented with a set of surface instrumental analysis to assess protection systems on brass and cast-iron mockups from the colonial Mexican period. The results indicate that system 1 had a significant chemical degradation as showed by the FTIR analysis, the degradation of the surface after the ageing conditions can be observed by the naked eye since it had a high measured colour change, with R_{ct} values of approximately 10^5 Ω-cm². In system 2, the chemical degradation after ageing caused an observable colour change with a final R_{ct} values of 376 Ω-cm².

The systems protected with the polyurethane coating did not present chemical degradation and therefore the colour change was imperceptible to the naked eye though measured with the colorimeter. The physical barrier provided structural stability with R_{ct} values of the order of 10^7 Ω-cm² for system 3. In system 4 the protective capacity was observed to decrease slightly with time due to thinning of the coating to a final R_{ct} value of the order of 1×10^6 Ω-cm². Accordingly, the inhibitor protective systems could be recommended for indoors environment while the coating protective systems for outdoor.

These results showed that the non-destructive methodological proposal is adequate to gather information in a timeline basis on the corrosion processes that affect these cultural assets and can help the development of long-term preventive and corrective conservation strategies.

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CONSERVAR PATRIMÓNIO

ARTÍCULO / ARTIGO / ARTICLE

El láser en la restauración de hierros arqueológicos intensamente mineralizados: criterios y protocolo de intervención en el caso de las armas de una necrópolis Vaccea (Valladolid, España)

O laser no restauro de ferro arqueológico intensamente mineralizado: critérios e protocolo de intervenção no caso de armas duma necrópole Vácea (Valladolid, Espanha)

Laser in conservation of intensely mineralized archaeological iron: criteria and intervention protocols in the case of weapons from a Vaccean necropolis (Valladolid, Spain)

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Resumen

En este trabajo presentamos la restauración de un conjunto de armas de hierro de la necrópolis Vaccea de las Ruedas de Pintia (Padilla de Duero, Valladolid) fechadas entre el siglo IV AEC. e inicios del II EC. Las condiciones de la cremación y el enterramiento han sido muy perjudiciales para la conservación de las piezas, generando una corrosión muy intensa y su completa mineralización. Esto hizo que las armas se encontraran en un estado muy frágil y quebradizo que dificultaba su restauración, ya que implicaba la eliminación de costras duras y muy adheridas a la superficie y, en ese proceso, las piezas corrían peligro de mayor fragmentación. Nuestra propuesta de intervención es el empleo combinado de técnicas de limpieza abrasiva tradicional junto con la limpieza láser Nd:YAG 1064nm que, además de eliminar productos de corrosión, transforman la superficie en magnetita, un óxido de hierro estable.

PALABRAS-CLAVE
Patrimonio arqueológico
Vacceos
Hierro
Limpieza láser
Conservación
Magnetita

Resumo

Neste trabalho apresentamos o restauro de um conjunto de armas de ferro da necrópole Vácea das Ruedas de Pintia (Padilla de Duero, Valladolid) datadas entre o século IV AEC e início do século II EC. As condições de cremação e enterramento foram muito prejudiciais à conservação das peças, originando uma corrosão muito intensa e sua completa mineralização. As armas estavam num estado muito frágil e quebradiço, o que dificultava o seu restauro, pois envolvia a remoção de crostas duras muito aderentes à superfície e, nesse processo, as peças corriam o risco de maior fragmentação. A nossa proposta de intervenção é o uso combinado de técnicas tradicionais de limpeza abrasiva juntamente com a limpeza a laser Nd:YAG 1064nm que, além de remover produtos de corrosão, transforma a superfície em magnetite, um óxido de ferro estável.

PALAVRAS-CHAVE
Património arqueológico
Váceos
Ferro
Limpeza a laser
Conservação
Magnetite

Abstract

The aim of this paper is to present the conservation treatment of a set of iron weapons from the Vaccean necropolis of the Ruedas de Pintia (Padilla de Duero, Valladolid) dated between the 4th century BCE and 2nd century CE. The cremation and burial conditions have been very detrimental to their state of conservation, generating an intense corrosion and their complete mineralization. This left the weapons in a very fragile and brittle state that made their restoration difficult, since it implied the removal of hard crusts that were much adhered to the surface and, during this process, the pieces were in danger of further fragmentation. Our proposal is the combined use of traditional abrasive cleaning techniques together with the 1064nm Nd:YAG laser cleaning that, in addition to removing corrosion products, transforms the surface into magnetite, a stable iron oxide.

KEYWORDS
Archeological heritage
Vaccaei
Iron
Laser cleaning
Conservation
Magnetite

Introducción

El presente artículo analiza la restauración de un conjunto de armas de hierro procedentes de la necrópolis vaccea de las Ruedas de Pintia (Padilla de Duero, Valladolid) fechadas entre el siglo IV AEC e inicios del II EC. Se trata de seis panoplias de guerrero extraídas en la necrópolis de Las Ruedas, en el yacimiento vacceo de Pintia (Padilla de Duero, Valladolid); un cementerio prerromano con enterramientos en hoyo señalizados por una estela de piedra, cuya cronología abarca desde los siglos IV AEC y II EC (Figura 1). Las panoplias están compuestas por punzones, hojas de cuchillo, puntas de lanza y regatones, puñales y sus vainas, tahalís, cinturones articulados, y los elementos metálicos de las *caetras*: umbos, abrazaderas, tirantes y también arreos de caballo [1-2]. La mayoría de estas piezas están fabricadas de hierro forjado; en ocasiones tienen decoración incisa en el propio hierro, como las abrazaderas de escudo, pueden llevar elementos decorativos nielados incrustados en cobre o bronce, o plaquitas de bronce decoradas cubriendo la chapa de hierro. Los motivos decorativos son geométricos: trenzados y ochos – incisos tanto en el hierro como en las plaquitas de base cobre –, rosetas, granulados, etc., estableciendo juegos de colores dorados y plateados, especialmente en las piezas de la tumba 109.

Figura 1. Vista de un área de la necrópolis vaccea de Las Ruedas de Pintia, con las estelas repuestas indicando la posición de la tumba (foto: CEVFW. U. Valladolid).

Lo que se ha conservado después de la cremación y tras más de dos milenios de enterramiento es la parte originalmente metálica de las armas, pero ahora transformada por la corrosión en un conjunto de compuestos minerales, fundamentalmente de hidróxidos y óxidos de hierro; óxidos, carbonatos y cloruros de cobre de las decoraciones, y todo ello cubierto por depósitos del terreno y amalgamado con la propia corrosión. La caracterización de estos productos fue realizada mediante difracción de rayos X, fluorescencia de rayos X y espectroscopía de plasma inducido por láser, como se detalla en la sección de análisis unas líneas más abajo. La parte orgánica que formaba los enmangues y vástagos de madera, así como los elementos presuntamente de cuero en vainas y escudos, se ha perdido. También hay escasos fragmentos de hueso que han quedado adheridos a algunas piezas, como al tahalí de la tumba 173, o el mango de hueso en la tumba 211, fragmentado pero prácticamente completo, sin rastro de haber estado en la pira funeraria de incineración; en él destaca la decoración incisa geométrica, habitual en piezas similares de industria ósea de la misma cultura vaccea.

Se trata de un conjunto de armas muy interesante desde el punto de vista arqueológico, que requería una restauración urgente y precisa para poder ser estudiado. A la vez, su delicado estado de conservación precisaba de un protocolo ya testado en hierros muy frágiles y el uso de las técnicas avanzadas que no implicaran mayor riesgo para las piezas, en concreto herramientas microabrasivas precisas y tecnología láser, y la posibilidad de comprobar los avances con diferentes estudios analíticos. Esta fue la propuesta de intervención realizada desde el Servicio de Conservación, Restauración y Estudios Científicos del Patrimonio Arqueológico (SECYR) de la Universidad Autónoma de Madrid.

Materiales

El catálogo completo de piezas restauradas en el presente proyecto lo integran 61 objetos y responde a la distribución por tumbas de la necrópolis vaccea. Para este estudio hemos seleccionado las muestras más representativas de hierro mineralizadas cuya restauración ha sido posible gracias al láser:

- La tumba 107 (SECYR 413-433) contenía la panoplia más abundante, compuesta por 21 piezas muy deterioradas, entre ellas, escudos, umbos (Figura 2a, SECYR 418), abrazaderas o grapas;
- La tumba 109 albergaba la panoplia de cinco piezas (SECYR 434-438) con la decoración más abundante y rica tanto en la empuñadura y en la vaina del puñal (SECYR 436) como también en el tahalí (SECYR 437). Esta decoración estaba cubierta por una dura capa de corrosión de hierro. Las piezas de esta tumba estaban mejor conservadas que la tumba 107. Así, destacaba el estado inicial del umbo de la *caetra* de esta tumba (SECYR 435); conservado prácticamente entero y sin fisuras, salvo por un foco de corrosión donde el núcleo se había perdido. Su estado contrastaba sin duda con el umbo de la tumba 107 (SECYR 418) que había perdido el núcleo metálico, estaba completamente fragmentado y cubierto de ampollas de corrosión (Figura 2b);
- La tumba 133 se componía de una panoplia de cinco piezas (SECYR 439-443) con un estado de conservación mucho mejor que el resto de panoplias, y manteniendo todas ellas la forma inalterada;
- La tumba 173 incluía una panoplia con nueve piezas (SECYR 444-452) en muy mal estado de conservación, muy fragmentadas y con huesos adheridos por la corrosión;
- La tumba 185 mostraba una panoplia formada por un conjunto en bloque (SECYR 303) integrado por cinco piezas: una hoja de puñal de filos curvos, tipo “Villanueva de Teba”, su vaina, el broche de cinturón y la punta de lanza;

- La tumba 211 albergaba también una panoplia abundante compuesta por 16 piezas (SECYR 453-468). En este conjunto destacan otro puñal tipo "Villanueva de Teba", la lanza, la vaina, un broche de cinturón articulado (Figura 2c, SECYR 457), el colgante de aguja (SECYR 464) y unos fragmentos de vaina y placa de bronce (SECYR 458) que tenían adheridas dos fíbulas de base cobre muy finas y relativamente bien conservadas.

Figura 2. Estado inicial de: *a)* umbo de la *caetra* de la tumba 107 (SECYR 418), cubierto de carbonatos y con una amplia fragmentación; *b)* umbo de la *caetra* de la tumba 109 (SECYR 435), cuyo excelente estado de conservación contrasta con el umbo de la tumba 107; *c)* broche de cinturón articulado de la tumba 211 (SECYR 457), afectado por una intensa corrosión.

El estado de conservación de las armas de Pintia

Para comprender el delicado estado de conservación de estas armas, resulta de interés referirse con mayor detalle al proceso de corrosión originado durante su prolongado enterramiento en los suelos agresivos de la necrópolis de Las Ruedas de Pintia, siguiendo un esquema bien conocido en estudios precedentes [3-4]. La corrosión producida durante el enterramiento ha provocado la pérdida del núcleo metálico del hierro y su transformación en minerales ferrosos que mantienen la forma y estructura general de las piezas, pero careciendo de la tenacidad y resistencia del hierro forjado. De ahí la extraordinaria dificultad de su restauración.

Como es habitual, la corrosión no es uniforme ni idéntica en todas las piezas, ni en todas las tumbas, por ello es preciso anotar las condiciones propias del contenedor geológico donde se asienta la necrópolis de las Ruedas, en pagos de Padilla de Duero, en un área inmediata a la margen izquierda de este gran río, que sería el primer factor de alteración de estas piezas. Los pequeños hoyos para alojar cada una de las tumbas con su respectivo ajuar se practicaron en un substrato geológico formado por arenas y gravas, salvo en la proximidad al paleocauce del actual arroyo de la Vega; una corriente de agua que en época de vigencia del cementerio discurrió en su orilla izquierda por el sector Noreste y Este de la citada necrópolis, hasta desembocar en el inmediato río Duero (Figura 3). Este curso antiguo hubo de generar las lógicas inundaciones del área inmediata de la necrópolis, pues en su momento se había construido una escollera seguramente con el objetivo de poder amortiguar o impedir la inundación del espacio funerario sagrado de estas gentes vacceas. Por tanto, la alternancia de ciclos de mayor humedad en el suelo con otros de mayor sequedad, provocados no solo por las precipitaciones sino por las inundaciones del arroyo inmediato, potenciaron la corrosión de los metales en este suelo arqueológico, especialmente de los hierros.

El equipo científico de campo ha confirmado a lo largo de los años de excavación en esta necrópolis vaccea que el grado de alteración de los objetos de hierro del ajuar es muy distinto según fuese la profundidad a que se había practicado el hoyo de enterramiento. Mientras que las tumbas de cronología más reciente (II-I AEC) situadas a mayor profundidad ofrecían una muy mala conservación de los objetos de hierro (por ejemplo, la tumba 185), las de cronología más antigua (IV-III AEC) excavados en los suelos arenosos más someros presentaban las piezas de hierro en un estado de conservación algo mejor.

Otro importante factor de alteración fue el proceso de cremación al que fueron sometidas las armas de la panoplia junto a su propietario. Este efecto térmico a unas elevadas temperaturas generó un impacto muy grave en los metales, acelerando su corrosión [5]. En esta necrópolis hay evidencias de la cremación de las armas y otros elementos metálicos junto con el cadáver en la pira, como se pone de manifiesto en el hallazgo de una fíbula de bronce con evidentes signos de deformación por calor en la tumba 9 de este cementerio vacceo de Las Ruedas [6].

Por otro lado, aquellas piezas que tenían decoración de cobre o se encontraban cerca de otras decoradas presentaban también productos de corrosión de cobre, especialmente cloruros. Estos casos en que en las piezas tenían una doble naturaleza metálica evidenciaban claramente la corrosión galvánica, en la que el hierro se había corroído en beneficio del cobre. Un ejemplo de ello sería el broche de cinturón articulado de la tumba 211 (Figura 4, SECYR 457), que incluye dos piezas de hierro con una placa superpuesta de bronce con decoración incisa y varios fragmentos de este mismo tipo de placa de aleación de cobre. En cada caso la corrosión era diferente: mientras la plaquita desprendida del cinturón y aislada del contacto directo con el hierro se había transformado por completo en minerales de cobre, las piezas mixtas en su construcción original cobre-hierro conservaban la plaquita decorativa de base cobre en muy buenas condiciones, con un grosor original considerable, mientras que la placa estructural de hierro estaba totalmente corroída y desnaturalizada.

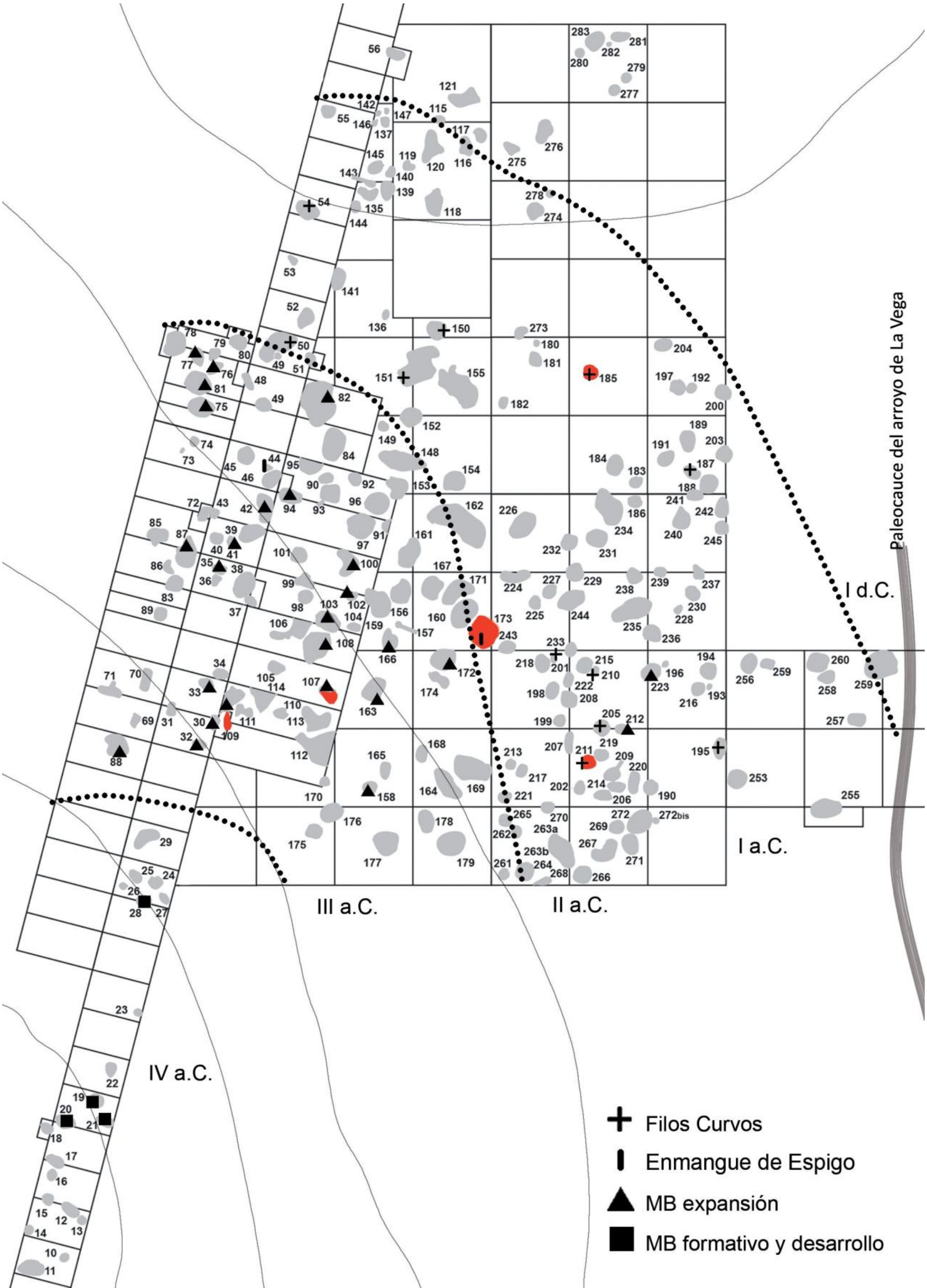

Figura 3. Plano general de las tumbas excavadas en la necrópolis de Pintia con indicación del paleocauce antiguo (CEVFW. U. Valladolid). Los puntos rojos corresponden a las tumbas en las que se han encontrado las armas.

Figura 4. Comparativa entre el buen el estado de conservación de la decoración de aleación de base cobre unida al hierro a causa de la corrosión galvánica (pieza inferior) y de la plaquita separada del hierro, mucho peor conservada (pieza superior). En ambos casos se muestra el estado tras la restauración de las piezas (SECYR 457).

Además de los productos de corrosión propios de los metales, las piezas mostraban numerosos depósitos del terreno, especialmente cantos de cuarcita de todos los tamaños y granos de sílice, totalmente adheridas a la superficie de los objetos por medio de la corrosión. Todos estos factores han determinado el estado de conservación de las armas, caracterizado por los siguientes rasgos:

- El metal se ha mineralizado por completo, transformándose su interior en hidróxidos de hierro sin consistencia, dejando las piezas extremadamente frágiles (Figura 5a) y, en los peores casos, muy fragmentadas, como es el caso del umbo de la tumba 107 (Figura 2a). Esta situación deriva fundamentalmente por la cremación y el contexto geológico de las tumbas;
- Las armas presentan una costra externa muy resistente y dura formada por cuarcitas, arenas y tierras provenientes del estrato arqueológico, amalgamadas por la corrosión del hierro (Figura 5b);
- Algunas piezas también están cubiertas por un depósito compacto y grueso integrado por carbonatos de calcio y silicatos;
- La superficie de las piezas está laminada y hojaldrada, fruto de la intensa corrosión sobre hierros sometidos a forja;
- En algunos casos concretos, bajo los depósitos y costras de corrosión, la superficie original se ha transformado en una capa de magnetita homogénea y resistente que conserva los detalles incisos de la pieza;
- Las piezas con decoración de cobre tienen una capa muy dura de productos de corrosión de hierro cubriendo esta decoración, a causa de la corrosión galvánica (Figura 5c).

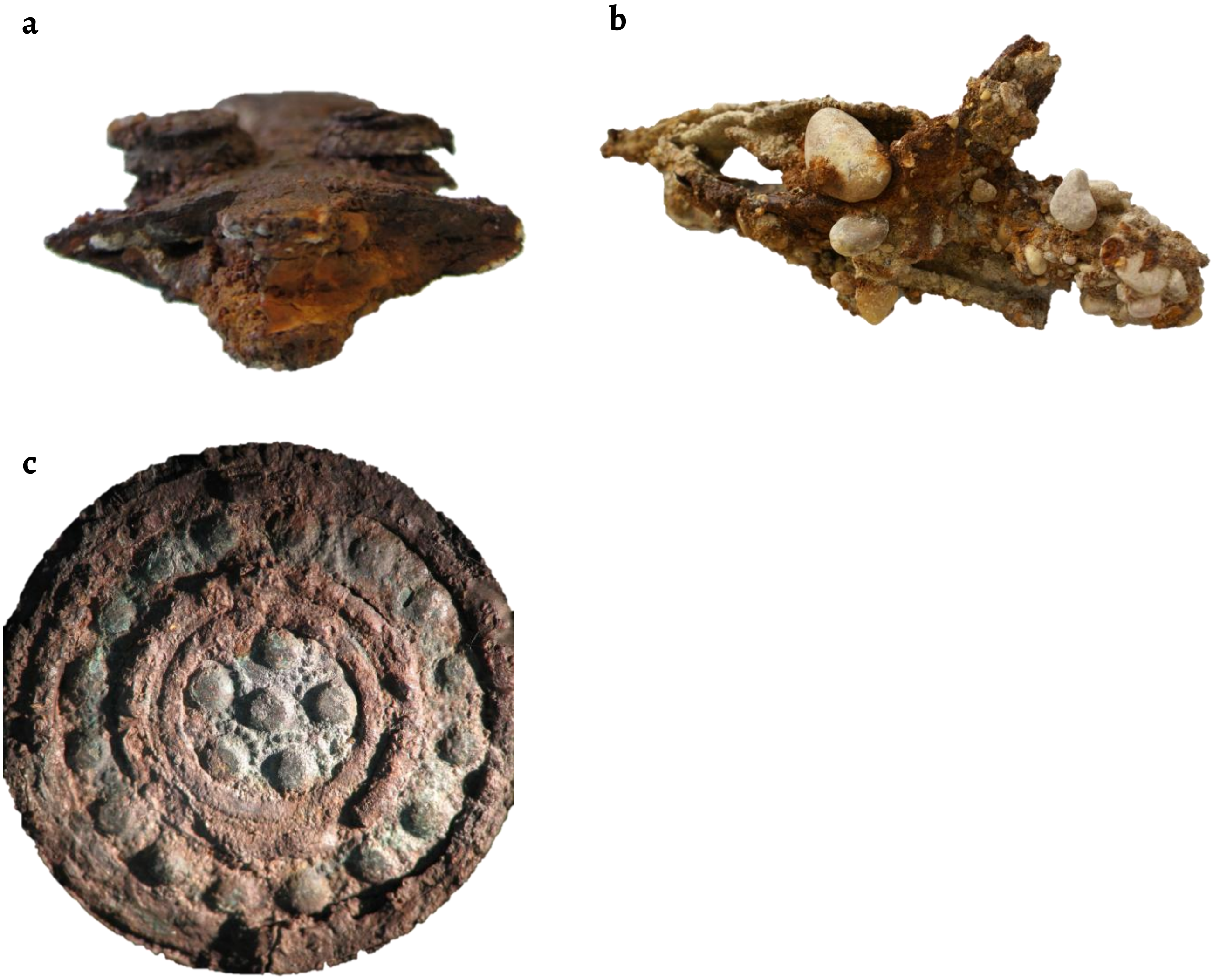

Figura 5. Detalles de: *a)* la completa mineralización de la hoja de puñal de la tumba 109 (SECYR 436) en el interior de la vaina; *b)* la potente costra exterior de productos de alteración de la panoplia de la tumba 185 (SECYR 303); *c)* la restauración iniciada de uno de los nielados de cobre de la vaina del puñal de la tumba 109 (SECYR 436), donde se ha retirado parcialmente la película de óxidos de hierro que cubría la decoración de cobre (ampliación 20×).

Análisis de las piezas

Como viene siendo una norma en el trabajo del laboratorio SECYR-UAM, en paralelo a la restauración de las piezas se desarrolló una investigación arqueométrica encaminada al conocimiento y caracterización de los materiales. Para ello se llevaron a cabo pruebas diagnósticas antes, durante y después del tratamiento, con el fin de identificar la composición de ciertas piezas y los efectos del tratamiento, especialmente de la aplicación del láser. Gracias a la naturaleza tan homogénea de los hierros forjados no fue necesario analizarlos todos, sino una muestra representativa de los mismos. Además, una caracterización más extensa no hubiese tenido un mayor impacto en la elección de un tratamiento de conservación. Por otro lado, el estado de mineralización de estas armas proporcionaba pocas opciones de análisis valiosas aparte de las que presentamos aquí, salvo que hubiésemos optado por seccionar alguna de las piezas; un criterio muy alejado de nuestros principios de conservación, aunque por desgracia habitual en la práctica operatoria de ciertos arqueómetras de la metalurgia antigua. A nuestro modo de ver, no hay deontología científica que justifique el sacrificio del enfermo que se pretender tratar y curar.

Las técnicas de examen y análisis empleadas

Análisis radiográfico

Realizado en el Instituto de Patrimonio Cultural de España (IPCE). Este es el primer examen de las piezas, antes de comenzar cualquier tratamiento. Las imágenes obtenidas mediante rayos X permiten conocer su estructura interna determinando la presencia y gravedad de las fracturas, fisuras o roturas. También permiten tener constancia de datos de su tecnología como la existencia de ensamblajes, uniones, espigas o remaches. Pero sin duda, en este caso, el resultado más significativo fue la posibilidad de documentar la decoración compuesta por otro metal distinto al hierro, cobre, y que no se veía a simple vista pues estaba subyacente bajo la corrosión de hierro (Figura 6, pieza derecha, SECYR 441). También se comprobó que había decoración incisa de motivos geométricos por cajeado en los pomos, guardas y vainas de algunos de los puñales. En definitiva, como suele ser habitual cuando se radiografía este tipo de objeto con potentes costras de corrosión, los datos resultan determinantes para abordar su restauración.

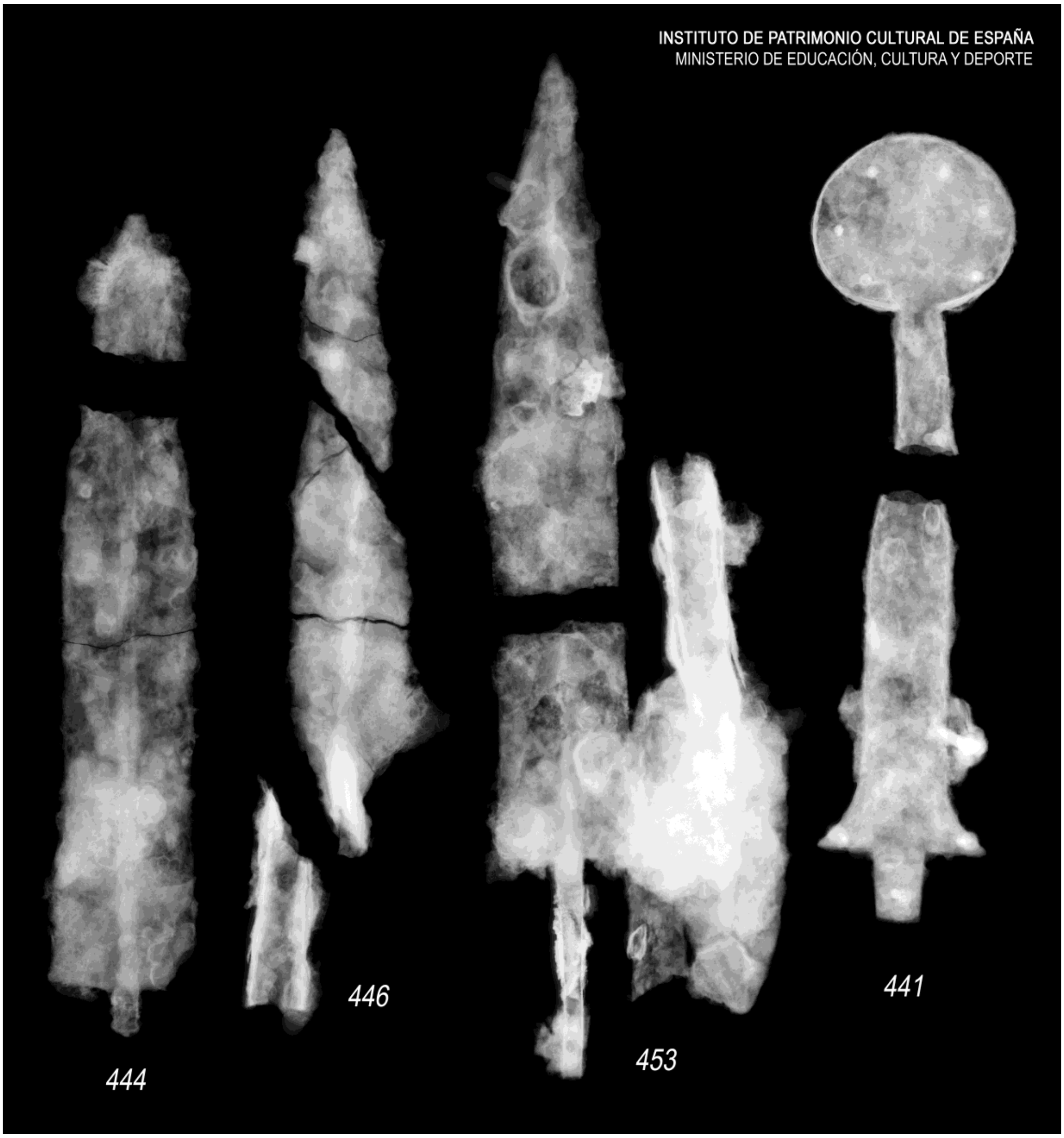

Figura 6. Placa RX de algunas de las armas de la necrópolis de Pintia, donde se reconoce la intensa pérdida de núcleo metálico en todas ellas, especialmente en las piezas SECYR 444, 446 y 443, además de numerosas fracturas, fisuras y ampollas (IPCE, Laboratorio de Análisis Físicos).

Difracción de raios X (XRD), Fluorescencia de Rayos X (XRF) e Espectroscopía de plasma inducido por láser (LIBS)

Realizadas, la difracción de rayos X (XRD) en el Servicio Interdepartamental de Investigación (SIdI-UAM), fluorescencia de rayos X (XRF) y espectroscopía de plasma inducido por láser (LIBS) en el SECYR-UAM. Estas tres técnicas analíticas han permitido caracterizar los productos de corrosión del hierro y diferenciarlos de los depósitos de otros minerales sobre la superficie de los objetos, así como de los metales usados en la decoración de las armas, todos ellos de base cobre. Especialmente interesante ha sido el resultado de la analítica realizada sobre la superficie de hierro tratada con láser, que ha revelado que se trata de una pátina de magnetita, un óxido de hierro estable. Las técnicas XRF (Figura 7a) y LIBS (Figura 7b) se emplearon sobre piezas completas, sin toma de muestra, antes, durante o después de la realización del tratamiento. Con XRF se aprecia una composición mayoritaria de cobre con escasos residuos de estaño y posiblemente de arsénico (elemento de habitual aparición en los metales de base cobre de época protohistórica en la Península Ibérica). Los espectros semicuantitativos de LIBS usado para la identificación elemental de dos láminas de la pieza SECYR 457: una corroída y otra dorada, determina que la composición mayoritaria de cobre y trazas de estaño es muy similar a la detectada con XRF, aunque ahora se reconoce los compuestos de óxidos de hierro y carbonatos de cobre en el área corroída, junto a otros productos como sílice, aluminio y magnesio procedentes de las tierras amalgamadas. Con esta técnica no se reconocen las trazas de arsénico.

En el caso de la XRD se ha hecho con incidencia rasante sobre la superficie más plana de la pieza y el resultado también ha puesto de manifiesto cómo, tras la limpieza con láser, hay una mayor señal de los compuestos estables de hierro, como la magnetita (Figura 8).

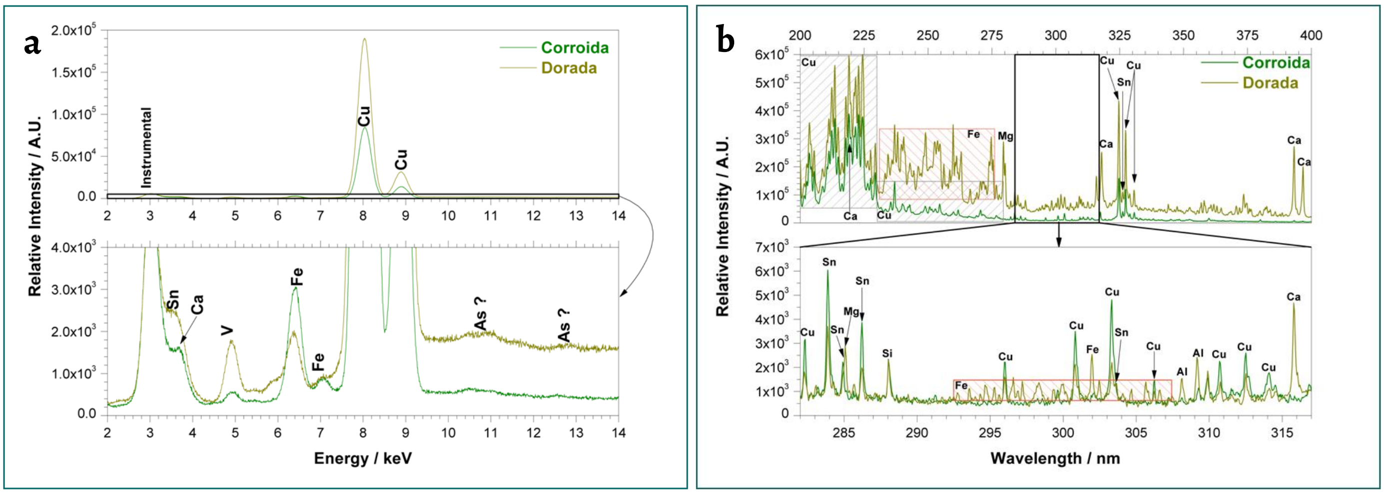

Figura 7. Espectros: *a)* de XRF de SECYR 457 para la discriminación de dos chapas; *b)* semicuantitativos de LIBS para la identificación elemental de dos láminas de la pieza SECYR 457: una corroída (verde) y otra dorada (dorada).

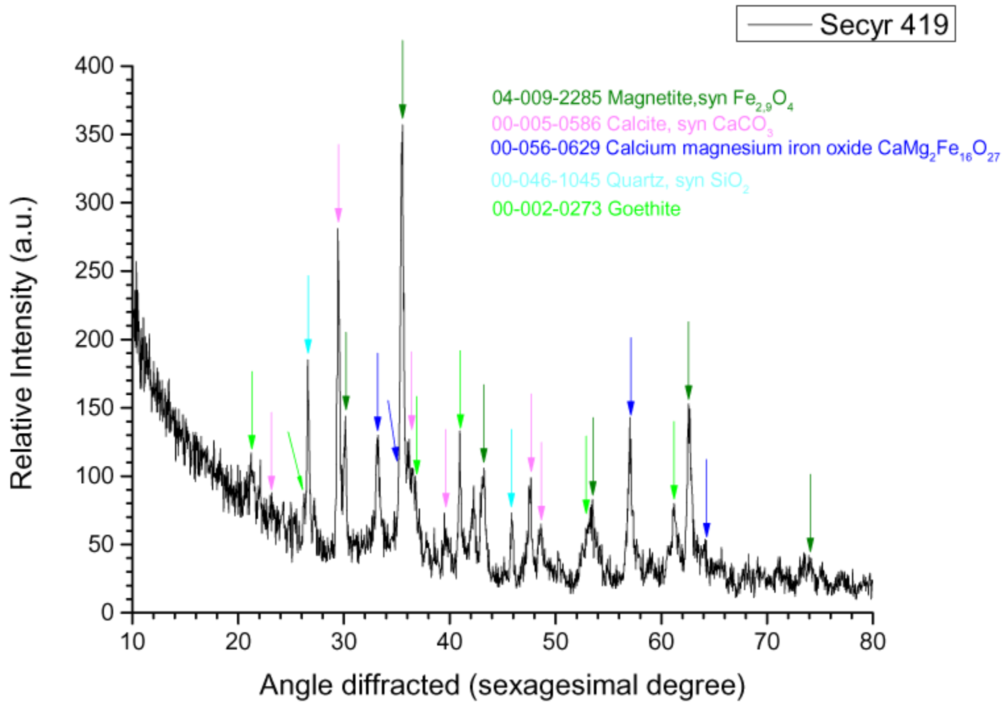

Figura 8. Difractograma en abierto XRD sobre la superficie original de la aleta de escudo de la tumba 107, SECYR 419) después de la aplicación del láser, donde se aprecia la preminencia de la magnetita en la pátina del hierro; lógicamente aún persisten algunos minerales de la corrosión inicial del hierro y de las tierras del contenedor geológico del enterramiento.

El papel del láser como herramienta de restauración del hierro arqueológico

Los métodos habituales de restauración de los hierros de procedencia arqueológica muy mineralizados han sido diversos según la disponibilidad técnica de cada momento histórico y según los criterios de intervención imperantes en esa época, pasando por los electrolíticos y electroquímicos [7-8], los químicos y los mecánicos manuales o bien con el uso de diverso instrumental. Desde los años 80 del siglo XX se ha producido una primacía casi total de los procedimientos mecánicos, que aún hoy en muchos casos sigue vigente según las condiciones de la pieza a intervenir [9]. Sin embargo, aunque estos métodos, especialmente los mecánicos, son eficaces a la hora de tratar hierros arqueológicos, tienen, también, importantes inconvenientes en piezas frágiles como las que nos ocupan. El propio funcionamiento de la limpieza mecánica por microabrasión, ya sea con microtorno o microchorro, supone la aplicación de fuerza o la proyección de un abrasivo para eliminar los productos de corrosión y, en ambos casos, esto puede conllevar la fracturación de las piezas, el rayado de las mismas o la pérdida de la superficie. Un resultado similar se obtendría con el uso de la espátula de ultrasonidos, cuya vibración interna podría derivar en la apertura de fracturas o desintegración de piezas sin cohesión interna, como son las de Pintia. De ahí la importancia de saber hasta dónde se deben emplear estas técnicas y hallar un sistema complementario de limpieza que aborde con éxito las lagunas de los sistemas tradicionales. Desde comienzos del siglo XXI esa nueva herramienta ha sido el láser, empleada con óptimos resultados [10-12], como también hemos recogido en trabajos anteriores [13-17]. Es una técnica excelente que no desbanca a las limpiezas tradicionales, sino que puede combinarse con ellas.

Para entender las ventajas del láser como técnica de limpieza en restauración, conviene recordar sus principales características y rasgos generales [10-11,18-19], comenzando por destacar que se trata de una radiación luminosa (laser es el acrónimo en inglés de Light Amplification by Stimulated Emission of Radiation):

- Es un haz de luz monocromática, es decir, tiene una única longitud de onda
- Presenta coherencia temporal y espacial
- Direccionalidad, fácilmente focalizable
- Emisión que permite transportar energía de alta intensidad
- Todo ello combinado es capaz de generar procesos de transformación

Su eficacia en restauración deriva de estas propiedades, especialmente de la última: la ablación o fotoablación es el principal fenómeno por el cual limpia el láser [20]. Durante esa ablación, se generan procesos de (1) vaporización rápida e ionización, (2) espalación, y (3) procesos de contracción y dilatación, tres fenómenos que suelen producirse en conjunto, y que conllevan la eliminación de los productos de corrosión superficial de los hierros arqueológicos muy corroídos y frágiles que, de otro modo, sería prácticamente imposible restaurar. Las ventajas de la limpieza láser pueden resumirse en cinco puntos:

1. al tratarse de una luz focalizada, no se ejerce presión, ni vibración, ni abrasión sobre la superficie; asimismo se evitan los productos químicos que pueden quedar remanentes y ser perjudiciales a futuro. Por ello esta técnica puede ser definida como muy poco invasiva;
2. la diferente absorción del haz láser por parte de los diversos materiales y substratos, en función de distintos factores como la naturaleza y cohesión del material, su color, la reflectancia de la superficie, la intensidad de la luz, etc. Esta diferencia en absorción provoca una eliminación selectiva de los productos de deterioro;
3. gran control durante el proceso, pues la materia que se va retirando con cada pulso es muy escasa, de pocos micrones, y así la limpieza se efectúa de modo progresivo. Este es un rasgo importante para mantener la integridad de las pátinas y la superficie original en los metales;
4. el control y precisión que permite el equipo láser con el que desarrollamos este trabajo, un El.En. EOS 1000 Nd:YAG Short Free Running (SFR) que trabaja en el infrarrojo cercano (λ:1064 nm y con una duración de pulso entre 60-120 ms). Es un equipo muy versátil en el que se pueden modificar sus parámetros principales, como la energía; el Spot y la frecuencia. La precisión está relacionada con todos estos parámetros y con la salida del haz a través de una fibra óptica y un manípulo muy ligero, con el que se enfoca el láser sobre todo tipo de superficies, adaptándose a las topografías irregulares de los hierros arqueológicos;
5. este sistema de limpieza es seguro para los profesionales que lo manejen, siempre que se establezcan y respeten los protocolos de seguridad, el empleo de equipos de protección individual y colectivo (EPI y EPC).

Con respecto a los inconvenientes que pueden surgir con el láser, al igual que en el resto de tratamientos mecánicos y químicos, este puede implicar riesgos serios para el/la restaurador/a o la pieza por hacer un uso inadecuado de la técnica. Por ello requiere una excelente formación en el manejo del equipo concreto que se vaya a utilizar y con protocolos de trabajo adecuados y adaptados a cada material, fruto de una amplia experimentación. De forma específica en la restauración de metales arqueológicos, hemos detectado la necesidad de tener una precaución específica con el riesgo de provocar microfusiones sobre la superficie de los metales blandos o más conductores. Estas microfusiones surgen por el rápido y excesivo calentamiento y enfriamiento de materiales como el plomo y la plata, pero en nuestra experiencia sobre hierros arqueológicos nunca se ha dado este problema.

Criterios de restauración

Parece oportuno referirse a los criterios de restauración que hemos seguido en la intervención de las armas de Pintia, y que deben hacer referencia obligada a la implantación de nuevas tecnologías en metales arqueológicos con estas condiciones. A pesar de que las Cartas y Documentos deontológicos de Restauración no se refieren específicamente a la intervención en metales arqueológicos, de su lectura detenida se pueden entresacar algunos principios generales que han guiado nuestra actuación.

El uso de una tecnología innovadora como el láser en un campo tan delicado como el de la conservación y restauración de los metales de procedencia arqueológica debe contar con el sustento de los principios deontológicos más actuales. Al surgir como tal investigación aplicada se ha apoyado en las ciencias analíticas y experimentales, como apuntaba el punto 5º de la Carta de Atenas (1931) [21] y luego recogía explícitamente el artículo 2 de la Carta de Venecia (1964): "La conservación y restauración de monumentos constituye una disciplina que abarca todas las ciencias y todas las técnicas que puedan contribuir al estudio y la salvaguarda del patrimonio monumental" [22]. Con el paso del tiempo este criterio se ha hecho más manifiesto, conduciendo la tarea de conservación y restauración hacia una actividad multidisciplinar. En este sentido, el punto 10 de la Carta de Cracovia (2000) indicaba: "Las técnicas de conservación o protección deben estar estrictamente vinculadas a la investigación pluridisciplinar científica sobre materiales y tecnologías (...) Cualquier material y tecnología nuevos deben ser probados rigurosamente, comparados y adecuados a la necesidad real de la conservación" [23]. Como se pone de manifiesto en este párrafo, el uso de tecnologías de vanguardia como el láser está perfectamente justificado siempre que se apoye en estudios arqueométricos positivos a su aplicabilidad y que certifiquen su aportación en la resolución de los problemas junto a los métodos tradicionales.

Por otra parte, en la restauración de materiales arqueológicos metálicos, la recuperación de la superficie original y el mantenimiento de su pátina es el criterio de mayor trascendencia aceptado en la deontología internacional y, por ello, en el trabajo con láser ha primado en todo momento ese respeto a la autenticidad de las piezas. El concepto de autenticidad viene ya recogido en la introducción a la Carta de Venecia (1964) y se repiten las referencias a su importancia en el resto de las Cartas de Restauro. Sin embargo, es en el punto 6 de la Carta de Cracovia (2000) donde se confiere a este principio un papel destacable, incluyéndose también en el apartado de Definiciones como "la suma de características sustanciales, históricamente determinadas: del original hasta el estado actual, como resultado de las varias transformaciones que han ocurrido en el tiempo" [23]. Debe reconocerse tanto la autenticidad del contenido material como del inmaterial de la pieza (en la materia física constituyente y en el contenido histórico representado). Este rasgo que protege el principio mencionado es imprescindible en los bienes del patrimonio arqueológico metálico, quizás porque la autenticidad es la referencia obligada y necesaria para los elementos pertenecientes a las denominadas culturas antiguas. El respeto a esta identidad auténtica es una de las premisas fundamentales en las actuaciones englobadas en el proceso de conservación/ restauración, también con las nuevas herramientas tecnológicas, aun siendo conscientes de que toda intervención sobre metales arqueológicos, dado su deficiente estado de conservación, lleva aparejada una cierta dosis de pérdida o modificación de esa autenticidad. Según nuestra experiencia, el láser es la técnica que mejor puede preservar estas condiciones de autenticidad en muchos de estos objetos.

El siguiente criterio aplicado es el de mínima intervención, que prima en la conservación arqueológica actual. Este supone que el proceso de intervención debe ser el mínimo exigible conforme a la situación específica de cada pieza y de sus productos de deterioro, que permita la estabilización y garantice la permanencia de estas piezas en el futuro. Quizás siga siendo muy útil la premisa "restauración en función de la conservación", siempre privilegiando los aspectos preventivos antes que curativos, y ya expresada en su momento con claridad en las teorías brandianas. En el punto 5 de la Carta de Cracovia (2000) se refiere a este criterio general haciendo una mención expresa al patrimonio arqueológico: "Como en el resto de los casos, los trabajos de conservación de hallazgos arqueológicos deben basarse en el principio de mínima intervención" [23].

No obstante, este criterio de mínima intervención debe ir de la mano del criterio de recuperación de la legibilidad, es decir, la recuperación de la entidad de las piezas mediante el descubrimiento de sus superficies originales que pudieran quedar en los distintos objetos. En el caso de las armas de hierro de Pintia cubiertas por costras de productos de alteración muy espesos y cubrientes, su legibilidad solo era posible si se efectuaba la retirada completa de los productos de deterioro que ocultaban la superficie original del arma de hierro. Siguiendo la denominación de las cuatro zonas de corrosión [3, 24], se trataba de retirar las dos primeras capas de corrosión más externas, formada la primera por tierras y piedras del contenedor del suelo (*soil* [S]) y, la segunda, por la mezcla de óxidos y tierras del estrato más externo de los productos de alteración (*transformed medium*, [TM]). Con su eliminación se dejaba a la vista la capa más densa (*dense product layer*, [DPL]), integrada en este caso por una mezcla de óxidos, hidróxidos y carbonatos (ghoetita, magnetita y maghemita). Esta capa es suficientemente compacta como para evitar la difusión de oxígeno y, por ello, es la más estable frente a la corrosión, su pátina, que puede conservar las huellas originales del objeto, su forma y su decoración. La cuarta zona definida por estos autores es el núcleo metálico (*metal*, [M]), que no debe salir a la luz, sino quedar protegido bajo la pátina estable.

En definitiva, estos principios sustentan nuestra "ética de restauración" que podemos resumir brevemente en el mantenimiento de la autenticidad, el respeto de la pátina y superficie original, la mínima intervención ajustada a las necesidades de la pieza, la multidisciplinariedad en la investigación exhaustiva de los problemas y causas de deterioro, la conservación preventiva que garantiza la seguridad física de las piezas, y la evaluación constante de las técnicas de vanguardia usadas en restauración.

Protocolo de restauración

El conjunto de armas tenía un estado de conservación relativamente homogéneo por lo que el tratamiento aplicado siguió la misma pauta, adecuando los tiempos y las técnicas a la singularidad de cada pieza.

El objetivo de la primera fase era eliminar las tierras y piedras que cubrían los objetos. El estrato más superficial y menos adherido se retiró sin dificultad con una limpieza manual, y un segundo estrato compuesto por cantos de río de diversa granulometría y fuertemente adheridos con los óxidos de hierro requirió del uso de herramientas de apoyo. Primero, con la espátula de ultrasonidos se separaron las piedras menos cementadas del bloque. Segundo, la aplicación del microchorro y microtorno debilitó la amalgama de óxidos en torno a cada piedra, para posteriormente desprenderlas sin problemas con ayuda mecánica. La extrema fragilidad de algunas panoplias, como las de las tumbas 185 y 211 hizo muy dificultosa, incompleta y lenta esta primera retirada de los productos más resistentes. A pesar del extremo cuidado, no pudieron evitarse algunas fracturas en las zonas de máxima debilidad, que ya se habían identificado gracias al estudio radiográfico inicial.

En la segunda fase el objetivo era rebajar la resistente corrosión intermedia de granos de cuarzo y óxidos de hierro de las zonas más compactas y para ello fue necesario utilizar el microchorro con un abrasivo de óxido de aluminio. Para las ampollas más endurecidas se combinó puntualmente con el microtorno, regulando la rotación para evitar las vibraciones. La aplicación cuidadosa y la alternancia precisa de ambas técnicas dieron un buen resultado para rebajar la corrosión, acercarnos a la superficie original y descubrir paulatinamente la decoración conservada en las empuñaduras, vainas y tahalíes de las armas más ricas, por ejemplo, los nielados o damasquinados con hilos y las placas de cobre.

El objetivo de la tercera fase era perfeccionar la limpieza de la pátina original compuesta fundamentalmente por hidróxidos u oxihidróxidos de hierro, como la goetita, y estabilizar la superficie transformando estos compuestos inestables en óxidos, en concreto en magnetita tipo espinela. Este procedimiento se realizó enteramente con láser, con el equipo descrito en líneas anteriores, que iba transformando y estabilizando poco a poco la superficie irradiada. Visualmente, esta nueva capa se identifica fácilmente porque el color se oscurece y la capa se va compactando a medida que se aplica láser. Si tratamos de repetir, enfocando el láser sobre la zona ya tratada, comprobamos que esta nueva superficie tiene menor capacidad de absorción del láser y su efectividad también baja enormemente. Por ello, para seguir limpiando y alcanzar una mayor estabilidad de la zona, combinamos cada pasada del láser con una suave limpieza mecánica de la superficie mediante cepillado. Así, retirados los depósitos menos adheridos de la zona irradiada, permanecen las áreas transformadas más compactas y se puede aplicar una segunda pasada de láser. Este procedimiento se repite hasta que el/la restaurador/a comprueba que el cepillado ya no elimina partículas y valora que la zona ha quedado consistente y dura. Esta es una de las aportaciones más interesantes del láser, que además de vaporizar una parte de los productos de corrosión, transforma otra, mejorando el comportamiento de la capa frente a la futura corrosión, pues los compuestos tipo espinela son poco permeables al oxígeno, y por ende muy estables (Figura 9). Además, el aspecto estético es inmejorable, pues se trata del mismo compuesto que la pátina original del hierro: la magnetita. Para establecer los mejores parámetros de limpieza nos basamos en las experiencias positivas del laboratorio de los últimos años en la restauración de piezas metálicas de naturaleza y estado de conservación similar [25], y en las propias pruebas realizadas sobre las armas de Pintia (Tabla 1).

La cuarta fase del tratamiento consistió en la integración de fragmentos, y la reintegración matérica y cromática. Los fragmentos desprendidos durante la limpieza se fueron adhiriendo con resinas epoxídicas (Araldit) cargadas con pigmentos naturales, consiguiendo que la pieza mantuviese siempre cierta solidez (Figura 10a). También fue preciso colocar refuerzos de fibra de vidrio en el interior de vainas y grapas de escudo adheridos con resina acrílica Paraloid B72. El objetivo de la reintegración matérica era aportar consistencia estructural al objeto, por ejemplo, en fracturas antiguas que ya no casaban correctamente, rellenando pequeñas lagunas también con una resina epoxídica (Balsite) cargada con pigmentos naturales para darle un tono de base similar a la pátina del hierro de las piezas. Esta resina resulta apropiada porque es fácil de manipular, es estable y ha ofrecido resultados muy positivos en otros casos de restauración de elementos metálicos arqueológicos con estados de conservación similares a los recogidos en nuestro trabajo [26]. La reintegración cromática se realizó al final del tratamiento (tras la primera capa de protección) con pigmentos naturales aglutinados con Paraloid B-72.

Figura 9. Acabado obtenido con el láser de la panoplia de la tumba 211 (SECYR 453); se observa la capa de magnetita que cubre superficie original de la pieza.

Tabla 1. Parámetros medios de láser utilizados con el equipo EOS 1000 Nd:YAG 1064nm SFR sobre las capas de corrosión formadas sobre el hierro original.

Laser EOS 1000 Nd:YAG 1064 nm Short Free Running	**Energía (mJ)**	**Spot (mm)**	**Frecuencia (Hz)**	**Fluencia J/cm^2**
Hidróxidos	100	5	2-6	0,5
Acabado	200	10	4-6	0,3

Figura 10. Estado final, después de la restauración, del: *a)* umbo de la tumba 107 (SECYR 418); *b)* umbo de la tumba 109 (SECYR 435); *c)* broche de cinturón articulado de la tumba 211 (SECYR 457).

En la quinta fase del tratamiento se planteó un tratamiento inhibidor de las piezas, con el objetivo de evitar su corrosión futura. Como hemos visto, en conjunto, las armas de Pinta presentaban poco núcleo metálico, por lo que la inhibición se limitó a las piezas mixtas con decoración de base cobre que sí eran susceptibles de corroerse en el futuro, y a aquellas que mostraban más núcleo metálico (como por ejemplo el umbo de la tumba 109, Figura 10b). Además, los inhibidores como en nuestro caso el Benzotriazol (BTA) [27] al 3 % en alcohol, son productos tóxicos cuyo uso debe reducirse a lo imprescindible, ya que afecta en el momento de aplicar el producto, y la pieza inhibida sigue emitiendo vapores durante mucho tiempo (a pesar de la doble capa de protección que se aplica a continuación).

La última fase de la restauración de las piezas de Pintia fue la protección final, que aportaba una mayor solidez a las armas tratadas. Para ello se aplicaron dos capas, siguiendo un protocolo habitual en piezas de estas características; una primera impregnación de resina acrílica (Paraloid B-72) al 3 % en acetona:xileno y, una vez evaporada, al menos 48 horas tras esta primera aplicación, una segunda capa de cera microcristalina (Cosmolloid H-80) al 10 % en eter de petróleo (White Spirit) [28].

La conservación preventiva es otra fase imprescindible del tratamiento de las piezas, y su mejor garantía de conservación futura. Consiste en asegurar unas condiciones medioambientales adecuadas, siempre muy estables, en especial una humedad relativa baja, que no supere el 40 %, tanto en el embalaje temporal como en las vitrinas en que van a ser expuestos los objetos, o en el depósito final [29]. Asimismo, aunque las piezas de Pintia se encuentran en un estado más estable y resistente tras la restauración, se recomienda moverlas y manipularlas lo menos posible y siempre de forma cuidadosa; por ejemplo, el puñal Villanueva de Teba de la tumba 211 (SECYR 453) nunca debe agarrarse de los extremos sino de la zona intermedia para evitar posibles fracturas.

Conclusiones

La restauración de las panoplias de la necrópolis vaccea de Pintia afectadas por una intensa corrosión del hierro ha resultado muy positiva, y en ello ha sido determinante la elección del protocolo basado en la combinación eficaz y la complementariedad acertada de técnicas tradicionales junto a otra de vanguardia como el láser. Hay que destacar el papel del microchorro con presión regulable de abrasivo de óxido de aluminio, empleado en la fase inicial e intermedia de limpieza, que ha permitido una remoción muy eficaz de la capa más dura de corrosión externa de las piezas que aglomeraba las piedras del terreno. Por su parte, el uso del láser SFR Nd:YAG de 1064nm ha mejorado notablemente la sola acción de los procedimientos de limpieza mecánica y abrasiva, a la hora de descubrir y restaurar con riesgos mínimos la riqueza extraordinaria de estas piezas de armamento, y ha permitido la recuperación de la pátina de magnetita. Tanto la valoración visual, como la inspección microscópica y, sobre todo, los datos objetivos de los análisis LIBS y XRD realizados en estas piezas antes y después de la restauración, validan claramente los buenos resultados obtenidos con los protocolos de limpieza descritos.

Tras esta experiencia de restauración, podemos concluir que la principal ventaja del láser aplicado a hierros muy mineralizados es la capacidad de reducir la corrosión de la forma más inocua posible para la pieza, sin ejercer presión sobre la superficie, sin rayarla y sin fracturarla, a la vez que la estabiliza, transformando los hidróxidos y oxihidróxidos de hierro en una pátina de magnetita, tipo espinela. Esta nueva capa formada por compuestos poco permeables al oxígeno es más resistente ante la posibilidad de una futura corrosión. En definitiva, estas piezas tratadas con láser tendrán un comportamiento más estable en el futuro (por supuesto, siempre que se mantengan unas condiciones de conservación preventiva).

Además, la obtención de esta capa de magnetita es muy deseable desde los principios estéticos porque no altera el color de la pátina y respeta la superficie original del objeto, ofreciendo una lectura más fiel que si se utilizara un microtorno, ya que con el láser se evita el riesgo de erosionar la pátina y "dibujar" o "reinventar" esta película original (Figura 10c).

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CONSERVAR PATRIMÓNIO

ARTICLE / ARTIGO

Estimating the firing temperature of a brick sample from a church *convento* archway ruin in Quipayo, Camarines Sur, Philippines

Estimativa da temperatura de cozedura de uma amostra de tijolo de uma ruína do arco da igreja do convento em Quipayo, Camarines Sur, Filipinas

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Abstract

The firing of bricks is one of the most critical manufacturing steps that affect its durability. It also directly reflects the past artisan's skills and technological knowledge. This study estimates the firing temperature range of a brick material from a Spanish Colonial Period church *convento* archway ruin in Quipayo, Camarines Sur, Philippines. A combination of different analytical techniques, namely energy dispersive X-ray fluorescence (EDXRF), Fourier transform infrared (FTIR) spectroscopy, X-ray diffraction (XRD), scanning electron microscopy with energy dispersive X-ray (SEM-EDX), and thermogravimetric analyzer (TGA), were utilized to determine the mineralogical and chemical composition. From the resulting composition data, the firing temperature of the brick material was estimated to be within the range of 900 to about 1,100 °C and burned in an oxidizing atmosphere. The information derived from this study provides a baseline chemical data of historical bricks that can help assess future conservation works.

KEYWORDS
Brick
Chemical characterization
Firing temperature
Analytical techniques
Philippines

Resumo

A cozedura dos tijolos é uma das etapas de fabrico mais importantes que afetam a sua durabilidade. Também reflete as competências e os conhecimentos tecnológicos do artesão. Este estudo estima a gama de temperaturas de cozedura de um material de tijolo de uma ruína do arco de uma igreja do convento do Período Colonial Espanhol em Quipayo, Camarines Sur, Filipinas. Foi utilizada uma combinação de diferentes técnicas analíticas, nomeadamente a fluorescência de raios X dispersiva em energia (EDXRF), a espetroscopia de infravermelhos com transformada de Fourier (FTIR), a difração de raios X (XRD), a microscopia eletrónica de varrimento com raios X dispersivos em energia (SEM-EDX) e termogravimetria (TGA), para determinar a composição mineralógica e química. A temperatura de cozedura do material de tijolo foi calculada entre 900 e 1100 °C, numa atmosfera oxidante. A informação deste estudo fornece uma base de dados químicos de tijolos históricos que pode ajudar a avaliar futuros trabalhos de conservação.

PALAVRAS-CHAVE
Tijolo
Caracterização química
Temperatura de cozedura
Técnicas analíticas
Filipinas

Introduction

Cultural heritage materials are tangible sources of valuable information regarding the past. Through material evidence, fundamental questions about the traditions, customs, and practices during the olden times can be addressed [1-4]. A common heritage material typically used in old masonry constructions is bricks. Brick making has been practiced since ancient times when raw clays were processed and were either sun-dried or fired in a kiln [5]. This material was widely used in constructing sacred places, fortifications, and secular buildings, among others, where stone masonry is either unavailable or difficult to procure [6]. Unlike other masonry work, brick making involves many human interventions, beginning with choosing the appropriate clay type, adding tempers or not, drying time, and finally, the firing temperature reached either in an open fire pit or in a kiln. These series of processes differ depending on the location, availability of materials, and skills of the artisans, eventually making the entire manufacturing chain variable [7-9]. In the absence of historical records, the chemical analysis of old bricks is an excellent strategy that will generate scientific-based data on their provenance.

In the Philippines, making bricks was believed to have been introduced in the late sixteenth century by the Spanish Empire during the colonial era [10]. Historical records on how bricks were made are fragmentary and were considered local initiatives that are not normally documented. One example was a descriptive account in the late nineteenth century showing that a brickmaker used carabaos (water buffalos) to mix thoroughly equal proportions of three different soil types collected in rice fields and along streams. After mixing, water was added to the mixture, followed by drying, and fired in a kiln or *horno* [7]. Attempts to broaden the historical information on colonial era bricks have been reported in literature through the chemical and mineralogical composition of selected bricks from the provinces of Ilocos Norte, Laguna, and Camarines Sur in the Philippines [8, 10-12]. By investigating the post-firing transformations of the raw clay minerals (aluminosilicates) together with the other non-clay minerals in these bricks, knowledge of the possible technological strategies employed by artisans and the temperature capability of their kilns can be known. Moreover, the firing temperature employed is viewed as a crucial step in any brick-making procedure because it influences the brick's overall microstructure, which eventually dictates its physical deterioration in the long run [13-14].

A rough indication of a historical brick sample's firing temperature can be obtained by investigating the post-firing minerals formed through different analytical techniques, namely X-ray (i.e., energy dispersive X-ray fluorescence – EDXRF – and X-ray diffraction – XRD), microscopy (i.e., scanning electron microscopy with energy dispersive X-ray – SEM-EDX), spectroscopy (i.e., Fourier Transform Infrared – FTIR), and thermal (i.e., thermogravimetric analyzer – TGA). Combinations of these techniques were utilized to estimate the firing temperature (<850 °C) of colonial era bricks from the Philippines obtained at the church convents of Milaor, Camarines Sur and Pagsanjan, Laguna, and the church bell tower of Liliw, Laguna [10, 12]. This temperature estimate was attributed to the absence of calcium silicate mineral phases and traces of calcite in the reported brick samples. In other studies, the presence of diopside, a form of a calcium silicate mineral, was used as evidence to show that the firing temperature is not more than 900 °C [15]. A firing temperature of between 900 to 1,000 °C was ascribed to the production of various old brick samples due to the presence of aluminum-rich spinel mineral phase and the disappearance of feldspars [16]. Furthermore, the existence of undecomposed clay, such as kaolinite, was also reported as a basis that the firing temperature did not exceed 550 °C [17]. By using these approaches, an estimate firing temperature range of a fragment of brick material from a nineteenth century, Spanish Colonial Period church *convento* arch ruin at Quipayo in the Province of Camarines Sur, Philippines, was investigated in this study.

The catholic mission in Quipayo was established by the Order of Friars Minor (OFM) or the Franciscans in the late sixteenth century, making it one of the oldest in the Bicol or *Kabikolan* region. Quipayo was one of the original mission centers of the Franciscans in Bicol and an important coordinating center wherein nearby towns were evangelized, and smaller parishes were supervised [18]. The brick material from Quipayo was analyzed using a combination of EDXRF, FTIR, XRD, SEM-EDX, and TGA, respectively. The result of this study aims to highlight the vital role of chemical analysis in providing scientific data as a prelude to any planned intervention and restoration work. Chemical analysis using various instrumental methods provides information on the structure and composition of heritage materials, which is necessary for crafting proper conservation frameworks suitable for the material. The use of rigorous chemistry techniques is not generally employed in conservation works in the Philippines, and there is a scarcity of published data in the Southeast Asian region. Hence, this paper will serve as a baseline data for more detailed studies on heritage brick materials in the future.

Background of the structure

Quipayo, where the arch ruin of the brick *convento* is located, is within the Province of Camarines Sur and used to be an independent town during the colonial era. Currently, it is under the jurisdiction of the Municipality of Calabanga (Figure 1). From Manila, the capital of the Philippines, Quipayo is almost 300 km away, heading towards the southeastern part of the main island of Luzon.

Figure 1. Map of the Province of Camarines Sur where Quipayo is located within the Municipality of Calabanga. Manila, the capital of the Philippines, is also shown in the map (source: Google maps).

Figure 2. Quipayo church *convento* archway ruin: *a)* archival photo facing east (October 1973, photography: *Parroquia de la Inmaculada Concepcion* parish office); *b)* archway ruin facing east (April 2014, photography: J. C. Cayme); *c)* view of the archway ruin relative to the main church structure (photography: Google maps).

The archway ruin is the only visible part of the historical *convento* that remained (Figure 2a-b). Like any church structure in the Philippines which was originally made of bamboo or wood and thatch-roofed during the early Spanish Colonial Period, the frequency of strong typhoons and other natural disasters perennially destroyed church buildings. As a remedy, renovation works have used more permanent building materials such as bricks [7]. Based on the relative position of the archway ruin to the church facade, it is most likely located on the extreme end of the *convento* either as an extension or part of a series of arches spanning the ground level (Figure 2c). The archway ruin may have supported a deck above, which may have been used as an open area or a service area attached to a kitchen. The area below the arch can be used for either storage or a horse stable [19]. Scant historical records state that the original brick masonry structure was probably built in the early seventeenth century, and the present *convento* ruins were believed to be a nineteenth century construction [20]. The archway ruin's structural purpose and a construction year of about the early to mid-1800s was ascribed by rough comparison with existing church *conventos* in the Philippines having similar architectural features [19].

Materials and methods

Clay brick sample

The brick masonry comprising the archway ruins are composed of bricks with average sizes of approximately 30.48 (length) × 6.99 cm (height) relative to its outer surface. Biological growth is also apparent from the brick's surface, especially those near the base. This is due to the damp and moist environment conducive to the development of algae, molds, fungi, or lichens [21] (Figure 3a). The brick fragment used in this study was collected in April 2014 inside the lower western end side of the *convento*'s archway (Figure 3b-c).

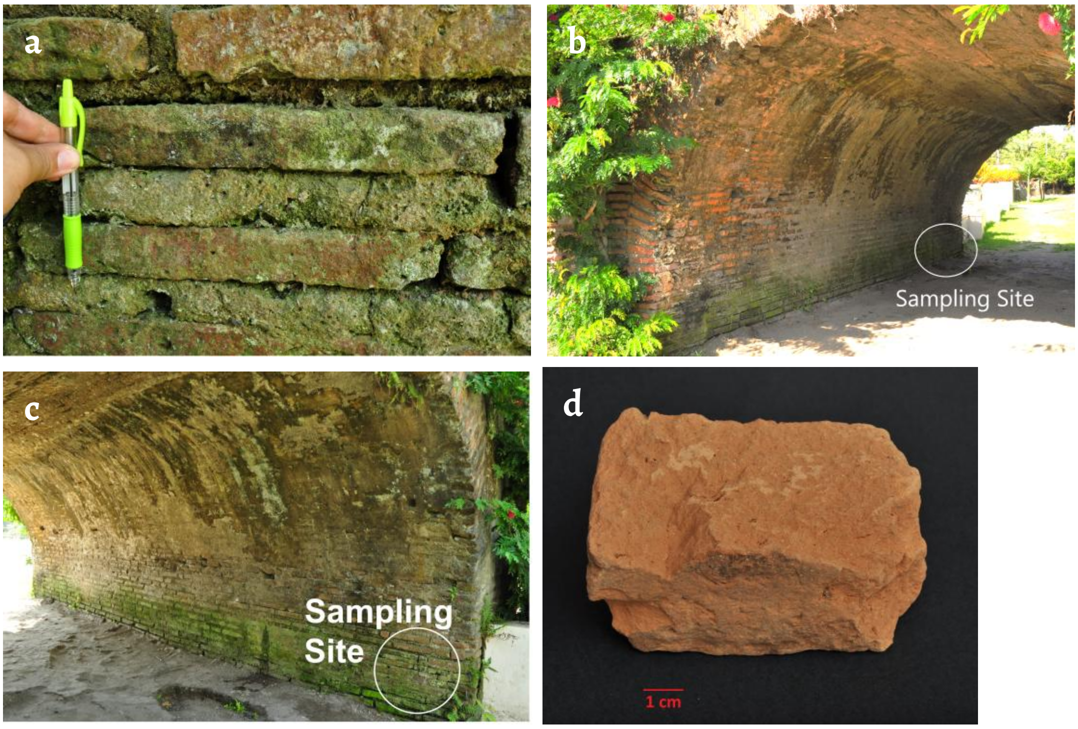


Figure 3. Archway ruin: *a)* Portion of the brick masonry wall where the sample fragment was retrieved; *b)* View of the front portion of the inner archway facing the east side; *c)* View of the back portion of the archway facing the west side (the approximate sampling site is indicated); *d)* The brick fragment, where the representative sample was obtained and tested with the different analytical techniques (photographs: J. C. Cayme, April 2014).

A brick fragment measuring about 7.87 × 3.81 × 2.54 cm was removed from an inconspicuous part of the structure approximately 30.48 cm from the base (Figure 3d) using a hammer and chisel. Extreme care was exercised in obtaining the fragment, and only an adequate amount was taken, which is enough for all the chemical characterizations used in this study. This precaution was practiced to ensure the historical authenticity of the ruins is maintained and preserved. From this fragment, a 16.2 g representative sample was scraped off from the inner portion about 1-2 cm from the surface to guarantee that no contaminants from the surroundings would affect the chemical analyses. This representative sample was homogenized and was dried completely at room temperature (around 37 °C) before testing using EDXRF, FTIR, TGA, SEM-EDX, and XRD analyses, respectively.

Analytical methods

Energy dispersive X-ray fluorescence (EDXRF) analysis

A Shimadzu EDX-7000 Energy dispersive X-ray fluorescence spectrometer was used to determine the elemental composition of the brick sample. A small bulk piece, enough to fit in the polypropylene cup holder, was run through a detailed analysis mode program (about 10 min run time) operated under a vacuum. The collimator was set to 3 mm. After the run, the results were reported as elemental oxides and undetected elements, such as absorbed crystalline water and organic compounds, are labelled LOI (loss on ignition).

Fourier Transform infrared (FTIR) analysis

The brick sample was homogenized and tested for qualitative mineral content and possible organic compounds using a Thermo Scientific Nicolet 6700 Fourier Transform Infrared spectrometer. The homogenized sample was prepared for analysis by using the KBr pellet method with a mixture ratio of roughly one part brick sample to three parts KBr. The pellet formed was scanned repeatedly for 16 times in the mid-infrared region (4000 to 500 cm^{-1}) at a resolution of 4 cm^{-1}. The FTIR spectrum was reported in the transmission mode.

X-ray diffraction (XRD) analysis

The mineralogical characterization of the brick sample was acquired using a Shimadzu Maxima XRD-7000 X-ray diffractometer. The sample was prepared by pressing a homogenized brick powder into an aluminum holder using a glass slide. XRD measurements were carried out through CuK_α radiation at a continuous scan range mode from 3-90°2θ. A scan speed of 2 deg/min was applied. The XRD pattern was graphed, and the mineral phases were analyzed using MATLAB program (The MathWorks Inc., Massachusetts, USA). The possible identity of the mineral phases in the sample was compared to the reference mineralogy database from the RRUFF Project (RRUFF Project, Arizona, USA) [22] and Web Mineral (www.webmineral.com).

Scanning electron microscopy with energy dispersive X-ray (SEM-EDX) analysis

SEM-EDX was employed to visualize the brick sample's microstructural changes and the corresponding elemental composition. A small, smooth cross-section representing the brick fragment was removed from the bulk and mounted into the SEM holder using a double-sided conductive adhesive tape, afterward coated with a thin layer of gold (JEOL JFC-1200 Fine Coater). The SEM image (1,500× magnification) was obtained using SEM/EDX JEOL JSM-5310 and analyzed by an Oxford Link Isis in spot-profile mode. Simultaneously, an EDX elemental profile of the SEM image region was also acquired at a 62 eV resolution.

Thermogravimetric analysis (TGA)

The brick fragment's thermal properties were measured using TA Instruments Discovery TGA55. The sample was placed in a platinum pan (Platinum HT), and the mass (24.96 mg) was weighed automatically by the TGA. The run program was set from 25 to 1,000 °C at a ramping rate of 10 °C/min under nitrogen atmosphere. The weight loss was monitored as the temperature increased.

Results and discussion

Chemical and mineralogical composition

Chemical elements originating from natural clays and their transformation products in the brick material after firing are reflected in the EDXRF and FTIR data shown in Table 1 and Figure 4, respectively. Clays are rarely pure and always include non-clay mineral impurities, most of which come from sand. EDRXF shows that the brick sample primarily comprises of silicates (SiO_2) at 46.51 %, which form part of the elements in quartz, feldspar, and clay phyllosilicates (i.e., clay minerals). Quartz is the primary source of SiO_2 in the sample and supported by the FTIR results showing characteristic infrared absorption bands assigned to Si-O stretching vibrations at 1061 cm^{-1} (υ3; asymmetrical) and 795 cm^{-1} (υ1; symmetrical), and bending vibration at 472 cm^{-1} (υ4; asymmetrical), respectively [10, 12].

From the EDXRF data, aluminates (Al_2O_3) account for 17.54 % of the sample, which forms part of layered aluminosilicates in clay minerals and is also found in feldspars. An indication for montmorillionite type clays in the sample is implied by the SiO_2/Al_2O_3 ratio of 2.66, while a possible mixed layered illite/smectitic clays are indicated by K_2O having < 1.0 % abundance and Fe_2O_3 at 4.0 to 7.0 %, respectively [10, 23]. Studies have reported that montmorillionite is one of the dominant clay types in the Camarines Sur province, where Quiapayo is located [24-25]. Furthermore, another historical brick from a church convent in Milaor which is within the same province also identified montmorillonite as a possible clay type [10]. K_2O and CaO are likely part of the potassium and calcium endmembers of feldspars in the sample and interlayer cations in clays as Ca^{+2} and K^+. A CaO content of 2.16 % based on the EDXRF data, which is less than 6.0 %, signifies a non-calcareous clay was used as raw material [26-27] in manufacturing the brick.

On the other hand, clay minerals, according to the FTIR data, generally have key absorption peaks situated at 3750 to 3400 cm^{-1} for the O-H stretching modes, 1200 to 700 cm^{-1} for the Si-O and Al-O stretching modes, with its corresponding bending modes at 600 to 400 cm^{-1} and metal-OH bending modes at 950 to 600 cm^{-1}, respectively [8]. Since the vibrating groups in clay phyllosilicates are more rigid than the loosely held Si-O group in quartz, overlapping with quartz is usually observed in a brick's FTIR spectrum. Furthermore, absorbed water can also have overlapping peaks, as demonstrated by the broad FTIR peak centered at 3448 cm^{-1} (O-H stretching mode) and 1637 cm^{-1} (H-O-H bending mode) [28].

Iron oxide minerals formed during the firing process are evident from the weak FTIR absorption bands at 542 and 579 cm^{-1}, assigned to hematite (Fe_2O_3) and magnetite (Fe_3O_4), respectively [8]. Besides the FTIR absorption peak for Fe_2O_3 being sharper compared to Fe_3O_4, XRD has also identified hematite as the primary mineral phase in the brick sample (Figure 5). These observations suggest that the brick sample was fired in open air or a perfectly oxidizing atmosphere when manufactured [10]. The total amount of iron oxide (5.05 %) is reported as Fe_2O_3 from the EDXRF.

The content of mineral fluxes which in the case of the sample are the total amount of K_2O, Fe_2O_3, CaO, and TiO_2, from the EDXRF, provided information on the vitrification process during firing. Since the total amount of fluxes (8.18 %) is less than 9.0 %, the raw clay material used for the brick is considered high refractory [27]. This result implies that a relatively higher firing temperature is needed to form a glassy material to bind the minerals together.

Historical accounts show that ashes from plant materials like coconut husks were mixed with clay in colonial period brick-making in the Philippines [12]. These burned plant materials served as a temper to prevent cracking at high temperatures and for the wet clay material to not stick on the brick mould [29]. This would explain the loss on ignition (LOI) in the EDXRF data at 26.34 %, which is attributed to these organic compounds left during firing in the clay matrix and other elements that are outside the limit of detection of the EDXRF. Furthermore, these organic compounds transformed into amorphous carbon ashes, which can be attributed to the large amount of carbon in the EDX analysis.

Table 1. Element oxides composition from the EDXRF

Element oxides	Percentage (%)
SiO_2	46.51
Al_2O_3	17.45
Fe_2O_3	5.05
CaO	2.16
SO_3	0.62
K_2O	0.51
P_2O_5	0.51
TiO_2	0.45
Cl	0.17
MnO	0.12
SrO	0.04
V_2O_5	0.03
ZrO_2	0.01
CuO	0.01
ZnO	0.01
Ir_2O_3	0.00*
LOI**	26.34

* Ir_2O_3 - 0.004 %; **LOI - loss on ignition

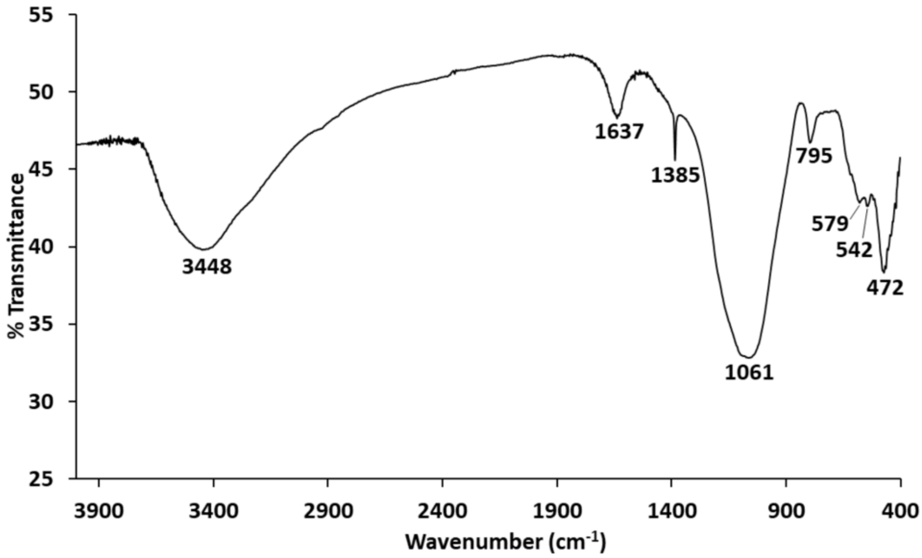


Figure 4. FTIR spectrum showing the significant absorption peaks.

Estimation of firing temperature

The FTIR spectrum (Figure 4) provides insights into the brick material's firing temperature range based on the absorption peak's intensity. The absence of detectable peaks at 1100 cm^{-1} (Si-O stretching) and 915 cm^{-1} (Al-OH bending), but instead, an intense broad peak centered at 1061 cm^{-1} was present, are typical spectrum patterns that resulted from the dehydroxylation and rearrangement of aluminum octahedral sheets in clay minerals. This transformation usually occurs when the material is fired above 650 °C [30]. The shift of the Si-O band toward higher frequencies accompanied by the intense broad peak is also indicative of a firing temperature that has reached 800 °C [31].

The existence of certain mineral types in the brick sample can also be utilized as an indicator of firing temperature. As seen in Figure 5, the transformation of quartz from the α- to the β-structure occurs abruptly at 573 °C [32]. The brick sample originated from a highly sandy montmorillionitic soil; hence the sand content minimized the amount of Ca and Na detected in the EDXRF and EDX. Montmorillonite, which was originally present in the raw clay material based on the EDXRF data, was absent in the XRD pattern, implying a firing temperature above 850 to 900 °C. Montmorillonite decomposes within this temperature range, and this property was employed to ascribe a possible lowest firing temperature limit of about 900 °C [33], consistent with the FTIR results. A similar analysis reported in literature for Spanish Colonial Period bricks in the Philippines from Pagsanjan and Liliw, both in the Laguna Province, have montmorillonite still present in the XRD pattern, hence have a lower temperature range compared to the Quipayo brick sample [12]. The brick sample was also made from a non-calcareous raw clay based on the EDXRF (Table 1) explaining the absence of newly formed calcium-silicate mineral phases [34]. Furthermore, since β-quartz is the only predominant polymorph of SiO_2 in the brick sample, as opposed to the high-temperature variety, which is cristobalite, the highest firing temperature should not exceed 1,100 °C [35].

SEM results (Figure 6) show the appearance of buckling in the clay plates (marked as 1) and starting to coalesce (marked as 2). These developments are classified as an extensive vitrification that typically forms at a temperature exceeding 950 °C in an oxidizing atmosphere [26, 36]. The presence of high refractory fluxes, as determined by the EDXRF data and confirmed through EDX (Table 1), implies that a higher temperature is needed to completely vitrify the brick's microstructure. The SEM did not detect any significant bloating pores, which are usually influenced by the decomposition of calcite or the release of CO_2 in $CaCO_3$. Since the brick sample is non-calcareous based on the EDXRF data and the EDX detected only < 1.0 % of calcium on the representative SEM image, calcite is found to be negligible and not involved in the formation of pores.

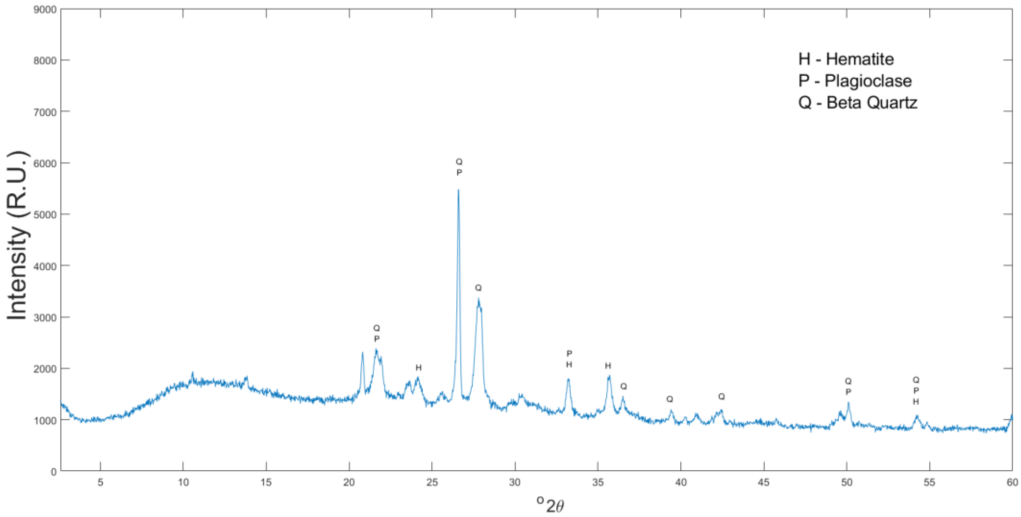
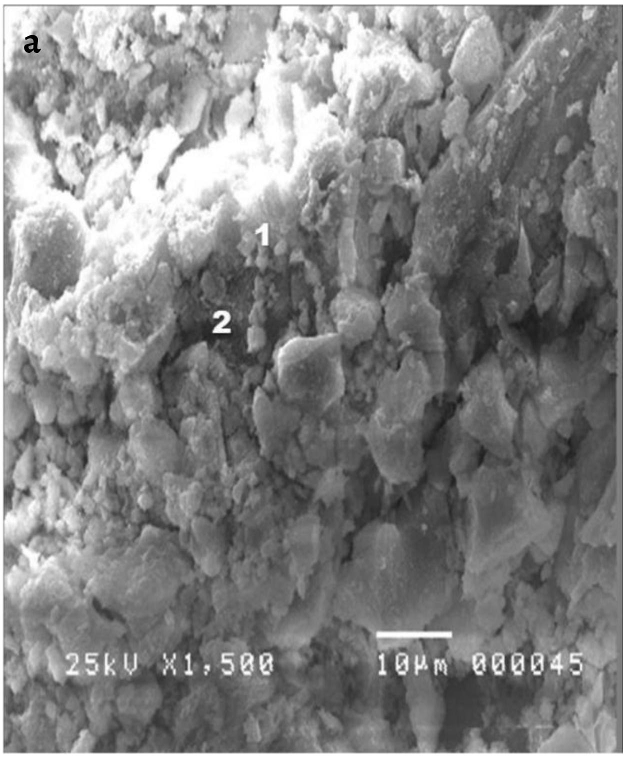
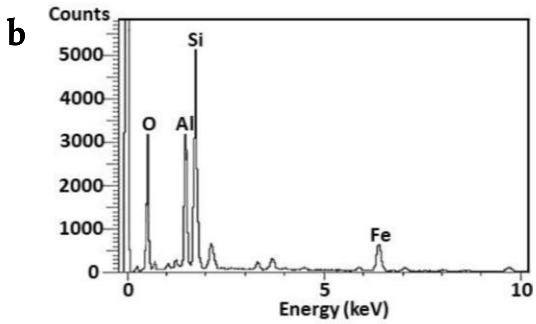


Figure 5. XRD patterns showing the different mineral phases.





Element	Atomic %
Si	11.07
Al	6.55
Fe	2.94
Ca	0.79
K	0.38
Cu	0.31
Ti	0.19
Na	0.12*
Mn	0.09*
Mg	0.04*
O	44.30
C	33.21
Total	100

*trace amount

Figure 6. Brick sample (inner core): *a)* SEM image (magnification of 1,500×); *b)* EDX spectrum and quantitative atomic percentage.

Thermal analysis

TGA methods were used to evaluate the dehydroxylation of clay minerals and the possible presence of calcite or $CaCO_3$ in the brick's microstructure. The TGA graph (Figure 7) recorded a continuous weight loss having a total mass loss of 10.3 %wt. from room temperature (~ 26 °C) to 1,000 °C. Two distinct weight losses were observed from the graph, one at 236 °C attributed to the absorbed hygroscopic water (1.5 %wt.) and another at 356 °C (1.7 %wt.). The latter is due to the combustion of highly volatile organic compounds, possibly from organic residues embedded in the ceramic matrix during the manufacturing process, clay mineral dehydration, and hydroxide decomposition, respectively [37]. There is no indication that $CaCO_3$ is present in the brick sample due to the absence of massive weight loss between 700 to 850 °C.

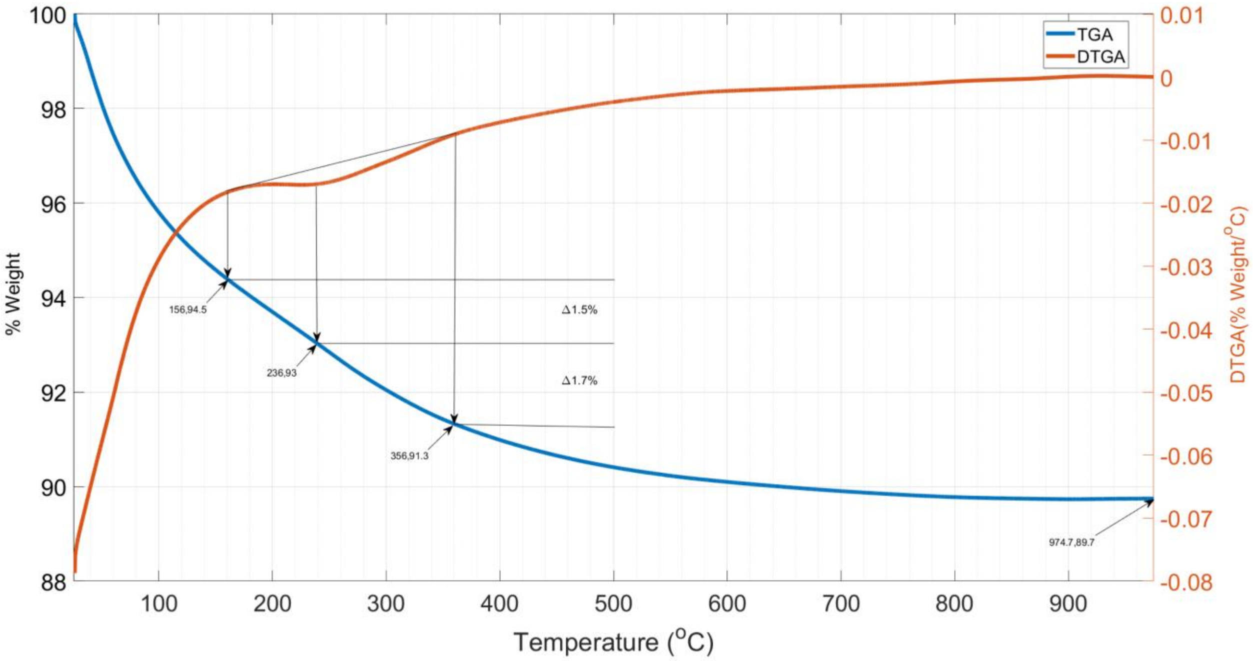


Figure 7. Thermogravimetric data of the brick sample. The blue line corresponds to the weight loss and the orange line is the first derivative plot.

Conclusion

The characterization of the Spanish Colonial Period brick from a church *convent* arch ruin in Quipayo was mainly produced from clay deposits that are non-calcareous, containing montmorillonite as one of the clay types and possible mixed layered illite/smectite clays, which are consistent with the geology of the surrounding soils in the province. Mineral phases, namely hematite, ß-quartz, and plagioclase, have also been identified. Based on the mineralogical content and phase transitions, it led to the conclusion that the firing temperature is within the range of 900 °C to about lower than 1,100 °C. The hematite also implies that the brick was fired in an oxidizing environment. The knowledge of the firing temperature will contribute to the understanding of historical methods, which will aid in crafting proper conservation protocols consistent with the original materials. Increasing the brick sample size in future studies should be done to highlight the variability in the firing temperature within similar colonial period structures.

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CONSERVAR PATRIMÓNIO

ARTICLE / ARTIGO

Conserving Sidi Affane mosque: heritage, building archaeology, and historical challenges

Conservação da mesquita Sidi Affane: património, arqueologia de edifícios e desafios históricos

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Abstract

Heritage preservation requires a personalized approach, with a specific date for each element. For historic buildings, especially religious sites, knowing their history, is crucial to maintain authenticity and guide conservation decisions: complex materials and construction techniques, as well as changes over time, make this task essential. Most of the renovation projects in Constantine since 2014, following its designation as the Arab capital of culture, were carried out after the preparatory works, leaving many mosques closed, including the mosque Sidi Affane. A methodology, derived from building archaeology integrates archaeology and architecture and aims to unveil the mosque's mysteries, offering a holistic understanding of its history through interdisciplinary collaboration. Our analysis of Sidi Affane mosque seeks to establish an archaeological-architectural analysis method based on meticulous elevation readings. This approach not only holds scientific significance but also serves a practical purpose by contributing to the preliminary study for the mosque's restoration and enhancement.

KEYWORDS
Dating
Building archaeology
Mosque
History
Conservation

Resumo

A preservação do património requer uma abordagem personalizada que inclui a datação de cada elemento. Para edifícios históricos, especialmente religiosos, conhecer a sua história é crucial para manter a autenticidade e orientar os planos de conservação: a complexicidade dos materiais e das técnicas de construção, bem como mudanças ao longo do tempo, tornam essa tarefa essencial. Desde 2014, a maioria dos projetos de recuperação em Constantine, após designação como capital árabe da cultura, foi realizada após trabalhos preparatórios, deixando muitas mesquitas fechadas, incluindo a mesquita Sidi Affane. Uma metodologia derivada da arqueologia da construção integra arqueologia e arquitetura, e visa desvendar os mistérios da mesquita, oferecendo uma compreensão holística da sua história através de uma abordagem interdisciplinar. A análise da mesquita de Sidi Affane pretende estabelecer um método de análise arqueológico-arquitetónico baseado em leituras meticulosas de alçados. Esta abordagem científica também contribui para o estudo preliminar do restauro e valorização da mesquita.

PALAVRAS-CHAVE
Datação
Construção arqueológica
Mesquita
História
Conservação

Introduction

Heritage vividly reflects the evolution of society through the ages. Conservation choices, artistic reinterpretations, and intentional additions or losses shape heritage into a dynamic and adaptive phenomenon [1]. This emphasizes the importance of considering not only the inherited legacy but also how we choose to shape and transmit it, weaving a rich and complex canvas over generations.

Over the past two centuries, efforts to preserve and understand historical monuments have been intensified significantly. Multidisciplinary approaches involving archaeology, art history, and heritage conservation [2] have redefined the contours of monuments and influenced our perception of their chronology. By fully understanding heritage history, curators can formulate strategies that respect authenticity while responding to contemporary needs.

Preserving the long-term conservation of monuments requires in-depth knowledge of their different intrinsic heritage values – historical, architectural, ethnological, archaeological, artistic, symbolic, spiritual, identity-related, or memorial [3]. Before intervening on ancient monuments, it is fundamental to identify and analyze these multifaceted dimensions to preserve their historical integrity [4] and cultural value for future generations.

The problem of heritage conservation in the deficiency of historical study

It is essential to have a thorough understanding of a heritage monument/building before undertaking efforts to conserve it, and this involves several aspects. A thorough historical and documentary study is essential before considering the conservation of a monument. The aim is to gather as much information as possible about its history, origins, designers, construction context, and evolution over time [5]. The analysis of the archives, period plans, site reports, and any existing documentation allows us to better understand the genesis of the building, the initial intentions of the builders, and its authenticity. This research also provides information on the successive campaigns of works, modifications, and restorations undergone, helping to understand the transformations and establish a reliable chronology. A thorough study of architecture, construction techniques, and materials is essential before any conservation operation of a monument [6]. This detailed knowledge is essential to understand the behavior of the monument and identify its peculiarities and weaknesses, without compromising its integrity.

The built heritage, consisting of emblematic monuments, historical buildings, and religious buildings, is a valuable tangible testimony to past civilizations. These structures embody much more than just materials, they reflect the lifestyles, know-how, social, cultural, and architectural evolutions that have shaped our history. However, many historical buildings suffer from a crucial lack of written or archival documentation of their origin, construction, and evolution over time. This documentary deficit casts a shadow over efforts to preserve and restore built heritage. Without reliable sources, restoration campaigns move into the unknown, making crucial decisions without the necessary information. This situation exposes the monuments to risks of denaturation. Well-intentioned interventions can then lead to irreversible alterations, distorting the memory and integrity of these unique witnesses of the past [7]. The lack of documentation threatens the faithful preservation of the rich heritage embodied by the built heritage.

Preserving Algerian heritage: the challenge of incomplete documentation

Algeria has initiated several operations to restore its heritage, some of them successful as the rehabilitation of the Kasbah of Algiers and the Ahmed Bey Palace in Constantine [8]. These iconic monuments have been restored and reused for cultural or tourist purposes. However, many projects remain unfinished, leaving partially restored buildings abandoned. To protect this rich heritage, Algeria relies on Law 98-04 establishing the legal basis for the preservation of built heritage. From this law derives the permanent plan for the safeguarding and development of protected areas (Plan permanent de sauvegarde et de mise en valeur des secteurs sauvegardé – PPSMVSS [9]), which establishes a strict regulatory framework for the conservation of historic buildings, the renovation of old neighborhoods and urban development, while guaranteeing the integrity and authenticity of the monuments.

The PPSMVSS of Constantine's old city outlines strategies for heritage preservation, including creating cultural spaces, museums, and tourist circuits. Financial incentives are offered to encourage private owners to restore old buildings, aiding in the transmission of centuries-old heritage. Despite legal protection, challenges persist, such as deterioration from age and weather, as well as inadequate maintenance. Rapid urban growth poses further risks, potentially leading to the destruction [10].

As part of the accompanying program of the event *Constantine, capital of Arab Culture 2015*, 11 mosques including the Sidi Affane mosque and eight zaouis are concerned with rehabilitation work, launched in 2014 and overseen by the National Office for the Management and Exploitation of Protected Cultural Property (Office de Gestion et d'Exploitation des Biens Culturels – OGEBC). The Sidi Afane mosque in Constantine is considered the oldest mosque in the city, according to the local community; it was built before the arrival of the Ottomans (this age hypothesis is based on word of mouth by the inhabitants without a thorough scientific study). The mosque is spread over a surface of 262 m² [11] (Figure 1a), consisting of a single level, it consists of:

- two separate prayer rooms (1, 2): the separation of prayer rooms for men (Figure 1b-d) and women emphasizes the tradition observed in mosques;
- El maidha (3): strategically located on the left side of the main access;
- Bit el imam (4): this room, positioned at the back of the patio, could serve as a space dedicated to religious and educational activities;
- The central courtyard (5): the heart of the mosque;
- The Maqsoura (6): this area is reserved or fenced, and the Minaret.

Between 1837 and 1915, the Sidi Affane mosque underwent a significant transformation into a school by the General Council of Constantine province, justified by the distance from the existing school in Bab El Kantara. The prayer hall was demolished to create classrooms, the outdoor space was redesigned for a playground, and the minaret was removed due to collapse risk [12, p. 1]. Despite these changes, remnants from before 1863 remain, offering insights into the mosque's original features before its colonial-era conversion. The French later rebuilt the minaret to its original design after 1915.

Despite the great heritage frenzy that there was in 2014, little significant effort was made to study the buildings to be restored, which led to the failure of this project. Together with the pre-arrival work, the study phase was initiated. Once the study report had been submitted, the OGEBC requested a review of the study because the historical-archival analysis component had not been established [13]. This has led to administrative conflicts, resulting in the closure of the place of worship to this day. This situation led to an almost total degradation of the architectural structures and the constructive components of the religious building. What are the long-term implications of the mosque's conservation when no in-depth study has provided any justification for the actions undertaken to transmit history and culture to future generations?

This lack of conservation and understanding of its history exposes the mosque to an increased risk of deterioration and loss of authenticity. The location of the mosque in the heart of the historic city of Constantine accentuates these challenges, as it faces increased urban pressure and a need for preservation in the face of modern development. What are the alternative strategies and approaches used to compensate for the lack of information during the conservation of this heritage?

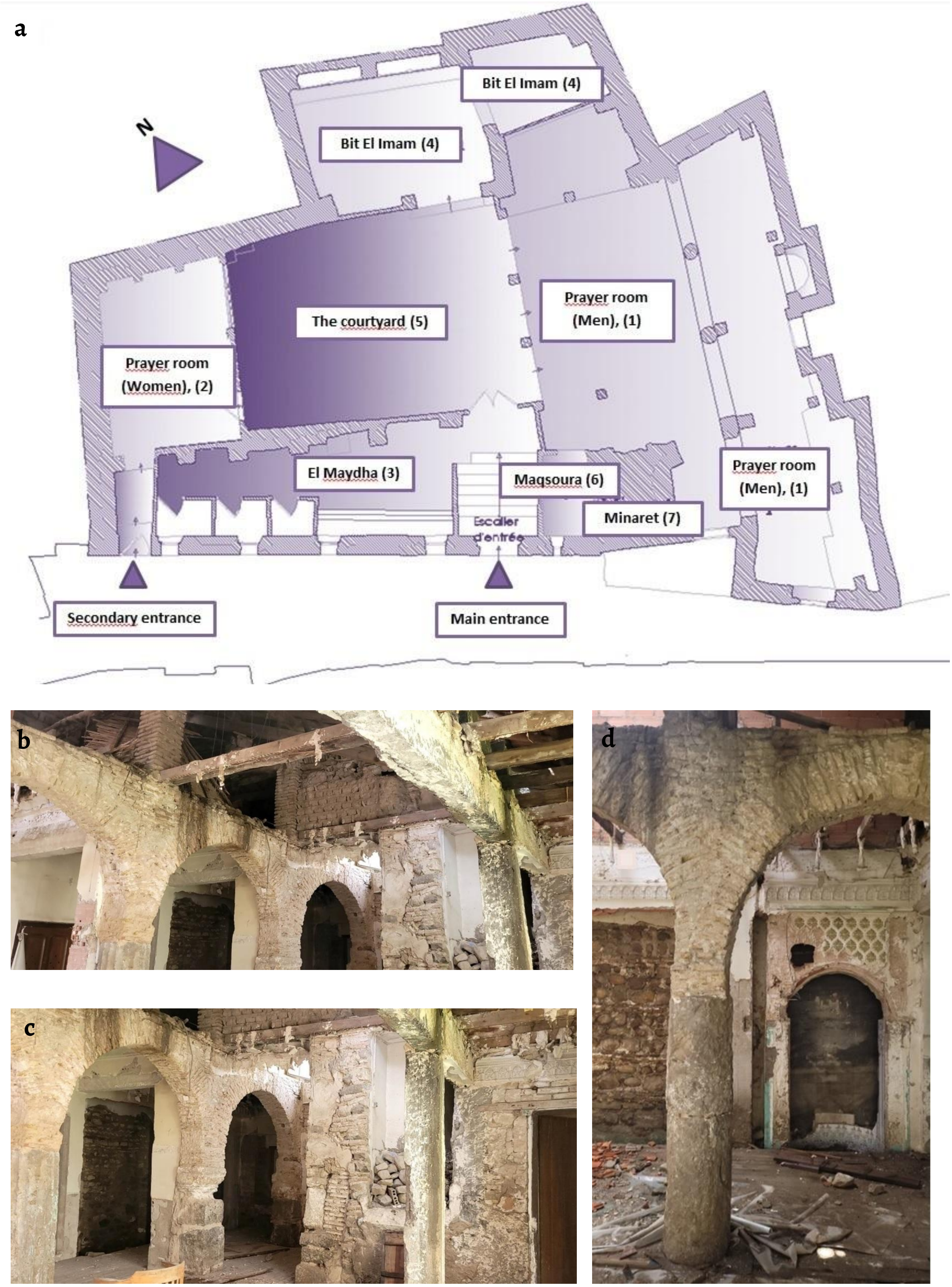

Figure 1. Presentation of the mosque spaces: *a)* architectural plan; *b)* the dome; *c)* prayer room; *d)* mihrab (photography: authors and BET ZIANI).

This documentary deficiency was confirmed after consulting the municipal archives of Constantine, the national archives in Algiers, the national archives, the national library of France, and the Library of Contemporary International Documentation, all in Paris.

The article aims to develop an archaeological-architectural analysis methodology focusing on elevation readings for mosque restoration, linking historical architectural developments to contemporary practice, and emphasizing examination, registration, and maintenance techniques. It aims to contextualize the mosque's appearance by studying construction techniques, space, and stylistic influences while achieving analytical coverage to identify architectural characteristics, technical elements, and chronological phases of construction.

Methodology and applied techniques

The proposed methodology (Figure 2a) is based on an innovative approach combining different methods [14] previously used independently on various buildings, each with different objectives compared to the current research. To understand the suggested methodological approach, it is essential to recall the epistemological foundations of building archaeology [15], the monograph [16], and the heritage diagnosis [17]. Those are three complementary approaches in the study and conservation of built heritage, each with its specificities, strengths, and limitations. Together, they provide a deep and nuanced understanding of historic buildings but also pose unique challenges in their application. The holistic approach to built heritage conservation [18] involves several interconnected disciplines, each contributing uniquely to the understanding and preservation of historical buildings.

Building archaeology is one approach that examines a building's materials, construction techniques, and evolution over time. This method offers insights into the historical journey of a building, allowing experts to understand its past changes and original design. However, building archaeology can involve physically intrusive methods that may damage the structure. Additionally, interpretations of material data can be subjective and lead to varied conclusions. This approach is also noted for being expensive and time-consuming, requiring input from various experts.

A monograph analysis in heritage conservation focuses on the building's history, architecture, and cultural context. This method provides a narrative framework that enriches archaeological discoveries within the built environment. The limitations of a monograph include its dependence on potentially incomplete or biased sources and a perspective that may be narrowly focused due to the author's specialization.

Lastly, the patrimonial diagnosis assesses the condition of the building, identifies conservation issues, and recommends preservation strategies based on a comprehensive understanding of the structure's historical and current state. This diagnostic process is crucial for planning effective interventions. However, it tends to concentrate primarily on the building's current physical state and might overlook the historical and cultural significance of certain elements, which could be vital in a holistic conservation strategy.

Each approach has its limits, underlining the importance of a multidisciplinary method for a complete understanding and conservation of architectural heritage. Hence the proposal of an archeological-architectural methodology that represents a multidisciplinary approach combining the methods of archaeology and architecture to decipher the mysteries of these historic buildings. By its transdisciplinary nature, it offers a holistic approach to deciphering the history of buildings even in the absence of reliable scientific resources. It combines the expertise of various fields to rebuild the puzzle of these monuments, thus allowing a better understanding of their past and preserving their heritage for future generations.

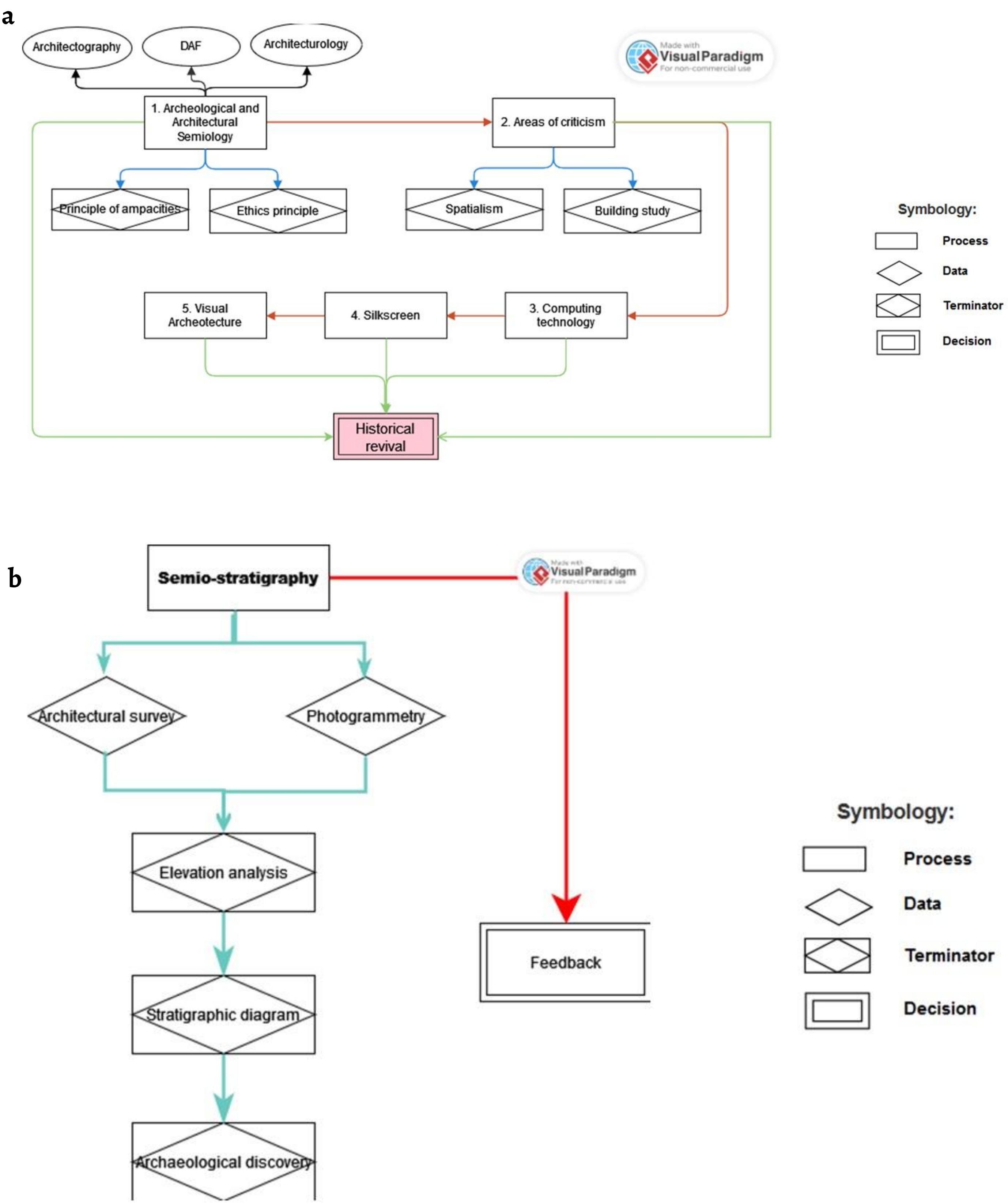

Figure 2. Diagram of the: *a)* archaeological-architectural methodology applicable to historic monuments; *b)* details of the semiostratigraphy.

The method of investigation enables an in-depth reading of the buildings from their base. It focuses on understanding the architectural evolution of buildings using stratigraphic analysis, offering a virtual reading of the different construction phases. This approach makes it possible to virtually reconstruct architectural changes over time (in 2D and 3D).

The concept of semiological architectural-archaeology integrates the fields of semiology and stratigraphy [7] to examine the layering and boundaries of building materials. This approach, known as semiostratigraphy (Figure 2b) [19], utilizes drawn contours to meticulously document the structure's history, aiding in further analyses and interpretations.

The principle of ampacities extends from semiostratigraphy, using the analysis of a building's layering and boundaries to hypothesize about the influential factors behind its construction and evolution. In terms of ethical considerations, the ethics principle in architectural archaeology emphasizes the importance of breaking down details to form a complete picture, weaving between micro and macro perspectives to create a synthesis.
Area of criticism typically focuses on the intersection between architecture and spatialism, exploring how architectural spaces influence and are influenced by human behaviors, social practices, and cultural contexts. This area critically examines the dynamic interactions within architectural environments.

Computing technology in architectural archaeology offers an impartial method to interpret structural changes in old buildings, avoiding biased assumptions about their causes. The concept of silkscreen in building archaeology is studying materials like stone types and sources are vital for understanding construction methods, trade networks, and builders' choices.

Finally, visual archaeo-architecture is similar to ichnology. It examines destruction modes and preserved remnants to uncover the history and context of lost artwork, considering both general and iconic details.

This fragmented and detailed approach offers a rich and contextualized reading of the history of the Sidi Affane mosque. By breaking down the building, part by part, by analyzing each architectural element and each aesthetic detail, we can reconstruct the complex puzzle of its evolution through the ages. This allows us to better understand not only its architectural history but also the cultural diversity that marked its development, thus offering a valuable testimony to the historical and artistic evolution of the region.

Table 1. Tools and techniques used in the proposed methodology for historical research.

Method	Tools used	Definition	Contributions
Architectural survey [20]	TOPCON GTP 3005S tachometer with 360° automatic target recognition system for 2 mm + 2p pm/km and 5" distance accuracy, 0.5 mgon for vertical and horizontal angles Faro X130. It has a 360°x270° scan field	Detailed documentation of the architectural features of a building, including its dimensions, layout, and ornaments	Helps to understand the evolution of structure, styles, and construction techniques over time
Photogrammetry [21]	Nikon D750 NU 80K camera Agisoft Metashape 2.0.4, meshroom, meshlab, and cloudcompare	Technique to reconstruct detailed 3D models from a set of photographs	Helps visualize and analyze architectural features in their spatial context
Elevation Analysis	Autocad	Meticulous study of the elevations (facades, walls) of a building, aimed at identifying the different phases of construction, reworking, and remodeling	Allows to understand architectural and stylistic transformations as renovations and additions
Stratigraphic diagram	The construction of the stratigraphic diagram was carried out analogically. The Stratifying software [22] did not take into account the intrinsic architectural logic in the sequencing of stratigraphic units. The layering of strata does not necessarily reflect the relative chronology, as the upper stratum is not systematically the oldest	Graphical representation of the archaeological layers of a site, showing the chronological relationships between the different strata	Helps to establish a relative chronology of human activities on the site and identify construction phases
Archaeological finds [23]		Objects, structures, or artefacts found during archaeological excavations, provide information about past life	Provides material evidence of human occupation, cultural practices, and historical events

The proposed analytical approach acknowledges inherent epistemological limitations despite its rigorous definition and relevant results. It strives for objectivity to avoid interpretative biases, yet acknowledges the subjective imprint inherent in scientific investigation. Efforts to minimize hermeneutic drifts and uphold scientific objectivity are crucial, especially considering the complex interplay between materiality and architectural symbolism. Interpretations may remain speculative without additional historical documentation, necessitating critical and comparative analysis. Visual renderings may vary based on available documentation, challenging historical accuracy, and emphasizing the importance of rigorous methodologies to minimize interpretative subjectivity.

Results and discussion

The comprehensive study of Sidi Affane Mosque delves into overlooked facets of its history, highlighting details and events absent in traditional narratives, enriching academic understanding, and contextualizing its regional significance.

The architectural survey

Survey points of the Sidi Affane mosque's architectural elements are recorded in XYZ coordinates using the NGA system to prevent errors, with double readings and references for accuracy. Canvas calculations are performed with *COVADIS* software based on site size and configuration [24].

Some details, the importance of which is particularly important, will be meticulously recorded by hand (Figure 3b-c). Beyond the numerical dimensions that the machine will be able to capture, the manual reading of the detail will allow a more refined analysis (sanitary state, materials, chronology).

These surveys (Figure 3a and Figure 3d) were carried out jointly with the design office: Ziani-Mahindad group, under the direction of Boussouf Faima. They are an initial source of a wide range of information that will serve as the initial basis for this study. Indeed, these precise data provide the exact dimensions of the structure, raising the question: why is the prayer hall positioned at a height of 1.20 m from the ground? In addition, they allow us to observe one of the distinctive and symbolic elements of mosques: the mihrab. The latter is distinguished by its deviation from its traditional position; unlike the typical alignment with the dome, there is a clear shift on the south wall.

The hypothesis suggests the initial alignment of the mihrab with the dome's axis, supported by dimensions resembling traditional mihrabs in an adjoining room (Figure 4), yet challenges arise regarding the southeast orientation of this religious element and its adherence to the proper prayer direction over time.

Archival documents referring to the mosque are extremely rare. They include cadastral plans of the town dating from before and after the French conquest of 1837, the Constantine waqfs register drawn up under Salah Bey [25], the work of the Constantine archaeological society [26], the minutes of the general council of the Constantine province in the Constantine department [27], as well as reports documenting recent discoveries made inside the prayer hall in 2014 [28]. The initial state of the mihrab is not discussed in previous documents; this hypothesis is derived from the material traces found on the spot.

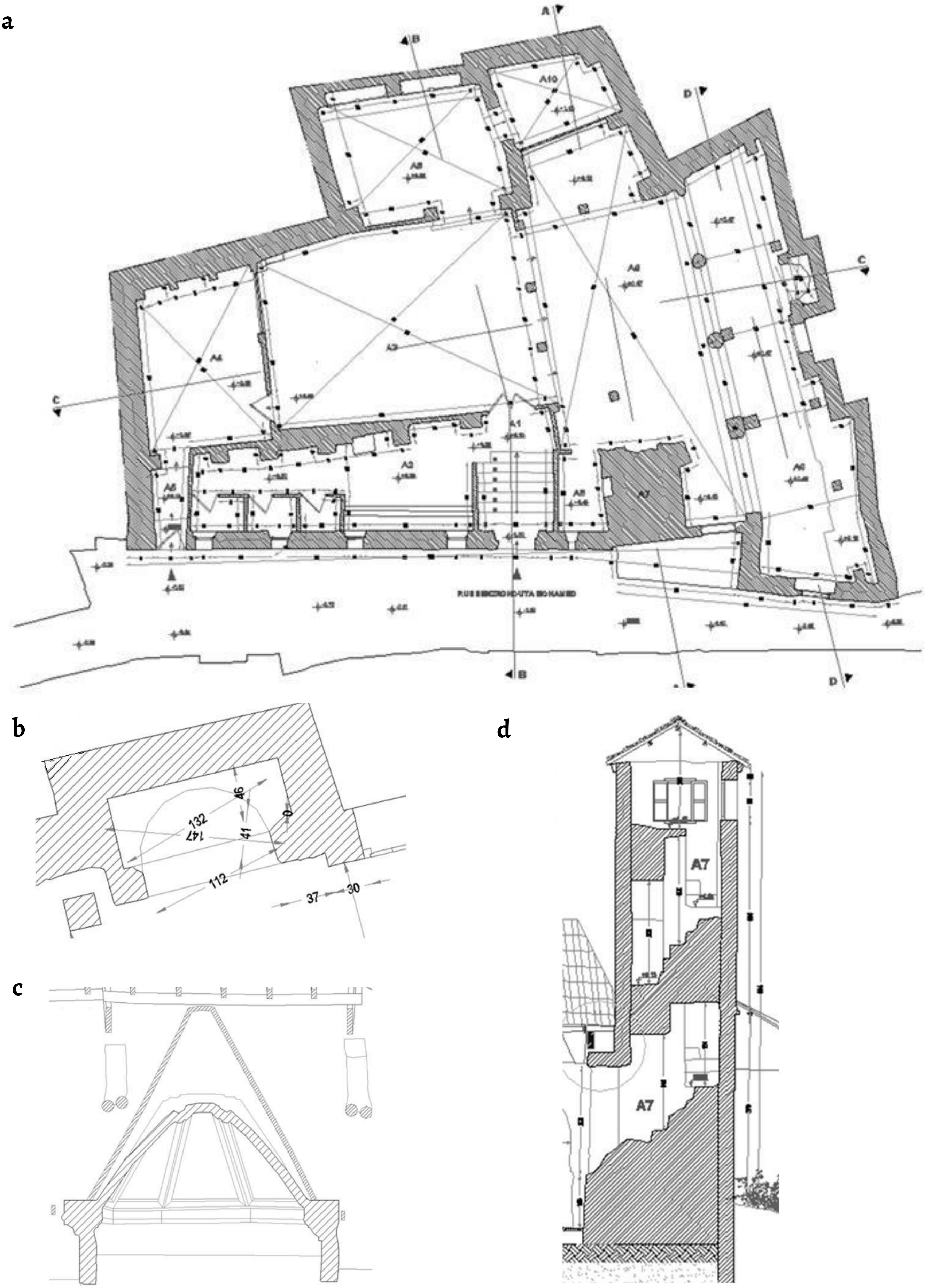

Figure 3. Survey of the Sidi Affane mosque: *a)* general view; *b)* the mihrab, *c)* the dome; *d)* the minaret (sources: authors and BET ZIANI).

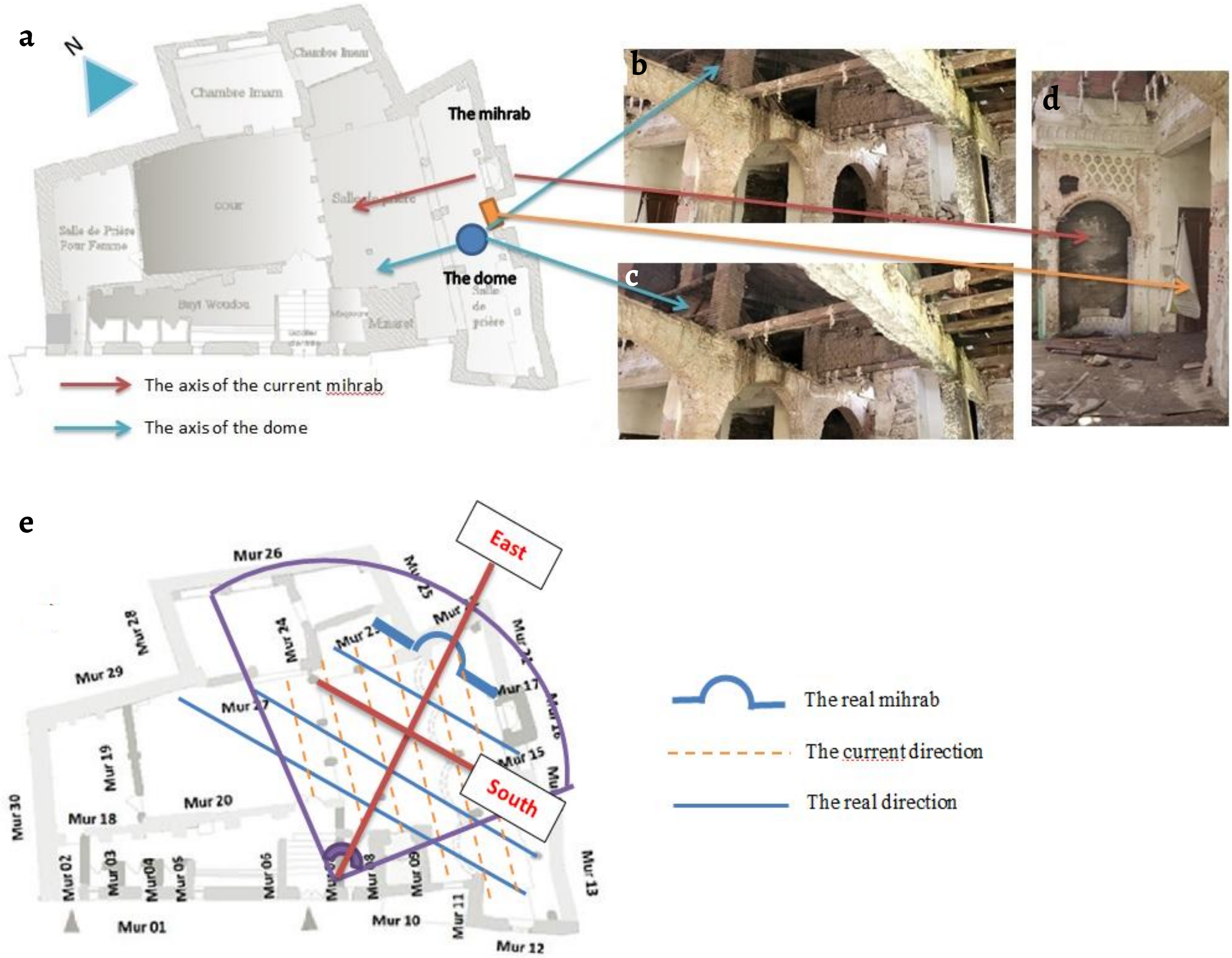

Figure 4. Mihrab: *a-d)* Arrangement of the mihrab axis with respect to the dome axis; *e)* and its real orientation.

The photogrammetry of the mosque

Photogrammetry was applied to the Sidi Affane mosque using *Agisoft Metashape*, *Meshroom*, *Meshlab*, and *Cloudcompare* software to generate accurate 3D models of this heritage structure. Particular attention was paid to the wall of the mihrab, which is difficult to access. Image processing resulted in a densified cloud of about 3 million points for this elevation, leading to detailed orthophotography. The main objective was the high-resolution 3D digital documentation for in-depth architectural analysis, recording of the current state, support for further studies, and heritage valuation.

By transposing the architectural photogrammetry project to the Sidi Affane mosque (Figure 5), we obtain:

- Data acquisition: the camera covers multiple wide and close-up overlays of at least 60 % between each shot to account for complex volumes;
- Data processing: alignment of photos into four separate blocks, manual filtering of outliers on surrounding vegetation areas (those installed by abandonment); final mesh generated with a density of 2 cm;
- Final results: 3 million point dense scatter; textured 3D model;
- Analysis and discussion: comparison to existing 2D plans: maximum deviations of 5 cm noted. Clarity of constructive details is acceptable under these conditions. Detection of mihrab degradation zones to quantify their replacement.

Figure 5. Result of densification points of the prayer room from different angles: *a-b)* taken from CloudCompare; *c-d)* taken from Meshroom.

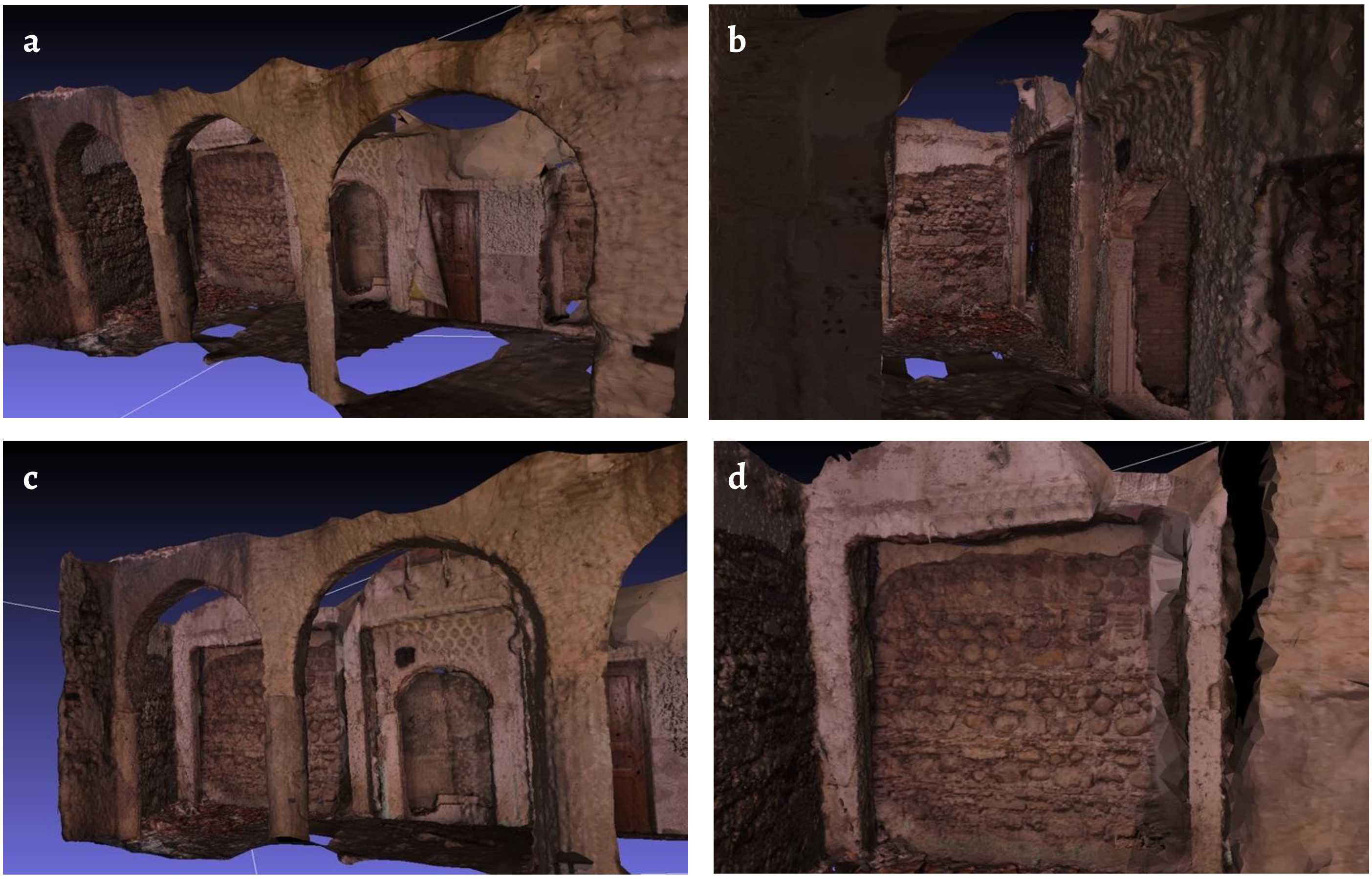

Figure 6. Textured 3D models of the south wall of the prayer hall: *a-c)* at different angles; *d)* detail on the corner.

Photogrammetry of the mihrab wall of the Sidi Affane mosque generated a detailed 3D metric data set. The final 3D model of this section contains more than 3 million points with an overall accuracy estimated at ±5 cm, which meets the expected specifications. The orthophotos produced for the inner facade of the mihrab have a pixel resolution of 5 mm, enabling details to be visualized precisely. Some areas, such as the upper part of the wall, could not be fully documented, due to the inaccessibility of certain camera angles.

This photogrammetry applied to the Sidi Affane mosque will allow its detailed architectural analysis (elevation analysis) (Figure 6). By meticulously capturing the complex geometry of this ancient structure, including the wall housing the mihrab, it has created a faithful virtual model for archival purposes and in-depth study of the transformations undergone over the centuries. This 3D representation facilitates the contextualization of the recent archaeological discoveries of the intramural necropolis and the future development of immersive cultural mediation experiences around this building.

Elevation analysis

The study of facades encompasses areas of exploration defined by their link with reality, whether tangible objects, traces of human activities, or symbols. We distinguish the artefacts [29], the clues, that is to say, the traces left in the building by human actions, (the testimonies), all these formally unclassifiable archaeological facts that are the punctual result of a specific action and preserve the memory of a minor or major event or decor that enters this part of the history of art and that participates in the archaeological analysis either for the dating.

On the wall of the mihrab persists the same method of construction, the Opus Mixtum, but with a contrasting visual diversity on both sides of the mihrab. To the left of it, the load-bearing walls consist of two distinct materials: solid brick and rubble, forming a wall of a thickness varying between 60 and 70 cm. This structure consists of several rows of rubble, separated by two rows of solid bricks, with a spacing of 60 to 80 cm between two successive rows of the same material. Lime mortar ensures the cohesion of these elements. However, on the right side, disturbances in the filling are noticeable at the location of the old mihrab. The difference in materials appears distinctly: alternating between bricks and stones, with interruptions in masonry: differences in the types of materials used at different levels of an elevation could indicate distinct phases of construction. The upper part of the wall is very distinct: a much later brick. The identification of the date thanks to the decorative elements is difficult because they come from reuse.

Stratigraphic diagrams

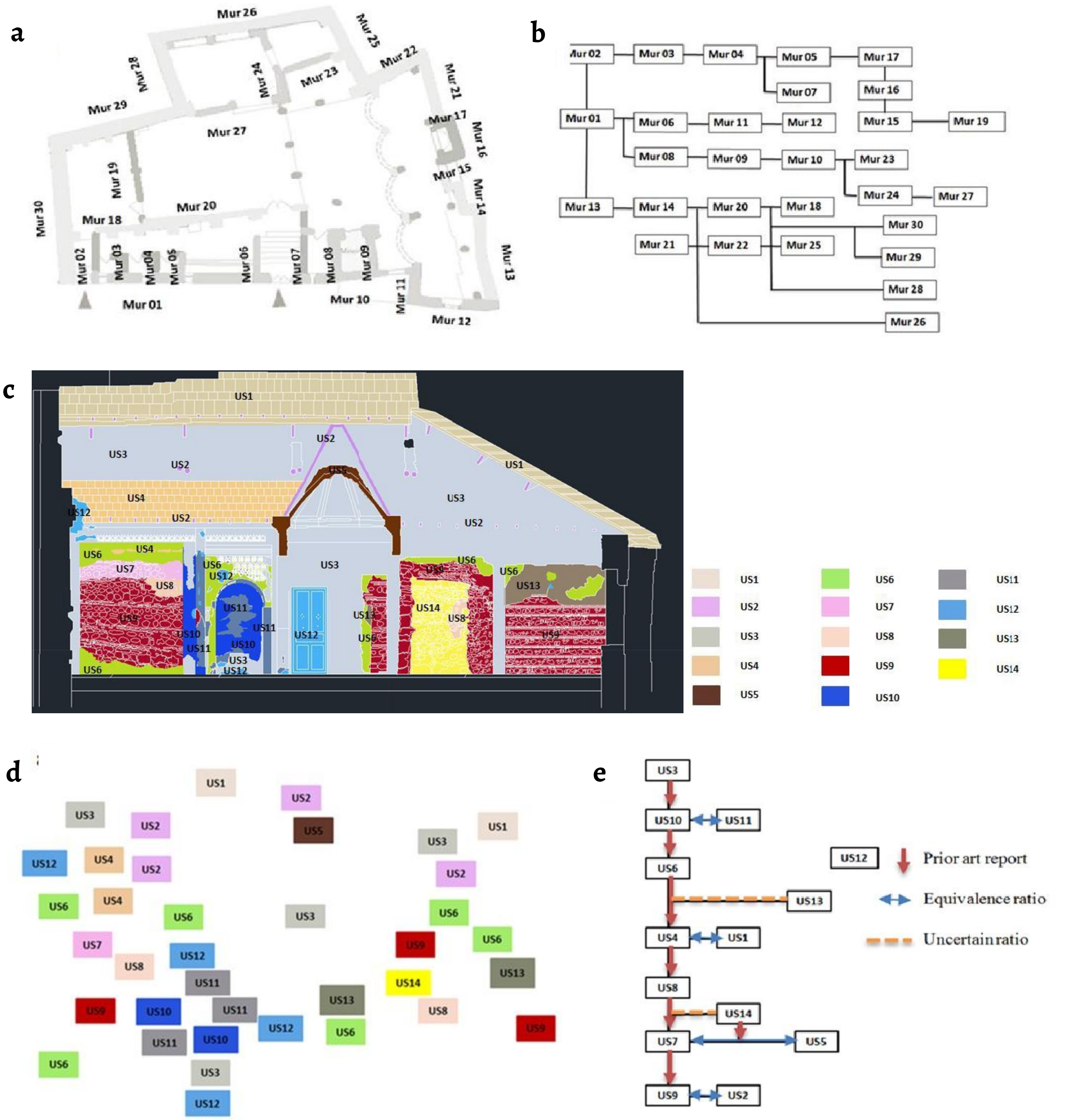

Figure 7. Walls of the Sidi Affane mosque: *a-b)* localization; *c)* identification of Us on walls 13, 14, 15, 16, 17, and 21; *d-e)* Us diagrams.

This archaeological stratification enables the phasing of the edifice's structural development and the interpretation of its primary building campaigns through the identification of construction units and their temporal relationships (Figure 7). Following on from the analysis of the mosque, the south wall was studied in depth, revealing evidence and marks from three distinctly different periods. Interface analysis led to the identification of 13 distinct positive layers and one negative layer (US12), potentially the result of deliberate demolition or modification to create an opening.

The graphic representation aims to detail the structural complexity of a single wall by highlighting its evolution and diachronic aspect. This approach allows us to understand its dual nature, both physical and historical, from its origins.

Archaeological findings

According to the work of E.Mercier in 1902 [30, pp. 43-96], an inscription was found inside the prayer hall, recorded under No. 55, written in Barbary characters carved in relief on the head Machhed (epitaph) of a wooden tomb 0.30 m in diameter. Here is the text with its translation:

بسم الله الرحمان الرحيم	In the name of God's mercy
هذا ضريح الولي الصالح	This is the mausoleum of a good guardian,
القطب الناصح سيدي جامع بن علي توفي	Consulting Pole Sidi Jammeh Ben Ali,
رحمه الله تعالي في اخر مولد محمد	May God's mercy come at the last birth of Muhammad
صلي الله عليه و سلم	Pray God upon Him and Peace,
١٢٤٩ سنة	Year 1249.

This date is very important in the historical genesis

In 2014, during the first restoration works of the mosque, a major archaeological discovery emerged under the floor of the prayer hall, at a depth of 40 cm. This discovery included several sepulchres (Figure 8) containing bone remains and ceramic fragments. In the preliminary report of the local national museum, it is specified that three of these tombs were erected using terracotta bricks, with lime-coated foundations, covered with slabs made of stone and terracotta. One of these tombs was 1.75 m long and 0.54 m wide. A team from the National Centre for Archaeological Research (NCAR), dispatched by the Ministry of Culture to conduct expertise, noted in its June 2014 report that these graves were aligned from west to east and that there seemed to have been a reuse of some of them for other burials.

The report of the rescue search, carried out between late June and mid-July 2014 by another team from the same establishment, presents limited information. This excavation allowed the discovery of about thirty sepulchres, facing northwest, as well as several unidentified tools, although these discoveries were not considered particularly significant.

What is certain is that among these graves, some are Muslim, and the direction of the mihrab towards the south could have distorted their orientation. In Islam, during funerals, it is common to bury the deceased in alignment with the Qibla (direction of Mecca) [31]. If the mihrab, which indicates the direction of prayer, is facing south instead of the Qibla, this could have affected the alignment of the graves of the deceased faithful.

Figure 8. Tomb discovered inside the prayer room (photography: NCAR, 2014).

Visual archaeotecture

Image archaeology for this mosque involves studying traces of destroyed or modified elements to potentially reconstruct the original architectural and decorative programs. For example, the southern part of the mosque, having been the first object of study, reveals a remarkable case study at the level of the mihrab part. One evokes a questionable form to describe a partially destroyed figure, retaining recognizable iconic monèmes or residual elements of its original structure.

On the southern wall of the building, to the right of the current mihrab niche, a striking contrast is observable: although the contours of the latter remain discernible on the elevation, the canonical influence of Islamic religious architecture seems curiously lacking. This deficiency is manifested by the blatant absence of moucharabiehs with characteristic geometric or arabesque floral patterns, the absence of zelliges – these famous glazed and glazed ceramic tiles – and even the total absence of any complex polychrome architectural decor. This architectural singularity raises intriguing questions about the evolution of aesthetic canons and craftsmanship in this region over time, perhaps suggesting various non-native cultural influences or major changes in vernacular artistic practices over time.

Historical genesis

The Sidi Affane mosque provided rich information (Figure 9). It is the result of constructions, ruins, and successive modifications and is the result of constant adaptations of the place to the needs of its occupants. This archeological-architectural study leads to certain conclusions and opens the way to other questions.

Occupied at least since 1249, the site of the mosque is installed inside the lower Souika. The care taken in the implementation of masonry (walls, basement) indicates that the primitive building has a typical architecture of the Hammadite period, characterized by its simplicity and sobriety, favoring simple forms and minimalist decorations, often in stone, indicating structural strength. The current structure retains features of this period, presenting an organized arrangement for prayers and architectural elements reflecting the mastery of stone at that time.

Figure 9. Sidi Affane mosque: *a)* chronological plan following the construction of the walls; *b)* the restoration of the interior of the mosque before 1830; *c)* restitution of the mosque environment with its accesses.

The mosque underwent a succession of alterations and destructions. The results of this research made it possible to highlight several states of the building. Unfortunately, they are difficult to relate to the events mentioned in the history of the city of Constantine. Although it is tempting to associate certain similarities with the Djemââ Lekbir [32] (the Great Mosque built in 1135) no physical trace can confirm this hypothesis.

On the other hand, what reinforces it is the similarity between the two mosques. The columns of the prayer rooms come from the reuse of ancient barrels and capitals and those of the mihrab remain purely Hammadid [33]. The two naves of the mihrabs are out of alignment with the prayer hall due to urban renovations during the French occupation. The facades and minarets also date from this period, but the location of the minarets may be original. They have a square base.

That said, the Sidi Affane mosque is poor in architectural elements and noble materials and it does not appear on most historical maps (contradictions with the list of waqf mosques where it is cited). Where it appears, it is associated with a courtyard (overlapping plots). Just behind, there is a sabat and a dead end that directly overlooks this courtyard [34] of the mosque and the axis of its entrance, or a passage that directly overlooks the main street from where the reason for its elevation. In its configuration and size, there was only the prayer room, the rather spacious backyard, the minaret, and the mihrab placed under the axis of the dome.

From this analysis, a chronological plan is proposed as well as a restitution of accesses.

While the stratigraphic analysis provides a valuable relative chronology, its limitations must be emphasized. The numerous repairs, re-workings, and additions of new mortar and cement observed in the structures inevitably disrupt the stratigraphic reading, introducing residual units and complex rearrangements in the sequence.

Conclusion

The comprehensive study of the Sidi Affane mosque has resulted in a detailed architectural documentation, providing new avenues for analysis and comprehension of this heritage site. Utilizing photogrammetry, particularly for the mihrab wall, has yielded a comprehensive 3D model, serving as a robust foundation for future research and the enhancement of the mosque's valorization. Examination of elevations unveiled notable disparities in building materials, hinting at distinct construction phases. Embedded within an epistemological framework, this architectural inquiry strives to advance understanding of the mosque within its regional context.

The determination of the mosque's age holds significant implications for Constantine's historical narrative and broader regional development. This insight facilitates a deeper comprehension of architectural evolution and cultural dynamics over time. Furthermore, the study evaluates the applicability and limitations of analytical methods on such structures, prompting methodological advancements. Graphic restitutions are utilized for heuristic purposes, exploring interpretative hypotheses and refining understanding while literary narratives aim to disseminate research outcomes to diverse audiences.

Accurate dating informs conservation strategies, guiding heritage practitioners in selecting suitable methods and materials to uphold the mosque's authenticity. Despite methodological challenges, the rigor of the study has significantly reshaped perceptions of the mosque, furnishing an essential documentary foundation for addressing regional historical inquiries linked to this architectural heritage. Through a combination of graphical representations and narrative approaches, a more intuitive and synthesized understanding of the mosque's architectural and historical evolution is promoted, fostering broader public engagement and appreciation.

Acknowledgements
We are grateful to the parties who have helped advance this research, for their assistance and information: Mrs Ziani Kacimi Meriem -Managing architect of BET Ziani and leader of the group Ziani – Mahindad, Mrs Boussouf Faima Project manager -Qualified architect by the Ministry of Culture of Monuments and Historic Sites- Lecturer at Constantine University 03 Salah Boubnider, Constantine and Mr. Saouli Nadjib, architect restorer, Annaba.

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CONSERVAR PATRIMÓNIO

ARTICLE / ARTIGO

Characterization of early 20th-century German bandstands metal alloys exposed to the Amazonian weathering of Belém, Brazil

Caracterização das ligas metálicas de coretos alemães do início do século XX expostos ao clima amazónico de Belém, Brasil

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Abstract

The iron industry's progress in the 18th and 19th centuries has left a noteworthy built heritage in non-European countries, such as Brazil. Among the cities, Belém holds five metallic bandstands imported from Germany and installed in Batista Campos Square in 1903. Despite the historical, architectural, technical, and social significance, these structures are facing gradual deterioration, disfigurement, and improper maintenance due to a lack of knowledge. To address these issues and gain a deeper understanding of the materials, this paper aims to characterize the metal alloys and corrosion products of these bandstands. Scanning electron microscopy, energy dispersive X-ray spectroscopy, and X-ray diffraction analyses were conducted on different structural parts. The results showed a significant use of nodular gray cast iron, steel application, their corrosion products, and an assessment of the conservation state of the coatings. This information enhances the knowledge of the use of ferrous alloys and their corrosion in historical buildings.

KEYWORDS
Iron alloys
Cast iron
Corrosion products
Iron architecture
Architectural heritage

Resumo

O progresso da indústria do ferro nos séculos XVIII e XIX deixou um património edificado notável em países não europeus, como o Brasil. Em particular, a cidade de Belém possui cinco coretos metálicos importados da Alemanha e instalados na Praça Batista Campos, em 1903. Apesar do seu significado histórico, arquitetónico, técnico e social, estes coretos estão sujeitos a uma gradual deterioração, descaracterização e ações de manutenção inadequadas resultantes da falta de conhecimento. Este artigo pretende caracterizar as ligas metálicas e os produtos de corrosão destes coretos. Foram realizadas análises por microscopia eletrónica de varrimento, espectroscopia de raios X por dispersão em energia e difração de raios X em diferentes componentes construtivos. Os resultados mostraram o uso abundante de ferro fundido cinza nodular, a aplicação de aço, o tipo de corrosão e o estado de conservação dos revestimentos. Essas informações ampliam o conhecimento sobre a utilização de ligas ferrosas e sua corrosão em edifícios históricos.

PALAVRAS-CHAVE
Ligas de ferro
Ferro fundido
Produtos de corrosão
Arquitetura do ferro
Património arquitetónico

Introduction

Different alloys, particularly ferrous ones, form part of the material fabric of the world's built cultural heritage. A significant portion of this legacy directly stems from historical events that unfolded in Europe during the eighteenth and nineteenth centuries, culminating in the advancement of the iron industry and the Industrial Revolution. As a result of these developments, several European nations manufactured and exported metallurgical and architectural products to other continents, including prefabricated iron buildings from 1840 onwards [1-2].

Buildings of this type, in which iron alloys were used as the main structural and constructive material and exposed means of aesthetic expression, were referred to as "iron architecture" [2-3]. Many Latin American countries, particularly Brazil, were major importers of this style. Belém, located in the Amazonian region of Brazil, stands out among the cities with the most important collections dating from the nineteenth and twentieth centuries. Among markets, chalets, pavilions, and street furniture, the city has a significant set of bandstands [2, 4].

The bandstands were imported during a period of intense economic growth driven by rubber exports. The surplus of wealth spurred an extensive redevelopment of the city's central urban area, focusing on the remodeling and creation of parks and squares [5-6]. According to official reports by Antônio Lemos [7], the city's intendant (1897-1910) and key figure in leading much of the transformation during this period, five musical pavilions of German origin were ordered in 1903 to be installed at the Batista Campos Square (Figure 1a-b).

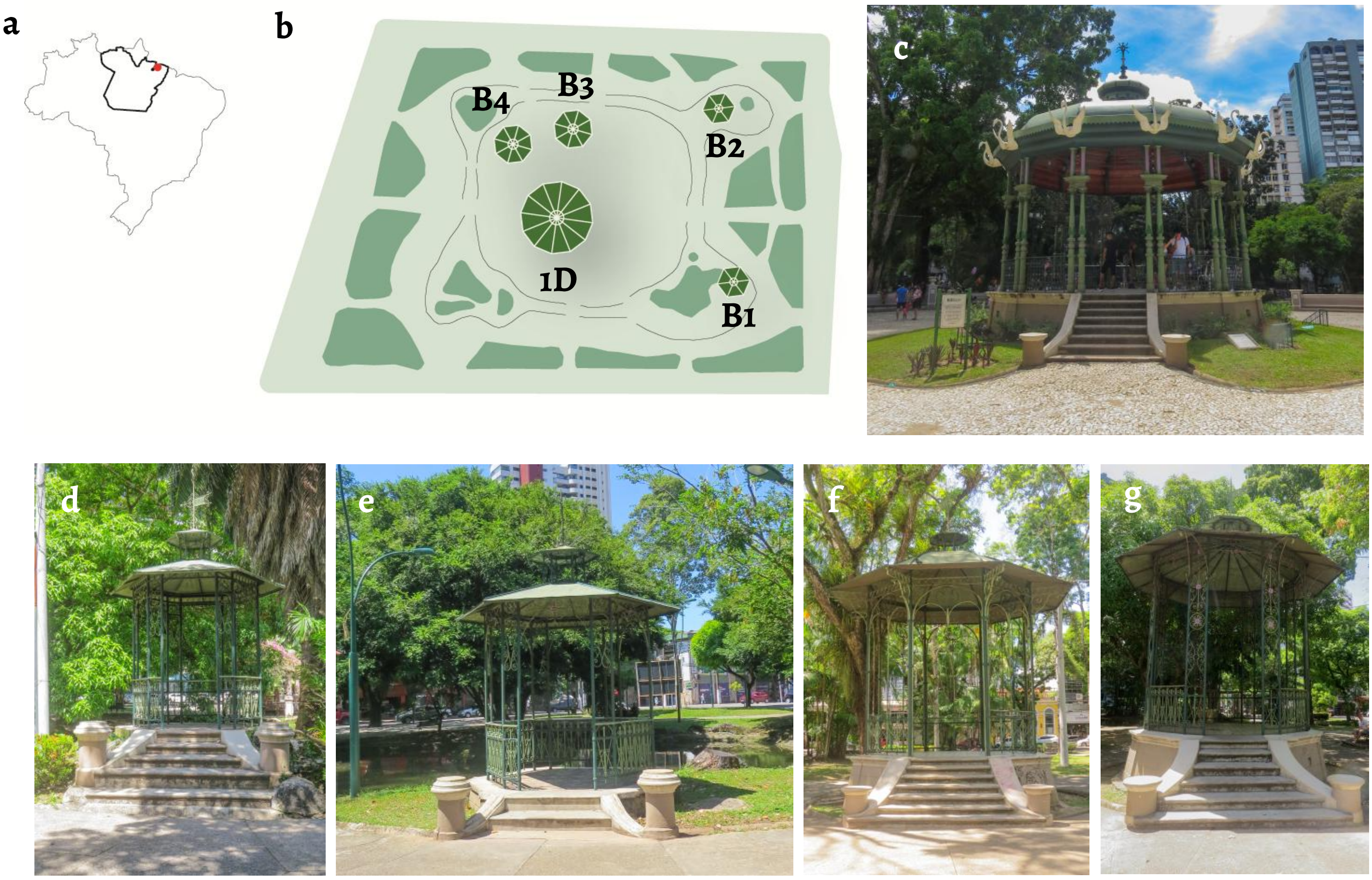

Figure 1. Musical pavilions of German origin: *a)* Location of the German bandstands within the Brazilian territory; *b)* the boundaries of the square; *c)* The Primeiro de Dezembro Pavilion; *d)* Bandstand 1; *e)* Bandstand 2; *f)* Bandstand 3; *g)* Bandstand 4.

Even though these structures vary in size, they share numerous architectural and stylistic features, supporting the theory that they originated from the same manufacturer [8]. The largest structure, located in the center of the square, is called the *Primeiro de Dezembro Pavilion* (Figure 1c). The other four, which are small to medium in size, are distributed throughout the park: Bandstands 1, 2, 3, and 4 (Figure 1d-g).

After more than a century, these structures have been listed as part of historical sites. Despite their significance, our understanding of them remains insufficient to address issues such as degradation and architectural disfigurement. These issues escalated in 2020/2021, when their severely decaying state demanded an intervention that primarily prioritized paint renovation. The maintenance of paints for metals is undoubtedly fundamental for protection and aesthetics [9]. However, the lack of information is especially pronounced when it comes to the detailed identification of their physical, chemical, and mineralogical characteristics through scientific methods. This missing knowledge is essential for guiding other appropriate conservation and restoration strategies, as well as for assessing the extent of deterioration.

It is also important to note that each country developed its own standards until the early twentieth century, resulting in a wide range of ferrous metals with heterogeneous properties [10]. There are still indications that knowledge was not shared between foundries [11]. Since the bandstands represent the technological development of an era, the study of these structures addresses broader issues beyond local context preservation. Both objective and subjective insights are expected to contribute to the history of technology and construction and to deepen the understanding of the global industrial heritage.

Given these considerations, this research aims to characterize the metallic alloys and corrosion products of Belém's German bandstands, located at Batista Campos Square, using analytical techniques. This investigation is crucial for the conservation and restoration of historical metals, as it provides evidence-based data and a solid foundation for defining conservation treatments [12-13]. Therefore, it serves as both a basis for restoration actions on the buildings themselves and as documentation of structures and construction technologies affected by the Amazonian weathering.

Materials and methods

Sampling

The samples come from the five buildings located at the Batista Campos Square: The Primeiro de Dezembro Pavilion and Bandstands 1, 2, 3, and 4. Since they are listed heritage, the sampling procedure was carefully conducted and authorized by Pará's Historical, Artistic, and Cultural Heritage Department (DPHAC)/Culture Department (SECULT) and Belém's Design and Landscaping Department (DPP)/ Environment Department (SEMMA).

Considering them as legally protected and recently restored buildings (2020/2021), the number of samples was restricted as much as the areas allowed for extraction. Small fragments, up to 2 cm, were collected from parts affected by gaps or crevices so that additional further damage was not caused. Even so, constructive representativity was ensured since different parts of the bandstands could be sampled. In total, nine samples from various architectural elements – such as roof sheet, pillar, guardrail, and ornament – were analyzed.

The collected materials included metal alloy, corrosion products, and coating samples. It should be noted that the presence of coatings was an incidental finding from the sampling process and not the primary focus of the investigation because they were new. Nonetheless, they were considered in this study for their important role in corrosion protection or progression. These samples are described in Table 1, and their locations and typical visual aspects are illustrated in Figure 2.

For historical metals, analytical techniques can be used to obtain crucial data through the microstructural and chemical characterization of the metallic substrate and corrosion products

[12-13]. On this subject, scanning electron microscopy and energy dispersive X-ray spectroscopy (SEM/EDS) are fit to observe these features. X-ray diffraction can additionally identify crystalline phases for mineralogical insights. Overall, they can provide information about manufacturing procedures and deterioration processes.

Table 1. Identification of the samples according to the building, area, type, and analytical technique used for the material characterization.

Building	Sample	Sampling area	Type of sample	Analytical technique
Primeiro de Dezembro Pavilion	1D-A1	Guardrail	Metal alloy, corrosion prod. & coating	SEM-EDS
	1D-A3	Roof sheet	Metal alloy, corrosion prod. & coating	SEM-EDS
	1D-A4	Roof sheet	Metal alloy	XRD
Bandstand 1	B1-A2	Guardrail	Metal alloy	XRD
	B1-A4	Guardrail	Metal alloy, corrosion prod. & coating	SEM-EDS
Bandstand 2	B2-A1	Ornament	Metal alloy	XRD
	B2-A4	Pillar	Metal alloy, corrosion prod. & coating	SEM-EDS
Bandstand 3	B3-A3	Pillar	Metal alloy, corrosion prod. & coating	SEM-EDS
			Metal alloy	XRD
Bandstand 4	B4-A4	Pillar	Metal alloy, corrosion prod. & coating	SEM-EDS
			Metal alloy	XRD

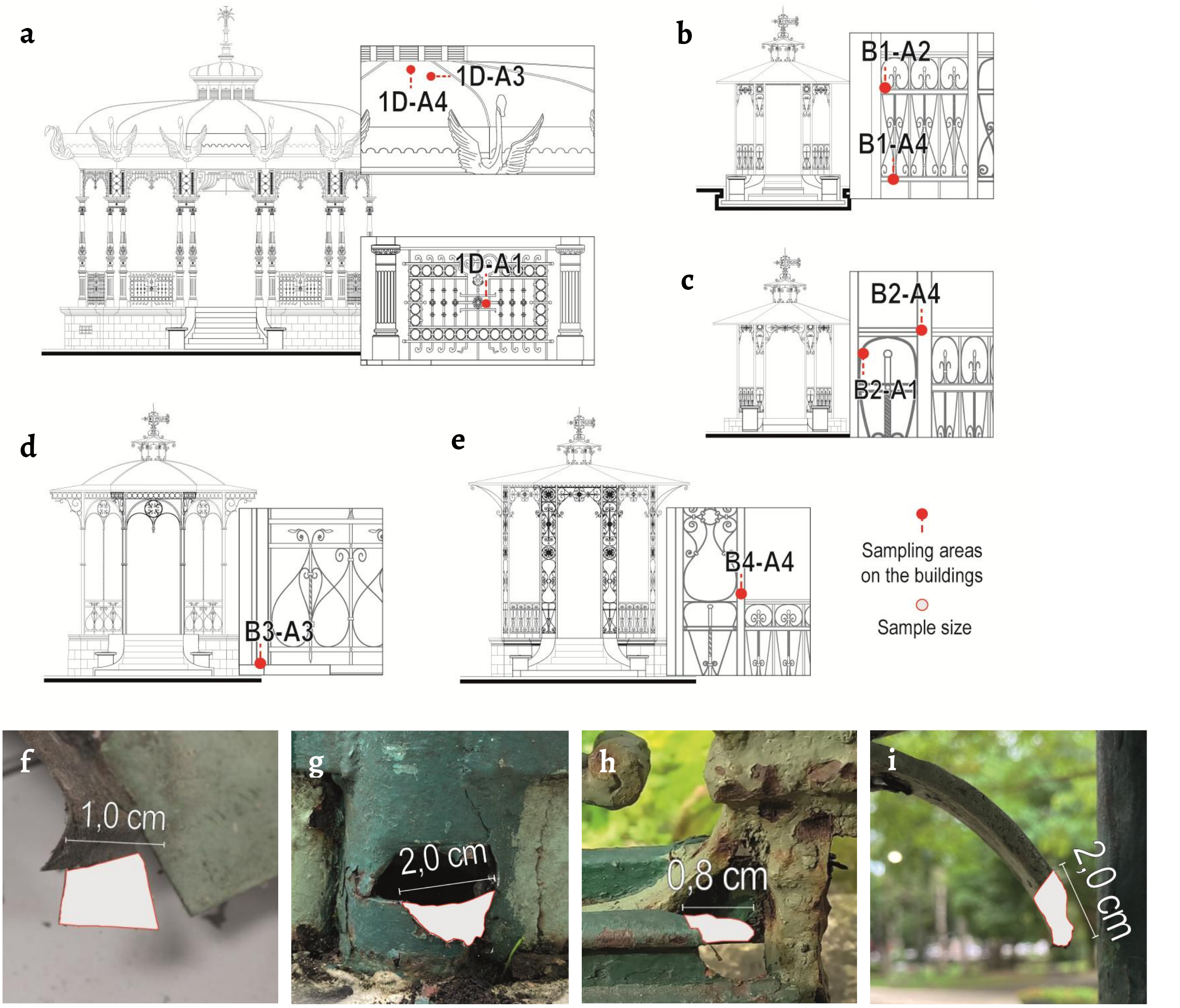

Figure 2. The sampling areas: *a)* Primeiro de Dezembro Pavilion; *b)* Bandstand 1; *c)* Bandstand 2; *d)* Bandstand 3; *e)* Bandstand 4; Examples of the covered architectural elements, areas, and sizes: *f)* roof sheet; *g)* pillar; *h)* guardrail; *i)* ornament.

Analytical techniques

The physical characterization was performed by scanning electron microscopy (SEM), combined with energy dispersive X-ray spectroscopy (EDS) for chemical element identification at selected spots. The microscope used was a Hitachi brand, TM3000 model, capable of magnifications up to 30,000× operated with acceleration voltage from 5 or 15 kV beams. EDS spectra were obtained using an Oxford Instruments brand, SwifitED300 model X-ray dispersive energy spectrometer, which detects elements from boron (B_5) to Uranium (U_{92}). The images and elemental analyses were obtained at an acceleration voltage of 15 kV and with an acquisition time of 40 s.

The samples were observed in cross-section using SEM-EDS to determine the boundaries of the layers: metallic substrate, corrosion products, and coatings. They were first embedded in polyester mounting resin and then polished. Manual thinning was performed with wet sandpaper of different grit sizes: 100, 200, 400, 600, 1200, and 1500. Final polishing was achieved using 1/4 μm metallographic diamond paste and velvet discs.

The mineralogical composition of the alloys was analyzed by X-ray diffraction (XRD) with a BrukerD2 PHASER model diffractometer. The analyses used a Cu Kα radiation (1.54184 Å), at 300 W (30 kV and 10 mA). Data were collected in the 2θ range from 5° to 75°, with a step size of 0.02° and a step time of 0.2 s. Phase identification was performed using PANalytical X'Pert High Score Plus software. In this study, its application was reserved for the alloys due to the availability of samples previously explained.

Because of the limited volume available of the samples, micropreparation was used for the XRD analyses. The samples were manually ground using an agate mortar and then transferred to silicon plates (zero background).

All mentioned equipment belongs to the Mineralogy, Geochemistry, and Applications Laboratory (LAMIGA) of the Geosciences Institute of the Federal University of Pará (UFPA).

Results

General characteristics of the sampling

Based on the SEM cross-sectional images, the nine samples exhibit two main physical characteristics related to texture, which initially separates them into two groups: 1) uncorroded metallic substrate and 2) corrosion products, as indicated in Figure 3. The first group consists of samples with a solid and homogeneous matrix. The second group, in contrast, displays less consistency caused by corrosion and forms a layer in immediate contact with the unaltered alloy. The groups also differ chemically, as indicated by the grayscale colors reflecting the contrast in atomic numbers of the elements observed through the backscattered electron mode of the SEM [14].

The EDS spectra confirmed that the chemical composition of the unaltered metal is primarily iron. Some points also revealed smaller amounts of other elements such as carbon, manganese, silicon, sulfur, and phosphorus (Figure 3). The diffractogram in Figure 3 supports these findings, pointing ferrite (α-Fe, pure iron) as the predominant mineral phase [15]. Additionally, the B3-A3 sample exhibited an extremely low copper peak in its mineralogical composition. The only exception was in sample 1D-A4, where only zinc was identified by XRD (Figure 4).

The chemical composition of the unaltered areas is consistent with cast iron alloys, specifically the gray cast iron. The appropriate concentrations of carbon, silicon, and phosphorus promote graphite formation, leading to the production of gray cast iron. Although manganese and sulfur have opposing effects compared to the elements mentioned above, they still play a crucial role in forming manganese sulfide (MnS) which neutralizes the effects of sulfur – usually originating from natural sources – thereby preventing undesirable effects such as material weakening [16-18].

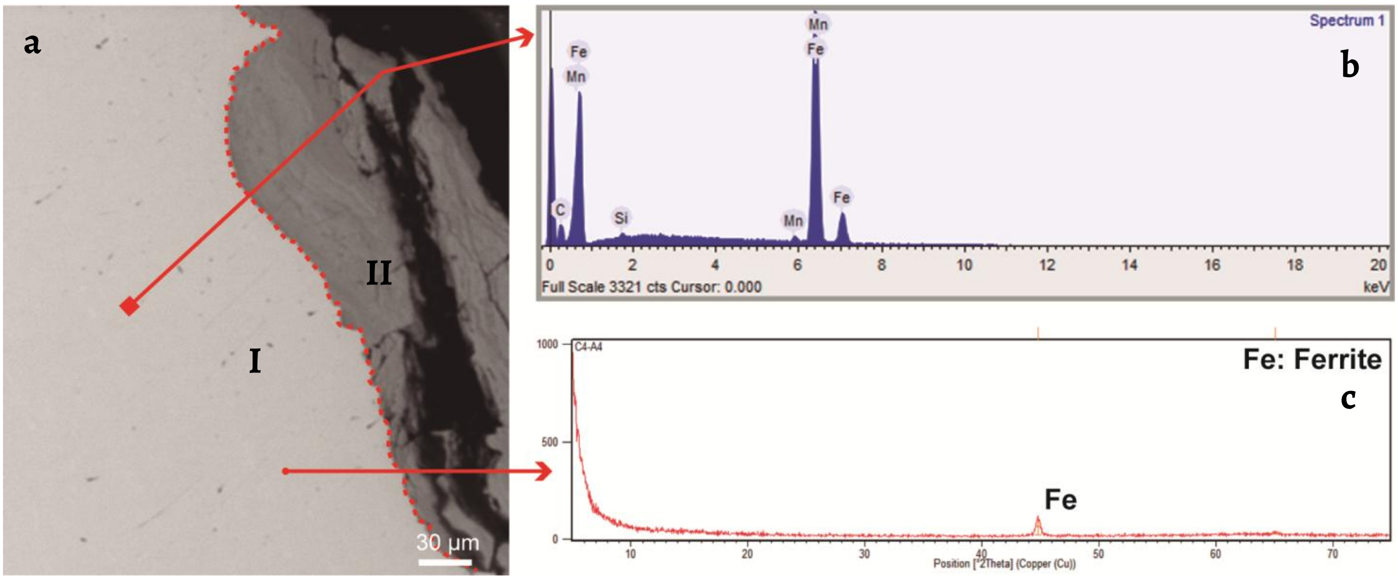

Figure 3. Sample B4-A4: *a)* SEM image indicating the boundary between the I) uncorroded metallic substrate and II) corrosion product layer; *b)* EDS spectrum; *c)* X-ray diffractogram, showing its chemical and mineralogical characterization.

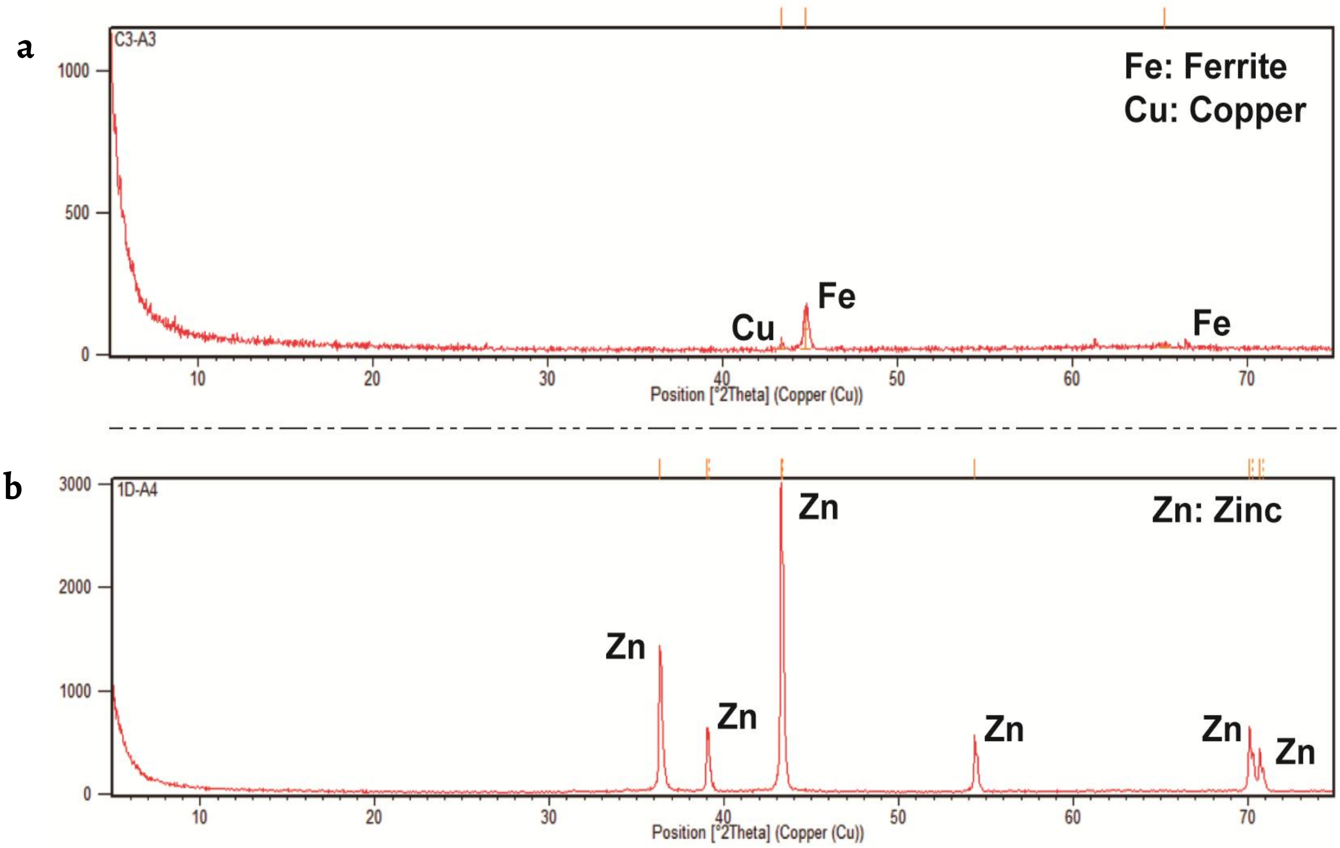

Figure 4. X-ray diffractograms: *a)* sample B3-A3 showing Fe and Cu; *b)* sample 1D-A4 showing Zn.

As expected, the corrosion products show a wider composition common to structures exposed to outdoor atmospheric corrosion. In addition to typical cast iron alloying elements, sodium, calcium, potassium, chlorine, aluminum, zinc, and bromine were also identified. These can be attributed to extrinsic materials (particles carried by the wind), air pollutants present in the form of chlorides and sulfates, and remnants of coatings. Notably, oxygen was present in all alteration layers and at higher concentrations than iron. This significant presence of oxygen indicates the formation of iron oxides and hydroxides, which are common iron corrosion products [19-21].

Uncorroded metallic substrate

Exclusively circular inclusions were identified in the unaltered iron matrix. These inclusions are not perfectly round and tend to appear moderately elongated, as observed in samples taken from the guardrails and pillars (Figure 5). This type of microstructure is characteristic of malleable or nodular (ductile) gray cast iron. Malleable cast iron is produced through heat treatments of white cast iron, which promote the formation of nodules. Nodular cast iron, on the other hand, is directly obtained during the casting process through the addition of inoculants that promote the nodular precipitation of graphite [16, 22].

The microstructure of both alloys is quite similar. However, some differences may arise from their manufacturing processes. The first factor is the cost: producing nodules during smelting and casting is less expensive than through heat treatments. Another factor is section limitation, as ductile iron can be produced in much larger sections compared to malleable iron [23-24]. Considering the need for efficiency and cost-effectiveness in historical prefabricated iron architecture, it is more plausible that the alloys studied are classified as nodular cast iron.

According to the chemical characterization of samples B1-A4, B2-A4, and B3-A3, the nodular precipitations are composed of elements other than iron: primarily carbon, manganese, silicon, oxygen, sulfur, and phosphorus. The isolated presence of aluminum and chlorine in samples B2-A4 and B4-A4 suggests contamination (*e.g.* from soil dust particles) and active corrosion in the alloy, leading to the formation of chlorides [15, 21] (Figure 6).

In samples 1D-A1 and B1-A4, areas (voids) with a different shape from the inclusions and a slightly darker gray color can be observed. However, there is no significant contrast in composition, as iron, carbon, oxygen, manganese, sulfur, and silicon were identified, almost entirely matching what was detected in the unaltered alloy and inclusions (Figure 6). This minimal variation can be attributed to the homogeneity in type, raw material of origin, and fabrication technology of the alloys.

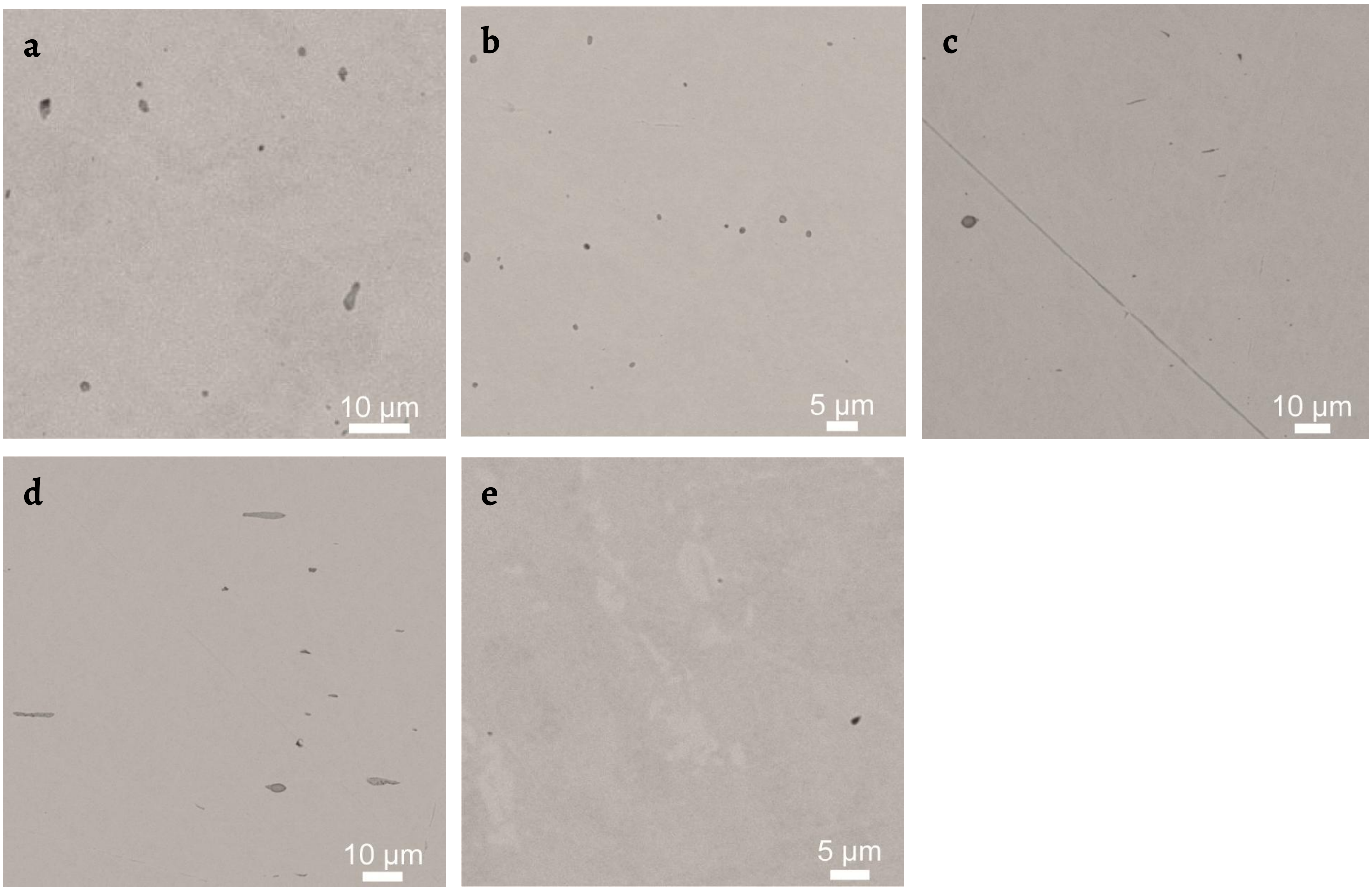

Figure 5. SEM images showing circular inclusions in the microstructure of the samples: *a)* 1D-A1; *b)* B1-A4; *c)* B2-A4; *d)* B3-A3; *e)* B4-A4.

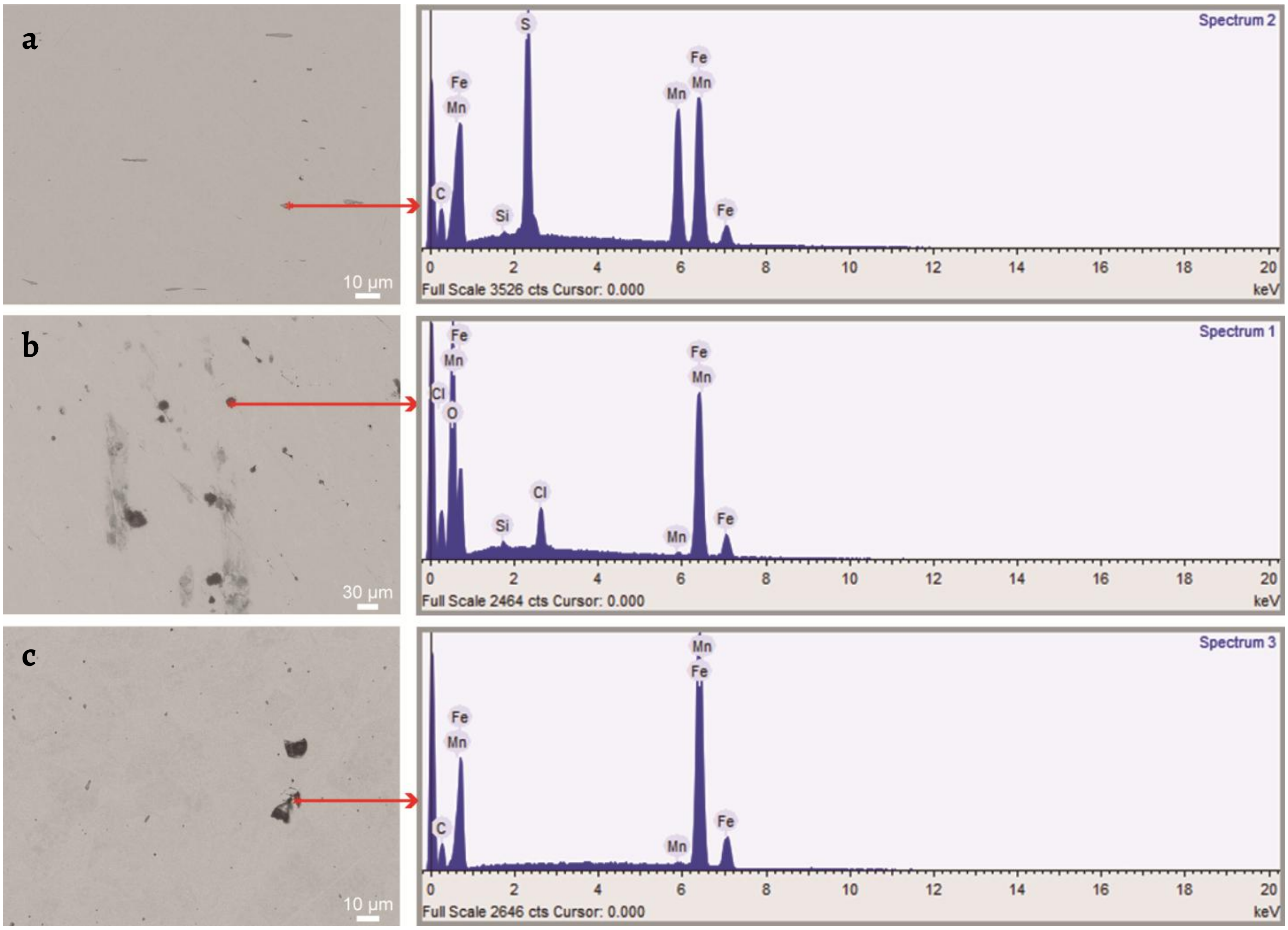

Figure 6. SEM images (left) and EDS spectra (right) showing: *a)* the chemical composition of the circular inclusions in sample B3-A3; *b)* the Cl identification in sample B4-A4; *c)* the chemical composition of the void areas in the sample 1D-A1.

One sample, 1D-A3, from a roof sheet, has a smooth texture and is free of inclusions. EDS analysis identified that the unaltered metal area is primarily composed of iron (Figure 7). In contrast, the XRD analysis of sample 1D-A4, taken from one of the faces of the same element as 1D-A3 and shown in Figure 4, indicates that the surface composition is zinc. The microstructure and zinc-rich surface composition were observed only on these roofing samples.

Although zinc is a typical metal for roofing in bandstands from the nineteenth and twentieth centuries [2], the contrasting chemical and mineralogical compositions suggest that it is an iron sheet coated with zinc. For an accurate determination of the ferrous alloy, the morphology and microstructure can be examined. According to the literature, lamellae and nodules are characteristics of gray cast iron; a fibrous texture formed by filamentous slags is typical of wrought iron; and the absence of these features distinguishes steel from the other types mentioned [22, 25-27]. Based on this information and the SEM images, it is reasonable to classify the 1D-A3 sample as a steel sheet.

Metallized steel sheet roofs have been used in historical architecture for centuries, similar to zinc coatings for metallic protection [28-29]. Concerning its function, the zinc coating on sample 1D-A4 acts as a protective mechanism for the base metal alloy (iron). It provides not only a protective barrier but also cathodic protection. In areas where the coating is defective and the iron is exposed, zinc serves as a sacrificial layer, corroding itself instead of the iron alloy [30].

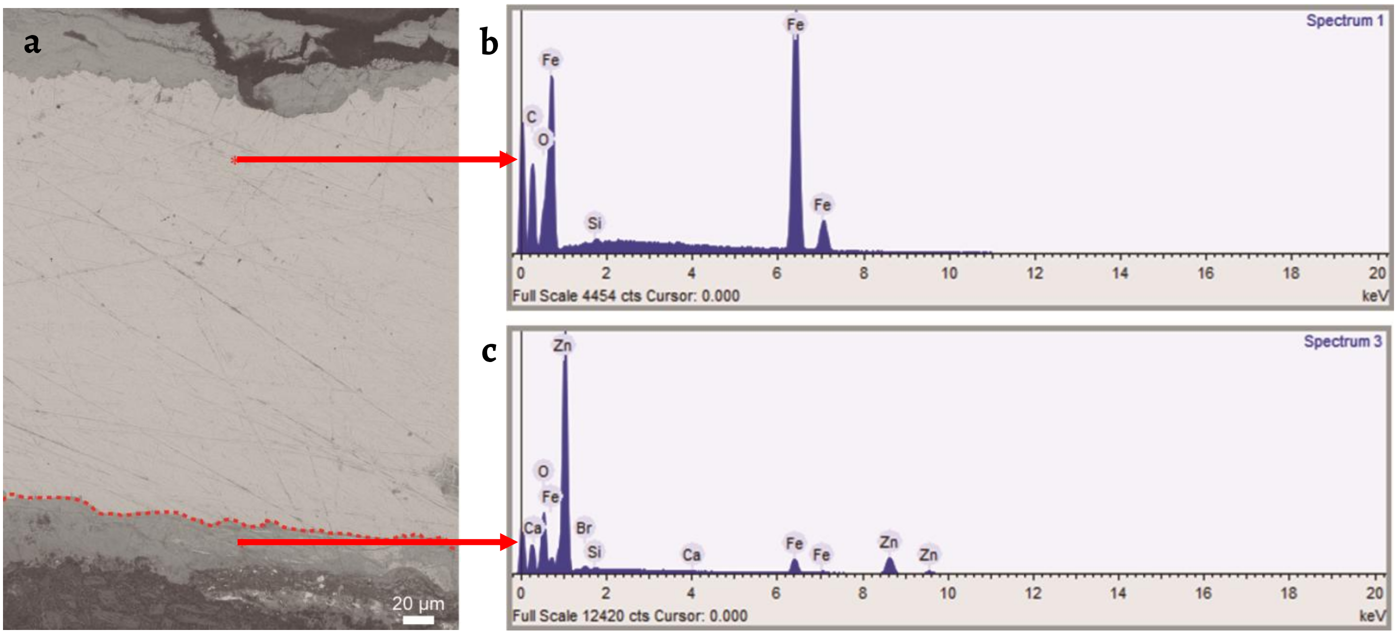

Figure 7. SEM image (left) and EDS spectra (right) of the roofing element showing: *a)* the absence of inclusions in sample 1D-A3; *b)* the alloy composition; *c)* the Zn coating in one of its faces.

Corrosion products

The samples investigated by using SEM/EDS included three groups of architectural elements: pillars, guardrails, and roof sheets. The images reveal a stratification consisting of unaltered metal, corrosion products, and coating remnants. In addition to chemical variations, coatings (paint or metallic) may be present or absent – as they, although recently renewed (2020/2021), were prone to loss due to the high chalking and dustiness of the parts.

Three sequences of layers were displayed: 1) uncorroded metal as the inner layer, followed by corrosion products intermediately, and paint as the outermost layer; 2) uncorroded metal as the inner layer and corrosion products as the outermost layer; 3) uncorroded metal intermediately and the corrosion product and zinc coating layers on the opposite faces of the element. Examples of the orders are shown in Figure 8.

In the Primeiro de Dezembro Pavilion, the position and composition of the corrosion products in samples 1D-A1 (guardrail) and 1D-A3 (roof sheet) differ. In sample 1D-A1, the corrosion appears as an intermediate layer, with the remaining paint as the outermost layer in 1D-A1. In contrast, in sample 1D-A3, the layers are not consecutive, as the zinc coating is present on only one face of the source object (Figure 8).

Sample 1D-A1 contained iron, carbon, oxygen, sodium, chlorine, calcium, potassium, and sulfur in its corrosion layer. Its paint layer was composed of iron, carbon, oxygen, manganese, silicon, sulfur, calcium, and chlorine. In the analysis of sample 1D-A3, the corrosion layer and zinc coating were found to consist of the following elements, respectively: iron, oxygen, and carbon in the corrosion layer; and zinc, oxygen, iron, bromine, silicon, and calcium in zinc coating. It should be highlighted that both compositions regard the iron substrate and metallic coating (Zn) corrosion.

In the other four bandstands, B1, B2, B3, and B4, only corrosion product layers were observed, in addition to the unaltered metal alloy. A notable feature is the extremely non-uniform thickness of the layers, along with high levels of fragmentation due to the advance of corrosion. The estimated thicknesses of the layers, measured by image proportion, varied between 15-30 µm in sample 1D-A1; 50-60 µm in sample 1D-A3; 10-17 µm in sample B1-A4; 20-30 µm in sample B2-A4; 10-60 µm in sample B3-A3; and 60-65 in sample B4-A4. The chemical elements detected were primarily iron, oxygen, and carbon with small amounts of silicon, calcium, sulfur, and manganese (Figure 9).

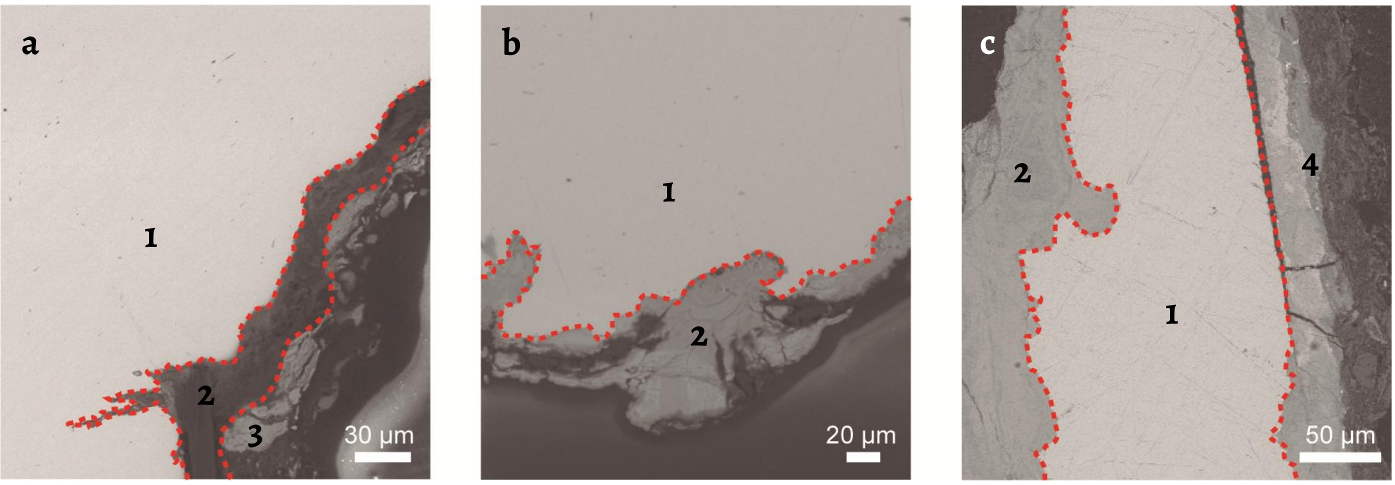

Figure 8. SEM images showing the stratigraphy of the layers in: *a)* sample 1D-A1; *b)* sample B3-A3; *c)* sample 1D-A3. 1 – uncorroded metal, 2 – corrosion product, 3 – paint, 4 – zinc coating.

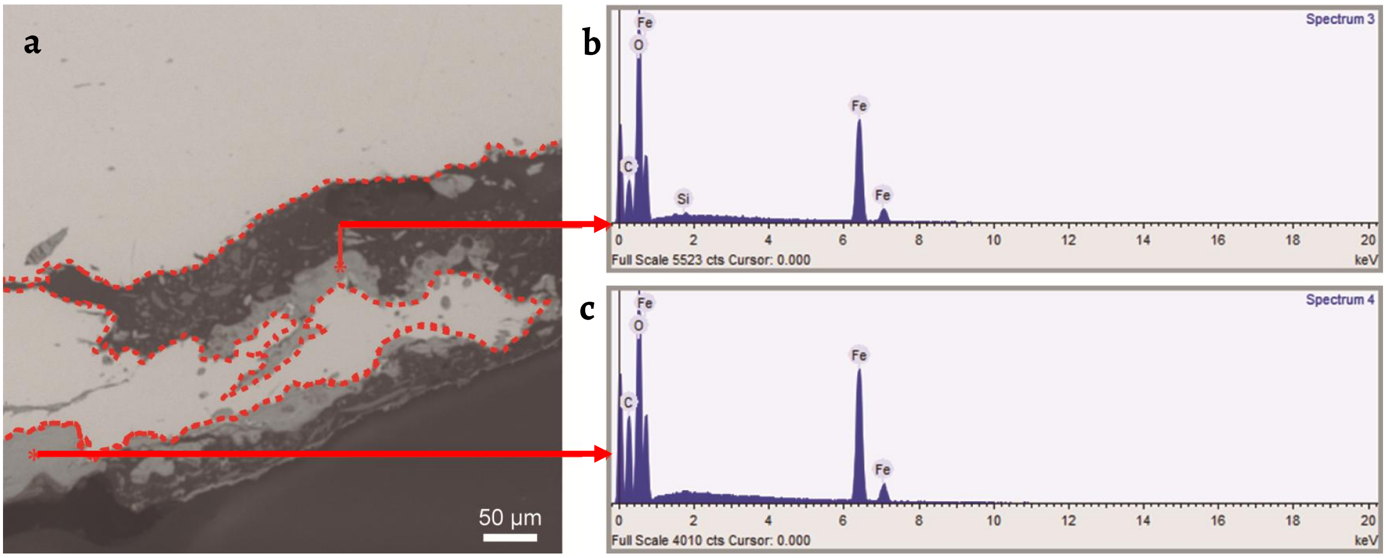

Figure 9. Sample B2-A4: *a)* SEM image showing the corrosion product layer thickness; *b-c)* EDS spectra of its chemical composition.

Regardless of the arrangement, it is evident that the layers are composed of elements common to cast iron alloys and other materials related to atmospheric pollutants, as previously mentioned. The presence of coating remnants (paint or metallic) is indicated by the detection of Zn in sample 1D-A3 and likely by the identification of Ca among other samples – possibly suggesting the presence of zincite (ZnO) and calcite ($CaCO_3$) from paints and primers applied to the surfaces of the bandstands [31].

Discussion

As anticipated based on the historical context of these buildings, the physical, chemical, and mineralogical characterization confirmed that the construction material is iron. However, the metallized steel sheet identified on the roof of the Primeiro de Dezembro Pavilion is likely a more recent addition or replacement. This inference is supported by documental alterations to the roofs of the music pavilions, as detailed in previous research [8, 32].

In addition to the buildings discussed in this article, circular inclusions were also found in the alloy used in another prefabricated structure from the same period, specifically in the characterization of the alloys of the Ver-o-Peso Iron Market, particularly in structural components [31]. The difference lies in the intended use of these inclusions, as nodules can enhance the material's mechanical properties [33]. However, this may not have been a consideration for the structures studied, as the material was used both in load-bearing elements (pillars) and in parts with ornamental functions (guardrails).

In related studies, lamellae graphite is more commonly identified within the microstructure of iron building components, as observed in the case of the Iron Market and the United States Capitol Dome [31, 34]. Additional research on cast iron street furniture by Soffritti et al. [21, 35-36] supports this observation, revealing various types of lamellae graphite in specimens of English, Italian, and French origins. Despite the variety of microstructures reported in these studies, spheroidal graphite is not commonly or significantly present.

The significant presence of nodular cast iron in the five German structures studied, likely from a common manufacturer, raises questions about the iron industry technology in 1903 and its application in architecture. Literature suggests that efforts to improve cast iron properties through the addition of chemical elements like magnesium and cerium began in the 1930s, leading to the development, enhancement, and patenting of nodular cast iron around 1950 [24, 37-38].

It is important to note that neither magnesium nor cerium were detected in the EDS spectra of the samples. Additionally, the buildings' construction dates are inconsistent with the period during which this alloy first appear. Consequently, the initial classification of the metal is questionable. Therefore, the characteristics observed in the samples do not allow them to be accurately classified as either malleable or nodular/ductile cast iron, considering both the chemical properties and manufacturing practices valued at the time.

Further research is needed to clarify the typological definition of historical circular graphite ferrous alloys. Although the microstructure appears recent in metallurgical terms, ongoing studies on the formation of nodules suggest that the debate is still active [39]. Moreover, the results observed across this group of buildings and their different elements are unlikely to be coincidental. This indicates a potential for further development in metallurgical knowledge related to iron architecture, including insights into manufacturers, techniques, and variety of alloys used.

Few studies have been conducted on the Amazonian scenario regarding corrosion progression in similar buildings. Evidence of corrosion between unaltered metal and paint layers, a sign of poorly protected alloys, has been previously identified [31]. This may suggest a pattern of deterioration in the local architectural iron monuments that requires confirmation. Nonetheless, the effects of the equatorial hot and humid climate are thus more detailed in relation to other types of historical substrates (for example, glazed ceramic tiles) [40-41]. Therefore, investigations should be conducted to advance this specific understanding of the metallic heritage behavior.

The estimated thicknesses of the corrosion layers show that the alteration process may have resulted primarily from a couple of years of exposure (2020/2021). Literature measurements consider that 10-year-old layers are over 100 μm thick [19]. Iron metalworks from the same historical period, but in different environments and with more years of corrosion progression, have shown to be within this rate. In contrast, most of the dimensions observed in the samples were approximately 10 and 30 μm. According to the yearly rates of 25 μm/y for non-polluted atmospheres and 150 μm/y for polluted ones [21], the local process aligns with the conventional model of outdoor corrosion.

The corrosion stratification, consisting of a single layer in the samples, displayed less complexity compared to the more common two/three-layered cases. The appearance of the samples indicates that they are porous and nonprotective. Their visual features also suggest no graphitic corrosion traces in terms of morphology. This specific form of cast iron corrosion, which is attributed to mild atmospheres and acidic precipitation, has been identified in European structures. This causes mechanical weakening of the material while preserving its shape [19, 21, 42]. From this perspective, the concerns involving the bandstands' conservation may not include sudden structural failure.

This context inevitably highlights their surface protection situation. Based on the investigation, there are no substantial corrosion differences compared to other structures and environmental conditions. However, the coatings could be an issue, as it has demonstrated a very short service life. These findings corroborate previous studies that pointed out irregular maintenance of the protective systems used in the restoration of the bandstands over the years [32]. The regular deterioration of organic coatings and potential regional challenges regarding the durability of surface treatments must be verified.

Conclusion

Part of the world's historical and architectural legacy from a century ago, Belém's German bandstands accrued significant heritage value and meaning. However, inadequate knowledge has impacted on their conservation and preservation, leading to advanced alteration processes, architectural disfigurement, and poorly scientifically grounded maintenances. For a better developed scientific knowledge and conservation practice, this study produced data on their metal alloys and corrosion products' physical (texture, thickness, and alloy microstructure), chemical, and mineralogical characteristics (mineral phases of the alloys).

The application of analytical techniques successfully provided technological data about these constructions. The analysis confirmed that iron is the primary material used, with a significant presence of nodular gray cast iron. This information is valuable for planning future restorations, particularly for the repair and replacement of components. Moreover, the observed microstructure highlights the expertise and practices employed by European foundries, mainly German.

Regarding the alteration processes, the results indicated that there are no significant differences in corrosion levels when compared to other structures and environmental conditions. Nevertheless, it showed that the corrosion on these buildings could be directly related to their coatings' rapid decrease in protection capacity. This highlights a concern: the bandstands, which underwent recent restorations in 2020-2021, are not receiving appropriate treatments. Accordingly, corrosion and coating behavior should be evaluated and inserted in the Amazonian weathering factors – extreme humidity, temperature, and rainfall – to further support these conclusions.

It remains valuable to collect and analyze samples from other construction parts. Such analysis would provide better opportunities to identify the alloys and materials used and assess the compatibility of past treatments. Additionally, given the unique characteristics observed, there is a need to develop a comparative study of German historical alloys. This is particularly important due to the scarcity of data on similar building materials from the early industrialization period and the same origin for contrasting information.

Subsequent steps should include testing ironwork material based on the composition of the historical material. This involves experimenting with methods for repairing or replacing parts and joining new metals with the original ones to prevent issues such as bi-metallic corrosion, structural failure, and excessive disposal of components. Additionally, testing the efficiency and durability of protective systems components, such as paints, under representative Amazonian conditions is essential. This approach, combined with critical theoretical thinking, would aid in developing conservation guidelines and provide insights into the preservation of metallic industrial heritage as a whole.

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CONSERVAR PATRIMÓNIO

ARTICLE / ARTIGO

Towards sustainable management of the World Heritage in Spain: from identification to monitoring of cultural values

Para uma gestão sustentável do património mundial em Espanha: da identificação à monitorização dos valores culturais

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Abstract

The management of World Heritage properties has reached a sufficient level of maturity accompanied by increasingly demanding monitoring processes focused on preserving their cultural values. This task is now being tackled, from a sustainable point of view, by involving the public. In the case of Spain, 50 properties have been declared since 1984, giving rise to an unequal situation regarding their management. Heterogeneity, the need to complete the declaration dossiers, concerning outstanding universal values and others, and the difficulty of implementing strategic and operational planning, are the origins of this situation. To address the sustainable management of this heritage and the monitoring of its cultural values, a diagnosis will be made, from the declaration to the implementation of the monitoring processes required by UNESCO, ending with a review of the implementation of management plans in Spain, understood as the tools that guarantee an integral vision of the property.

KEYWORDS
Outstanding Universal Value
Sustainable conservation
Management plan
Heritage impact assessment
Active protection
Conservation monitoring

Resumo

A gestão dos bens do património mundial atingiu um nível de bastante maturidade, acompanhado de processos de acompanhamento cada vez mais exigentes, centrados na preservação dos seus valores culturais. Esta tarefa está agora a ser abordada, de um ponto de vista sustentável, através da participação do público. Em Espanha, foram declarados 50 bens desde 1984, dando origem a uma situação desigual no que respeita à sua gestão. A heterogeneidade, a necessidade de completar os dossiers de declaração, relativos aos valores universais excecionais e outros, e a dificuldade de realizar um planeamento estratégico e operacional estão na origem desta situação. Para abordar a gestão sustentável deste património e o acompanhamento dos seus valores culturais, será feito um diagnóstico, desde a declaração até à implementação dos processos de acompanhamento exigidos pela UNESCO, terminando com uma análise da implementação dos planos de gestão em Espanha, entendidos como as ferramentas que garantem uma visão integral do bem.

PALAVRAS-CHAVE
Valor Universal Excecional
Conservação sustentável
Plano de gestão
Avaliação do impacto no património
Proteção ativa
Monitorização da conservação

Introduction

The World Heritage (WH) List, created after the *Convention Concerning the Protection of the World Cultural and Natural Heritage* in 1972 [1], has evolved over the years following the development of the international discourse regarding the conceptualisation of heritage and its management. It originated as a tool for conservation, particularly in the aftermath of the World Wars and as a result of the first experiences of international cooperation, which have since been established to ensure the effective protection of heritage. A far cry from the current scenario, in which heritage is understood as a "source of resilience, humanity, and innovation" [2], a resource that contributes to improving people's quality of life.

The evolution of the heritage discourse applied to WH management [3] reflects an opening up of its conceptualisation, objectives and approach, pursuing: 1) opening up the limits of the consideration of heritage, going beyond the more objectual and monumental concept of the mid-twentieth century; 2) approaching preservation from a broad perspective that is not focused on conservation or protection, moving towards sustainable management or shared stewardship of heritage; 3) enriching the initially materially focused problem approach to give way to a value-based and ultimately people-centred approach.

The concept of sustainable management was generalised [4] once the World Heritage Committee – the international body updating the different Lists at its annual meetings, as well as following the state of conservation of the properties inscribed – declared heritage as an instrument for the sustainable development of society, starting with the Budapest Declaration [5]. The subsequent development of this premise has come hand in hand with the contribution of sustainable heritage to local development, both in economic and social terms and in environmental and cultural terms [6], considering heritage assets as facilities in their territorial and urban environments [7].

The Faro Convention [8] further established this paradigm shift in WH management, incorporating an awareness of the importance of citizenship in decision-making processes, primarily associated with intangible heritage [9] and the reformulation of the notion of management plans [10]. Specific people-centred methodologies have since been developed for specific domains, not necessarily in WH sites, such as archaeology [11] or cultural landscapes [12].

A value-based approach provides the foundation for current WH management, focusing on "sustained and enhanced significance, where significance is understood as the overall value of heritage, or the sum of its constituent heritage value" [13]. After the "social turn" it is now, in the first quarter of the twentieth first century, where we can situate the expansion of the "participatory heritage turn", assuming its challenges, contradictions and contributions [14].

This approach is compatible with the methodology followed to compile the WH List, established in the 1972 Convention, which required a property to be considered of Outstanding Universal Value (OUV) in order to be inscribed. This was justified by satisfying a set of selection criteria [1] which have been updated along with the evolution of the heritage discourse. The definition of OUV, the concept underpinning the Convention, has been the subject of continuous reflection, which has been reflected in the progressive diversification of the List. Since 1998, States Parties were asked to include a Statement of Significance in their nominations to the List, articulating the exceptional heritage values of each property to clarify its monitoring. However, it was not sufficiently specified how this statement should be defined, meaning that these values were usually not adequately developed or justified in relation to the criteria [15]. It is not until 2005 that the Statement of Outstanding Universal Value (SOUV) is introduced, articulating a consensual format for the justification of the selection criteria and fully incorporating the concepts of integrity and (for cultural properties) authenticity of attributes as key issues for the conformation of the OUV. This requirement was activated for registration procedures in 2007, while establishing a period of homogenisation and retrospective drafting of the SOUV for previously registered properties, which is gradually being implemented [16].

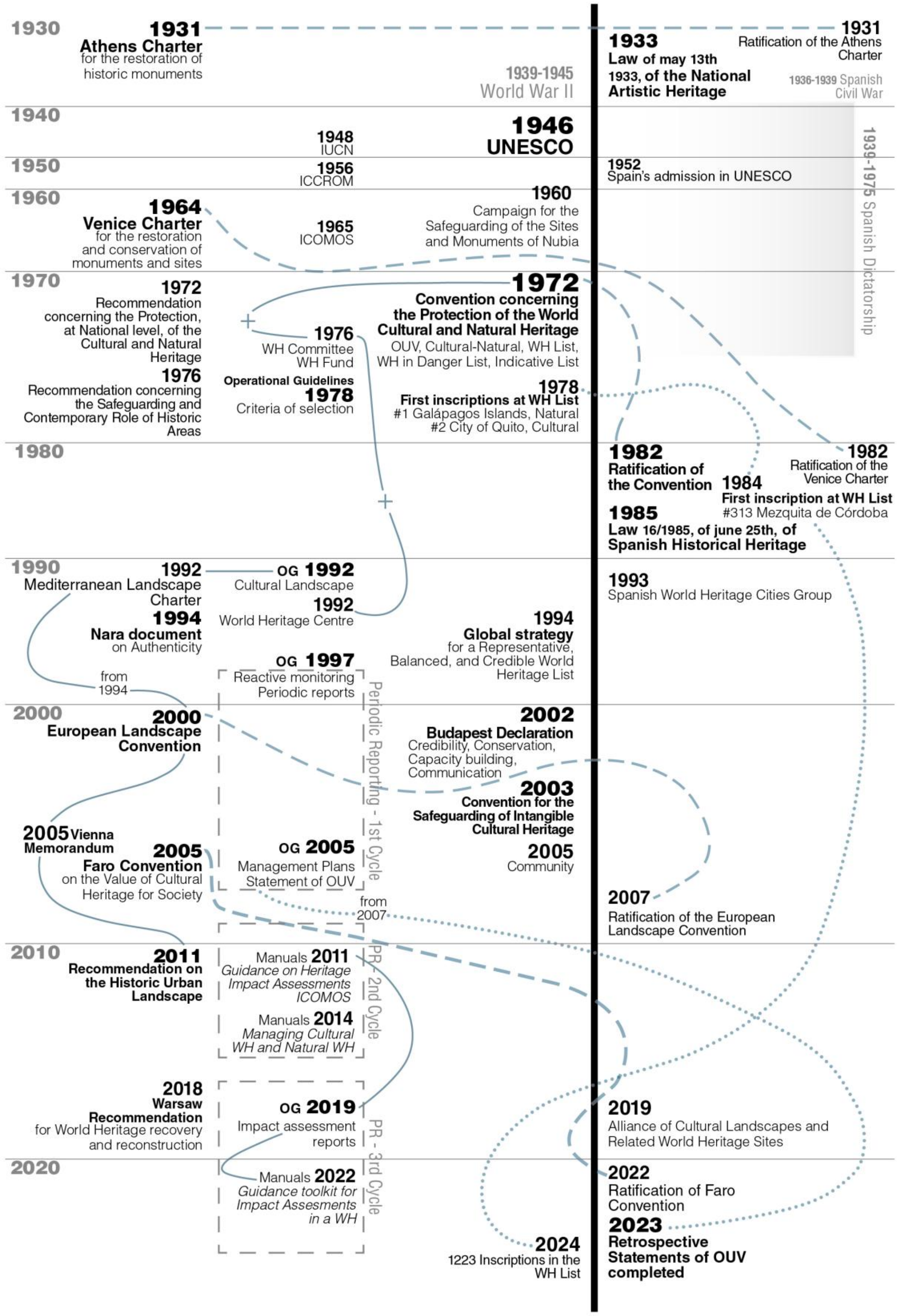

Figure 1. Genealogy (from top to bottom) of the evolution of World Heritage management on the international scene (on the left), listing international reference charters and texts (1st column) and the guidelines and tools developed within UNESCO (2nd and 3rd columns), in relation to what has happened in Spain (on the right).— relationship between processes derived from one another in the international scene, ···· Spanish participation in issues related to the evolution of the World Heritage List; --- time frame for Spain's ratification of international texts.

Since its foundation in 1946, UNESCO has developed a set of normative documents, charters, declarations and international recommendations to safeguard heritage and assist member states in its protection, conservation and knowledge, thus generating a dense network of consensual tools with a common objective [17] (Figure 1). The development of international charters mirrors an evolution of heritage sensitivity in which UNESCO's own reflexive work has always played an active part, while emerging issues in the international scene are incorporated into UNESCO's body of guidelines, making use of the annual WH Operational Guidelines for their implementation from 1978 onwards [18].

Thus, Community is incorporated into the strategic objectives of the Budapest Declaration following the drafting of the Faro Convention on the value of cultural heritage in society, the WH Cities Programme is set in motion in 2001 to adapt the conservation and management of urban heritage sites towards dynamic processes of safeguarding cultural significance [19] and, anticipating the progressive evolution and recognition of the concept of landscape on the international scene, Cultural Landscapes would be incorporated to the List in 1992, as a category that recognised the development of society in its physical context over time [20]. That decade saw efforts to open up the List to new heritage concepts, promoting inscriptions related to industrial archaeology, modern heritage works, itineraries and cultural landscapes [18], culminating in the definition of a Global Strategy for a Representative, Balanced and Credible World Heritage List.

Spain follows its own path in parallel to this evolution, strongly marked at the beginning by the international blockade of Franco's dictatorship. In the 1980s, the ratification of the convention coincided with the approval of a new Historical Heritage Law and the presentation of the first Spanish candidatures to the List. Spain became part of international cultural cooperation, albeit demonstrating varying degrees of proactivity in the ratification of international instruments [21]. The Historic Urban Landscape Initiative was launched by UNESCO in 2005 to develop cooperation with the World Heritage Centre (WHC) in protecting and managing living historic cities. However, in Spain this issue had previously attracted sufficient attention, as early as 1993, leading to the creation of the Spanish World Heritage Cities Group, aiming to carry out common projects and proposals and develop a network for shared experiences [22]. The Alliance of Cultural Landscapes and Related World Heritage Sites was created following a similar objective, joining sites in Spain, Portugal and Andorra after the international assimilation of the concept of Cultural Landscape.

Spain inscribed its first property in 1984, initially participating in the growth of the List considerably and slowing the pace of inscriptions at the turn of the century (Figure 2). With the last inscription, in 2023, Spain reached 50 properties on the List.

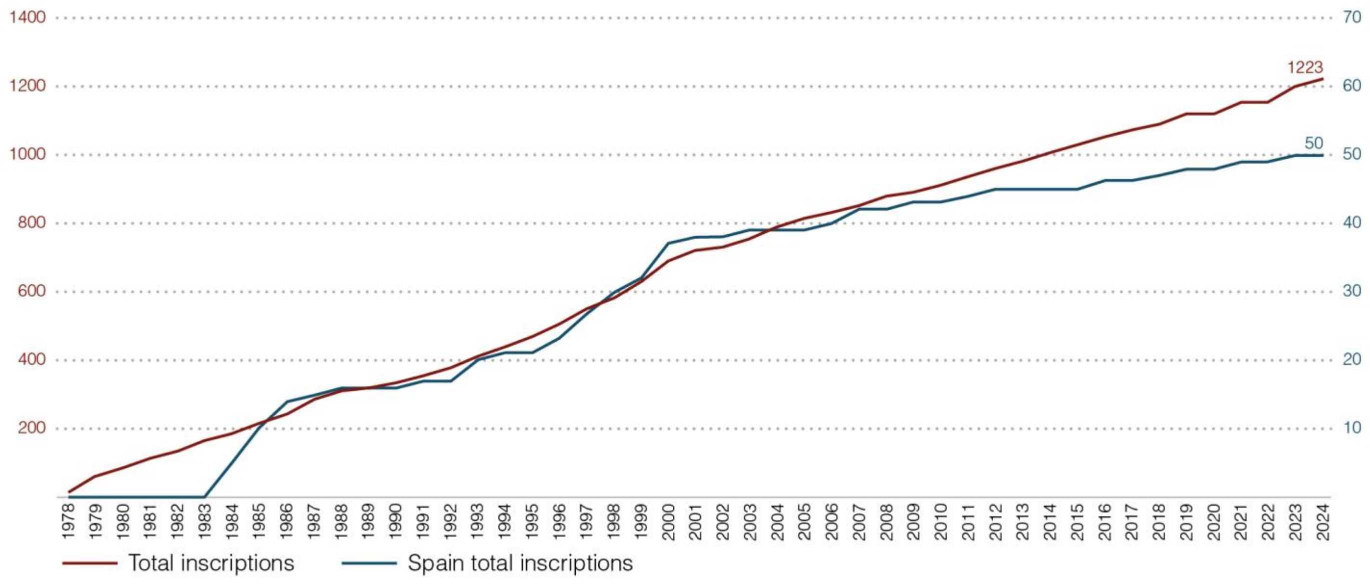

Figure 2. The WH List through time. Total inscriptions (red) vs. Inscriptions in Spain (blue).

In hindsight, the WH List has slowed its growth, moving away from the objective of heritage identification to an emerging critical need for guiding sustainable management [23]. Before assessing the heritage impact an intervention may produce on a WH property – a task for which Heritage Impact Assessments (HIAs) are carried out [24] – it is necessary to identify the cultural values, not only the OUV but also others identified and consented with the citizens. Beyond the authorised heritage discourse [25], the aim is to improve the planning and monitoring processes of cultural values in WH properties. This task is approached in awareness of the social shift that characterises the end of the twentieth century, giving way not only to the anthropological recognition of heritage but also to the importance of the "discursive" approach in confronting the predominance of materiality that had prevailed until then [26]. Sustainable conservation management is a relatively recent discipline whose challenges include focusing the debate on the cultural significance of heritage [27]. In the Spanish case, the management of the WH requires studies to evaluate management models, and to adapt planning to the new holistic paradigm promoted by UNESCO [28].

Based on the premises above, this article seeks to analyse the state of WH management in Spain in light of the evolution of international criteria. Information on the declaration processes will be collected, with emphasis on the temporal development of the recognised values as well as on the processes for their monitoring, being the ultimate objective of the analysis of the implementation of Management Plans (MP). These are understood as tools capable of reinforcing the integral vision that should characterise the consideration of the property, which must include reference to sources of a diverse nature for the recognition of values, the integration of immaterial and local issues [29], as well as ensuring the identification of the actors involved.

Methodology and data sources

The working methodology followed for the development of this research focuses, firstly, on the knowledge of the basic requirements that UNESCO has been dictating for the management of a WH property, as well as the proposed system for the drafting of monitoring reports, analysed from the perspective of the evolution in the conservation of heritage values. Their classification, the analysis of their scope and periodicity, will allow for a review of WH's management, applied to the Spanish context.

To this end, a table is drawn up where the data related to the implementation of the management are compiled, classifying them in four blocks: 1) identification of the Spanish registered properties; 2) inscription on the WH List; 3) documents for management and planning; 4) monitoring carried out by UNESCO. Each of these sections breaks down the information relating to each of the properties studied, obtained from different sources of information: i) publications, reports and dissemination of the sites themselves; ii) freely accessible documents for UNESCO monitoring (periodic reports, state of conservation reports); iii) congresses and conferences.

The identification of the WH properties includes, where applicable and where known:

- Denomination: the exact name under which the property or group of properties is registered;
- Location: place and city in which the property or properties are located – in the case of Spain, the Autonomous Community in which the property is located will be decisive, since competences in the field of culture were progressively transferred to the autonomous communities from the State after the establishment of democracy (1975);
- Managing body: public institution responsible for the management of the property;

- Affiliation: to a specific group organised to share experiences. Such is the case in Spain of the Alliance of Cultural Landscapes and Related World Heritage Sites, Patrimonio Nacional or the group of World Heritage Cities.

The Inscription column focuses on the aspects covered by the declaration:

- Category: natural, cultural or mixed (as indicated in the 1972 convention);
- Type of asset, when it is officially stated: monument, world heritage city, site, cultural landscape;
- Date of inscription: year in which the declaration dossier is approved;
- Extension: when applicable, the date on which the property or area designated in the initial declaration is extended;
- SOUV: the year in which the SOUV is delivered. A colour code is applied to mark whether the SOUV was established together with the registration documentation of the property or retrospectively, to adapt the OUV to the indications provided by UNESCO in the 2005 guideline [30-31].

The management of the property is addressed by collecting data on planning documents, management plans, or master plans related to it. Reliable sources are prioritised for the location of these documents, preferably official media, open data and information provided in the reports. This means that for some properties it may not have been possible to find sufficient information, limiting the assumed scope of the research. A colour code is applied to the identified documents to differentiate between: 1) documents that meet international requirements for management; 2) documents under development or not approved; 3) documents that partially address the management of the property; 4) documents of partial effect under development or not approved. The type of document, the link to open access to its contents and the year in which it was approved are indicated.

Finally, the last column is devoted to compiling information related to the monitoring carried out to date by UNESCO through the different monitoring processes, indicating the information available on UNESCO's website related to state of conservation reports, monitoring reports and HIAs [32].

The synthesis of the information gathered will allow for analysis and diagnosis of heritage management applied to the Spanish case study. Based on the shortcomings detected, conclusions will be proposed to improve the management of these assets, with special emphasis on the sustainable perspective.

World Heritage monitoring processes: reactive and periodic reports

Following the enactment of the Convention, the issue of the conservation of inscribed properties gained prominence, leading to a series of initiatives for the evaluation of their state of conservation. In the 1990s, the Committee received reports drafted by the Advisory Bodies, developed on their own account and following different models and methodologies [15]. In 1997 the procedure was standardised, establishing a distinction between reporting in response to threat situations and a periodic and systematic reporting exercise that establishes an ongoing monitoring of the conservation of the property.

Reactive monitoring: state of conservation reports and heritage impact assessments

From the first ad hoc reports, the procedure evolves towards a reactive approach to monitoring, whereby States Parties are called upon to report whenever an external threat or planned activity likely to affect the conservation of the OUV of the property is detected. The Committee may then request the drafting of a “State of Conservation Report”, which should address the follow-up to any previous decisions of the Committee – a common procedure for properties on the List of WH in Danger – information on threats identified by the State Party to the OUV of the property concerned, as well as a description of the planned actions that may lead to alterations to the OUV, including its authenticity and integrity [33].

Since 2008, the Committee has expressed an interest in the potential of these reports as a source of experience to help map patterns of need and identify priorities in the conservation of these properties [34]. In 2011, the “State of Conservation Information System” was created, a computerised information system that contains the history of the WH's states of conservation and provides a tool for the detection of affecting factors and informed decision-making. On the associated web platform, the factors with the most associated reports to date are those related to management and institutional factors (3072), buildings and development (1699), conflict (1410) and social/cultural uses of heritage (1274) [35].

A fundamental tool for monitoring conservation are HIAs, developed and standardised after the documents generated by ICOMOS in 2011 [36] and UNESCO in 2022 [17]. These reports complement planning towards sustainable management of WH properties, constituting a prerequisite for activities affecting the attributes of the property or its surroundings and having continuity during and after the development of the specific action [37].

HIA is a preventive exercise, which makes it possible to identify positive or negative effects on the property in advance and to consider alternatives if deemed necessary [33], making it a tool for achieving sustainable development compatible with the protection and conservation of the WH. Assessing the ability of an action to achieve environmental, social and economic outcomes provides not only a means to protect the OUV, but also integrate those co-existing values that may not be recognised within the SOUV, but which underpin it, such as national and local heritage designations or values held by associated communities [17].

Planned monitoring: periodic reports

Periodic reporting constitutes the strategy for the continuous monitoring of the application of the Convention, where each property undertakes a self-assessment exercise of the work carried out for the conservation and protection of its values [33]. In 1998, the procedure was established in cycles of approximately six years, during which each region (Arab States, Africa, Asia and the Pacific, Latin America and the Caribbean, Europe and North America) must submit the reports on all their properties. A period of reflection is set between cycles for evaluating the results and revising the forms for the next cycle [38].

Reports are structured in two sections: 1) Section I, filled in by the national focal point, contains the legislative or administrative provisions adopted by the State Party for the implementation of the Convention in its territory; 2) Section II is addressed to the managers of each property, who respond on the SOUV, it's integrity, management, factors of affection and monitoring arrangements [39]. The ultimate objective is to generate a system of regional cooperation, in which States Parties benefit from the exchange of information and experiences in the implementation of the Convention, drawing up regional Action Plans based on the reports at the end of each cycle [40].

Three cycles for reviewing and updating periodic monitoring

Since the establishment of periodic reporting, the duration of cycles has varied slightly (Figure 3). The first cycle took place between 1998 and 2006, with the participation of the properties inscribed up to 1997 [39]. Among the conclusions drawn from the results, it was noteworthy the creation of a Retrospective Inventory [41] with a view to harmonising and updating the files of the properties inscribed between 1978 and 1998 as well as the request for State Parties to finalise all missing SOUVs [42]. A general assessment of the process was carried out during the reflection period, looking for the adaptation of the form to suit complex properties such as cultural landscapes or serial properties.

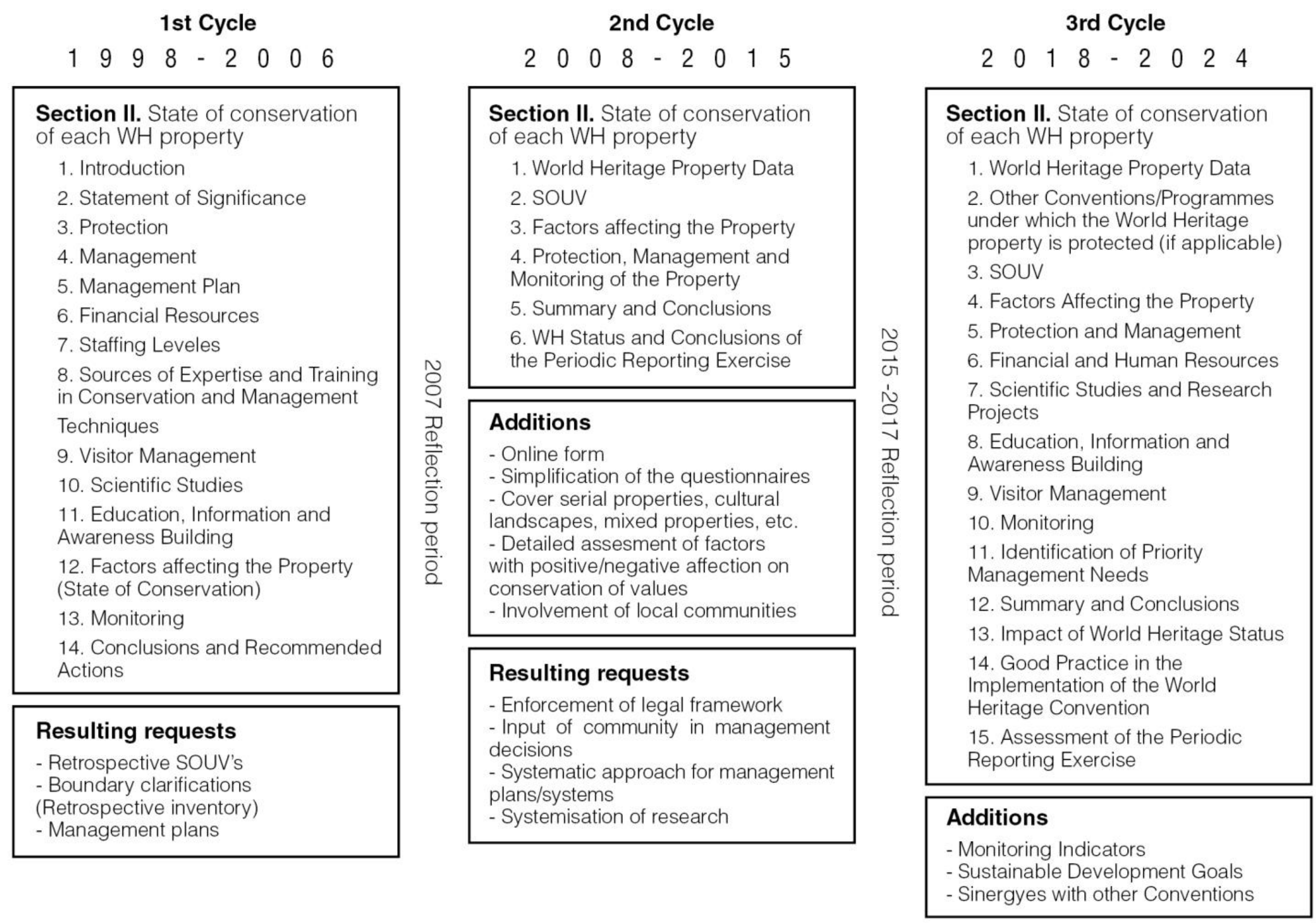

Figure 3. Section II of Periodic Reporting through the cycles. Structure, additions and resulting requests.

The second cycle (2008-2015) marked the effective transition to the online completion model, simplifying the content structure and incorporating scoring tables on conservation risks. Conclusions derived from this exercise were the adaptation of the legal framework towards conservation, and the need to implement management systems, integrating local communities and research in the management task [43].

From its inception, the reports have sought to obtain accurate information through a generic short-question model for the entire WH, a process in which it is now questioned that the specificities of each property may be blurred [44], that is why the revised questionnaire for the third cycle (2018-2024) incorporates a focus around the 2030 Agenda, relying on WH as a platform for sustainable development and considering synergies with other international conventions and developing a framework of monitoring indicators to assess trends by thematic areas [40]. By 2024, we are in the final stretch of the third cycle, with the last Action Plan -for Europe and North America- due to be presented in July.

A tool for planning conservation: Management Plans

Heritage management was merely suggested in the original text of the Convention, but after the first cycle the Operational Guidelines definitively incorporated the mandatory elaboration of MP for WH properties in 2005. The effective long-term management of a property is understood as the main tool for safeguarding the OUV, therefore the implementation of a management system joins the selection criteria, integrity and authenticity as defining pillars of the OUV [45].

Management plans are the main planning tool available to the agents involved in the management system of a property. Although designed to ensure the effective protection of the

OUV, it is important to consider that the MP will normally cover a much larger collection of values, underlying the value recognised as outstanding. With the development of society and the heritage discourse, these values may evolve without necessarily implying a modification of the OUV, resulting in a complex scenario in which MPs must be a tool capable of embracing this evolution, promoting the valuation of the property along the desired path [3].

In view of the great diversity of heritage cases included in the List and of the different management systems in each country, the definition of a single international model for the content of the MPs becomes a problematic task. This is why UNESCO only provides a definition of the competences and instrumental issues that each property must then individualise according to its national reality, legislation and local specificities [33].

A diagnosis of World Heritage management in Spain in the international context

Inscriptions on the List

Spain is the fifth country with the highest number of inscribed properties, behind Italy (60), China (59), Germany (54) and France (53). In its 50 properties, cultural heritage significantly outweighs the other categories, and, to a certain extent, the Spanish case can be interpreted as an approximate reflection of the international composition of the List (Figure 4). However, UNESCO's efforts to create a representative and balanced list after the turn of the century result in a continuous growth of less represented types, while in Spain the gradual diversification is less pronounced.

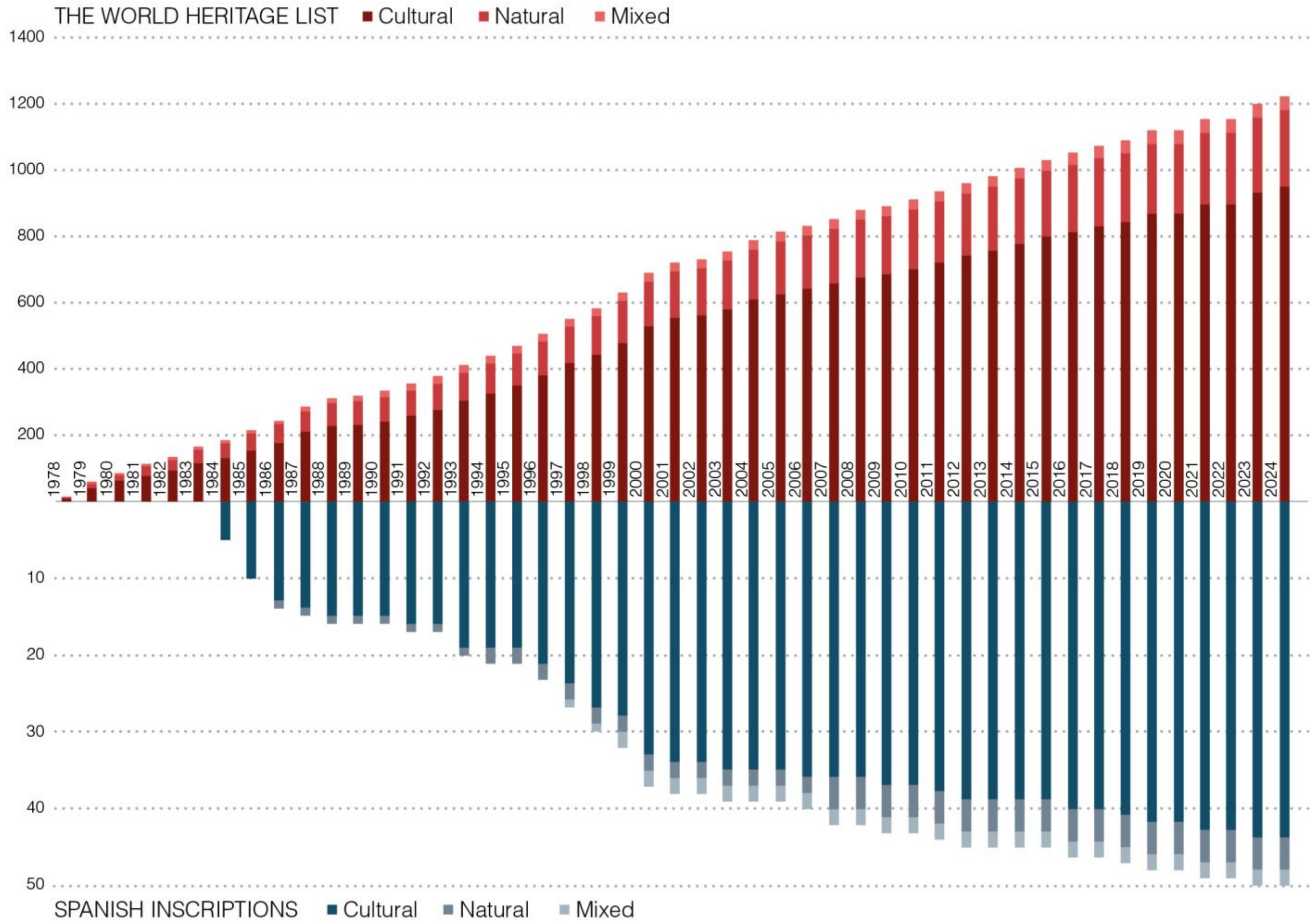

Figure 4. Inscription of properties in the World Heritage List vs. Inscriptions in Spain, by categories.

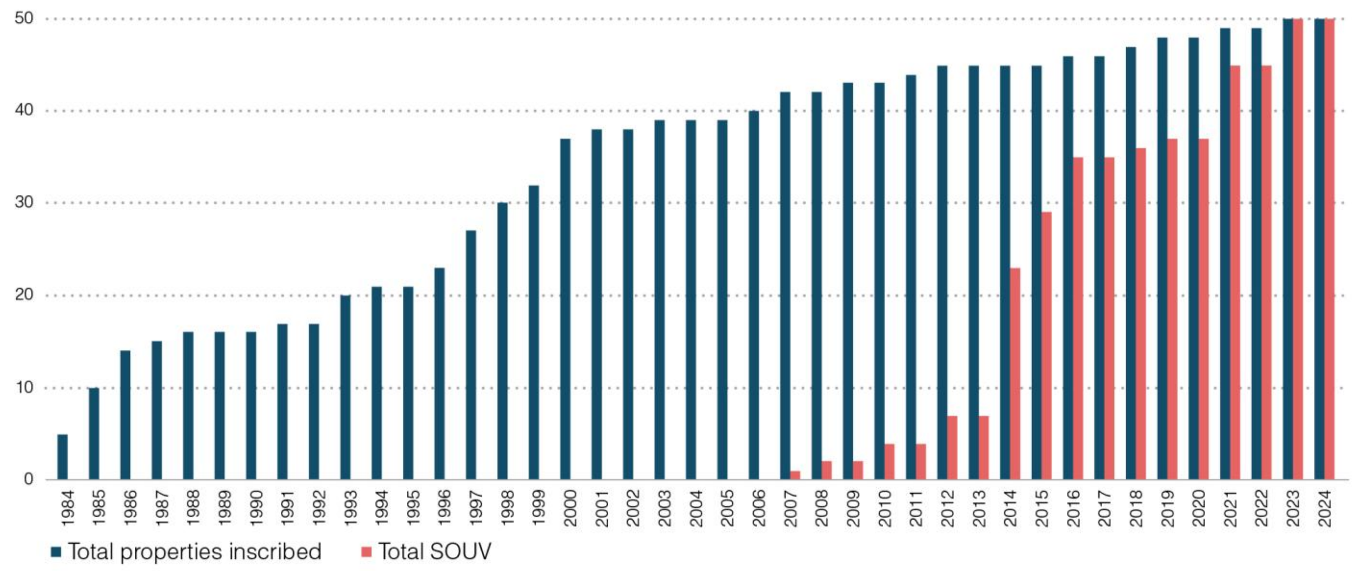

Figure 5. World Heritage inscriptions in Spain and Statements of Outstanding Universal Value.

The first inscriptions (1984) had an evident monumental component, even if some of them were later extended to incorporate the urban dimension (the Cordoba Mosque became the Historic Centre of Cordoba and the Alhambra and Generalife saw the Albayzín district added to their inscription). Natural heritage was recognised very early on, with the inclusion of the Garajonay National Park in 1986, and mixed heritage was inscribed for the first time in 1997, with the cross-border inscription of Monte Perdido, which is also the first Spanish site inscribed as Cultural Landscape.

Characterisation of WH properties as Cultural Landscapes does not exempt them from inscription according to the selection criteria within the categories of Cultural, Natural or Mixed Heritage, but adds another layer of information that expands the significance of their values. In Spain there are five properties registered as Cultural Landscape, all of them, except for Monte Perdido, added since the turn of the century. Examples like the industrial archaeology of Vizcaya Bridge (2006), Heritage of Mercury (2012) or the cultural itineraries of the Routes of Santiago de Compostela (1993) also reflect an international interest in opening the List to other types of heritage.

Retrospective SOUVs are developed in efforts discontinued over time so, taking into account that from 2007 onwards all new registrations already contain the consensual SOUV, it is not until 2023 that a rate of 100 % of properties with a SOUV is achieved (Figure 5).

Monitoring the Convention

From the implementation in 1997 of the monitoring mechanisms, Spain has submitted a total of 82 State of Conservation Reports to account for its work towards the implementation of the Convention (Figure 6). The number of reports a property or State Party needs to undertake reflects the complexity of its management and conservation, as well as the threats to which it may be exposed. Among cultural properties, most of them have never required such reports. This is why cases such as Salamanca stand out, having drafted ten reports since its inscription. On the other hand, natural properties tend to appear on the other side of the table, with Doñana as a paradigmatic case with 16 reports. The Teide National Park is the only natural property that has not drafted such reports since its inscription in 2002.

Regarding periodic monitoring, Spain participates in the three cycles developed so far, submitting its reports within the Europe and North America region (Figure 7). The 27 properties inscribed at the beginning of the first cycle participate by submitting the corresponding reports when the region's turn comes in 2007 (despite having already inscribed 40 properties by then). Something similar happens in the second cycle, in which the 42 properties inscribed at the beginning of the cycle (2008) participate, despite submitting their periodic reports in 2014 when Spain had 45 properties on the List. In the third and final cycle to date, however, the national focal point has submitted reports to the WHC for all 49 properties inscribed in the submission year, 2023, leaving out only Talayotic Menorca which is inscribed in the same year. This means that properties registered during the period of the third cycle started to prepare their reports as an immediate task after their inscription.

From the information available on the outcomes of these reports, we have looked at the resulting data on the declaration by property managers regarding the existence of an adequate Management Plan in use. Thus, while in the first cycle only approximately 7.4 % declared that they had a MP, in the second cycle 33.3 % did so, and in the third cycle 87.5 % of the assets declared positively.

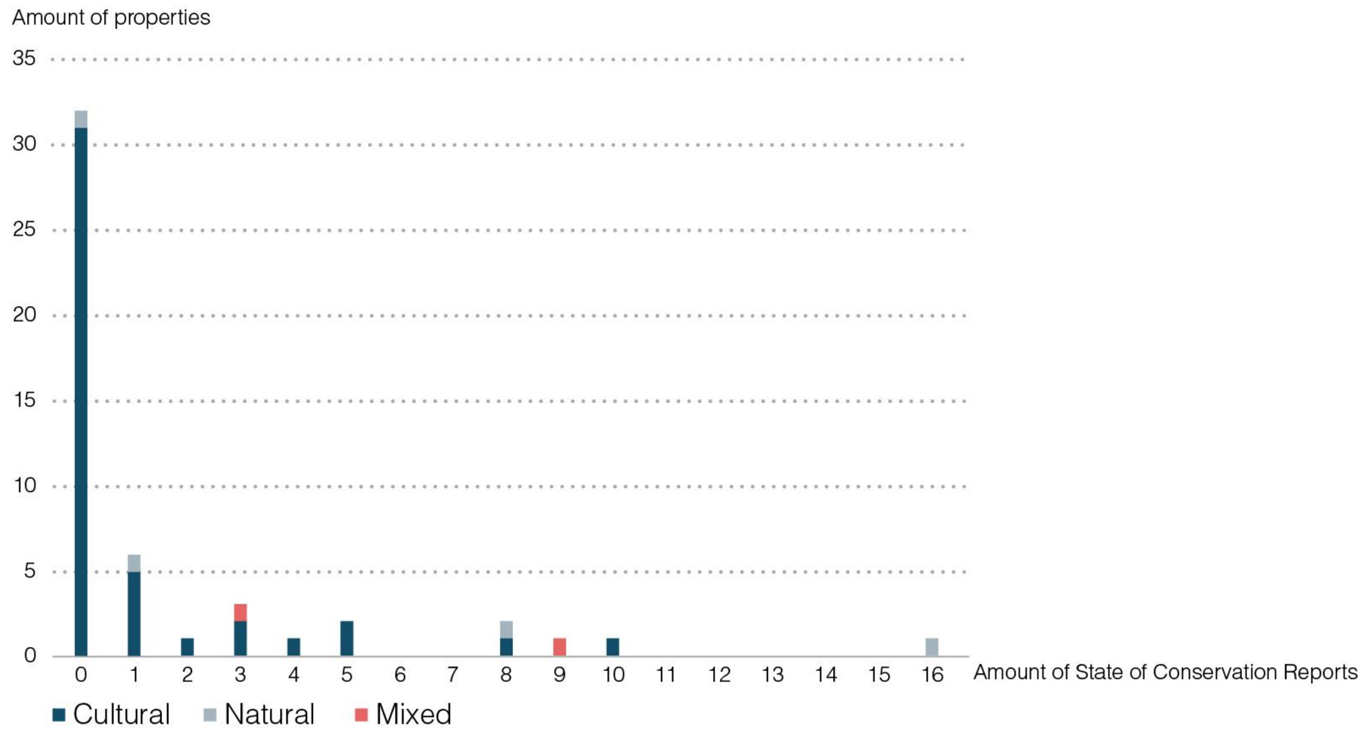

Figure 6. Amount of State of Conservation Reports by classification of World Heritage in Spain.

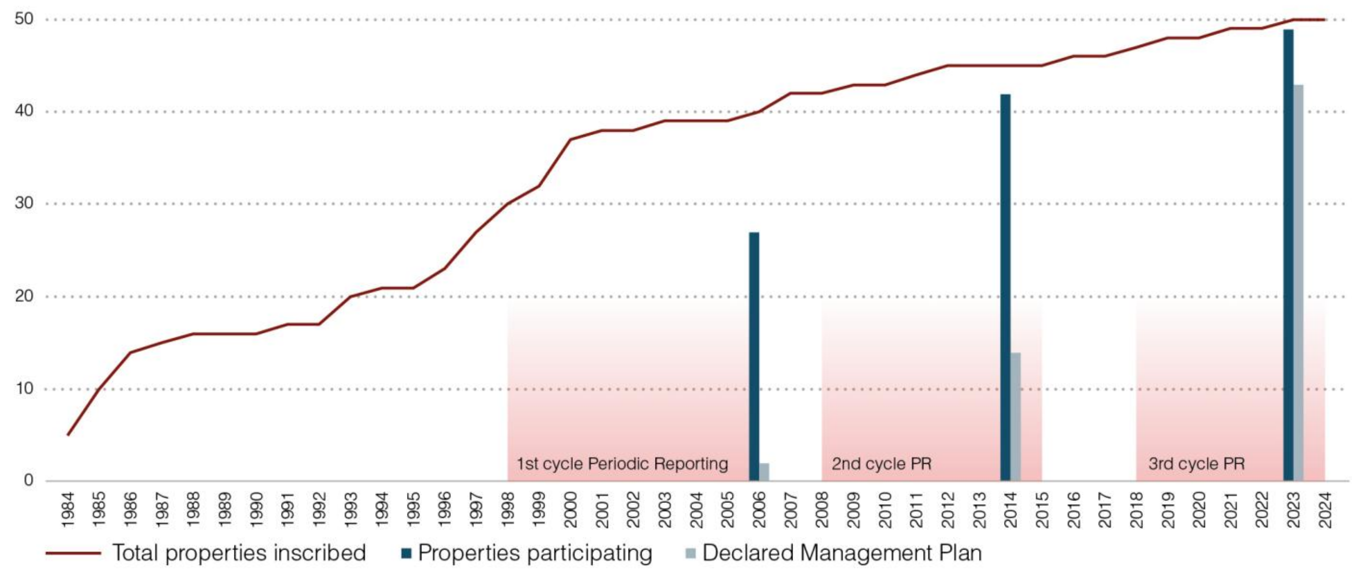

Figure 7. Percentage of properties declaring Management Documents in each Periodic Reporting Cycle in Spain.

Managing WH

The difficult relationship between international requirements for managing WH properties and adapting them to local resources and specificities produces a picture that varies according to the different national contexts.

In Italy, the responses to these requirements are usually centralised. The Ministry of Cultural Heritage and Activities began to prepare MPs for a large part of its WH properties in the 2000s, publishing a series of guidelines [46] which in 2006 were reinforced by the integration of this figure into national legislation [47]. Where previously the law only considered planning documents for natural parks, historical centres and monumental complexes now fall within its scope, notwithstanding the struggle to reconcile them with existing management tools [48].

However, one of the most influential actors in the international heritage scene, with the potential to overtake all others in number of inscriptions, paints a somewhat different picture. The geographical, historical and demographic particularities of China contribute to form a picture of great institutional complexity, marked by an administrative decentralisation in which operating responsibility lies with local administrations and a historical departmental structure in which responsibilities often overlap [49]. In the last decades, China's involvement in international heritage policies has resulted in a development boom, the result of a prevailing conception of heritage as a tool for local development through its tourist exploitation that has yet to efficiently integrate the interests of local communities [50].

Spain has accompanied these two countries at the forefront of the List for decades, applying a model closer to the Italian one, in which the Ministry of Culture issues grants and advice for projects for the management, protection and conservation of WH properties, and looking at already existing planning tools for its compatibilization with the new requirements.

When analysing the emergence of the various documents used by Spanish properties for their management and conservation, we can highlight two types of heritage which, because they have received specific attention from UNESCO in recent decades, enjoy a particular development apparent in the results of the research. We refer to Cultural Landscapes and World Heritage cities and Urban Heritage. These are not incompatible affiliations and in the Spanish case there are properties pertaining to both, just as they can be assigned to both Spanish specific groupings created for the joint work of these sites (Table 1).

The first documents to appear for the management of historic sites or with an urban component are urban planning tools, which, despite their legislative quality, leave numerous questions necessary for the planning and deployment of strategies for the protection, conservation and management of these properties to be addressed. However, in the case of historic areas, there is a direct relationship between the drafting of subsequent MPs and their membership of the Spanish World Heritage Cities Group, which has been trying over the last decade to draft the plans of all its member cities.

In the case of natural and mixed heritage, the Master Plan for Use and Management appears as the only management tool, as it is the document established by Spanish regulations for the planning and conservation of Natural and National Parks. Although it is a document with legal and binding capacity, the Management Plan (2018-2028) developed for Monte Perdido opens the door to the proposal of documents that better meet international criteria for heritage management.

From the data compiled within the context of this investigation, we have been able to draw up a fixed picture of the suitability of the management and conservation documents available to the Spanish WH to date (Figure 8). Thus, compared to 46 % who have tools considered adequate according to UNESCO's criteria, 34 % do not have any documents at all. It must be noted that the last group includes most of the so-called serial properties, which usually require the prior preparation of individualised management documents for each of the properties that comprise them (or in cases that cover different territories, such as the Routes of Santiago de Compostela or the Rock Art of the Mediterranean Basin Peninsula, for each autonomous community). While the effort generated for the creation of many of the individual plans is acknowledged, progress for the joint documents has barely reached the drafting stage. Assets that have management documents in line with international consensus, but only cover partially the WH delimitation, have been considered separately.

Table 1. Spanish WH properties as Cultural landscapes (CL) and World Heritage Cities Program (WHP). Affiliation to national groups for shared management and experiences, Alliance of Cultural Landscapes and Related World Heritage Sites (Alliance of CL) and Spanish World Heritage Cities Group (WHCG).

Property	Category	CL	WHCP	Alliance of CL	WHCG
Alhambra, Generalife and Albayzín	Cultural		×	×	
Historic Centre of Cordoba			×		×
Old Town of Ávila with its Extra-Muros Churches			×		×
Old Town of Segovia and its Aqueduct			×		×
Santiago de Compostela (Old Town)			×		×
Historic City of Toledo			×		×
Old Town of Cáceres			×	×	
Cathedral, Alcázar and Archivo de Indias in Seville			×		
Old City of Salamanca			×		×
Archaeological Ensemble of Mérida			×		×
Historic Walled Town of Cuenca			×		×
University and Historic Precinct of Alcalá de Henares			×		×
San Cristóbal de La Laguna			×		×
Roman Walls of Lugo			×		
Aranjuez Cultural Landscape		×	×	×	×
Renaissance Monumental Ensembles of Úbeda and Baeza			×		×
Cultural Landscape of the Serra de Tramuntana		×		×	
Risco Caido and the Sacred Mountains of Gran Canaria Cultural Landscape		×		×	
Paseo del Prado and Buen Retiro, a landscape of Arts and Sciences		×	×		
Pyrénées - Mont Perdu	Mixed	×			
Ibiza, Biodiversity and Culture			×	×	×

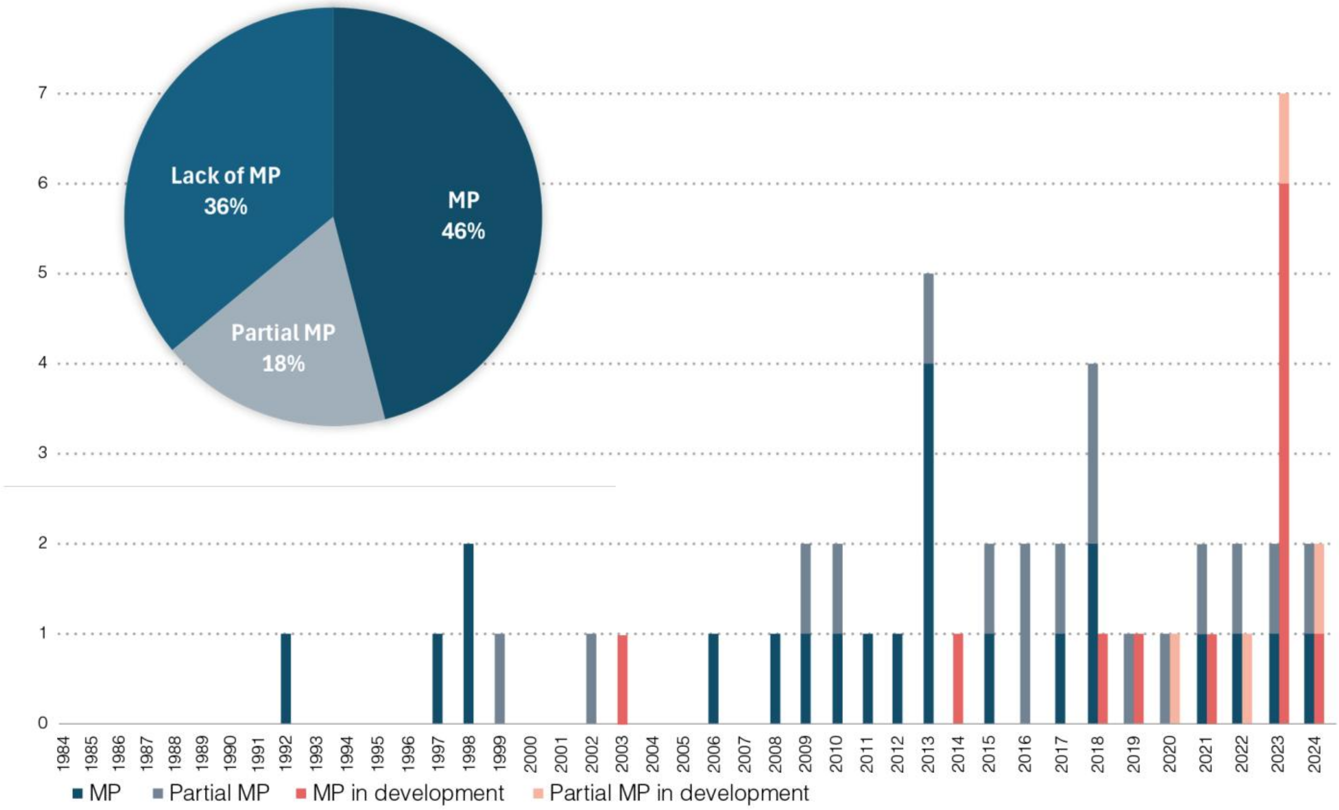

Figure 8. Percentage of properties presenting Management Documents, Partial Management Documents, and properties without an adequate Management Plan in Spain, 2024 (circle). Amount of Management Plans approved or in development (bars).

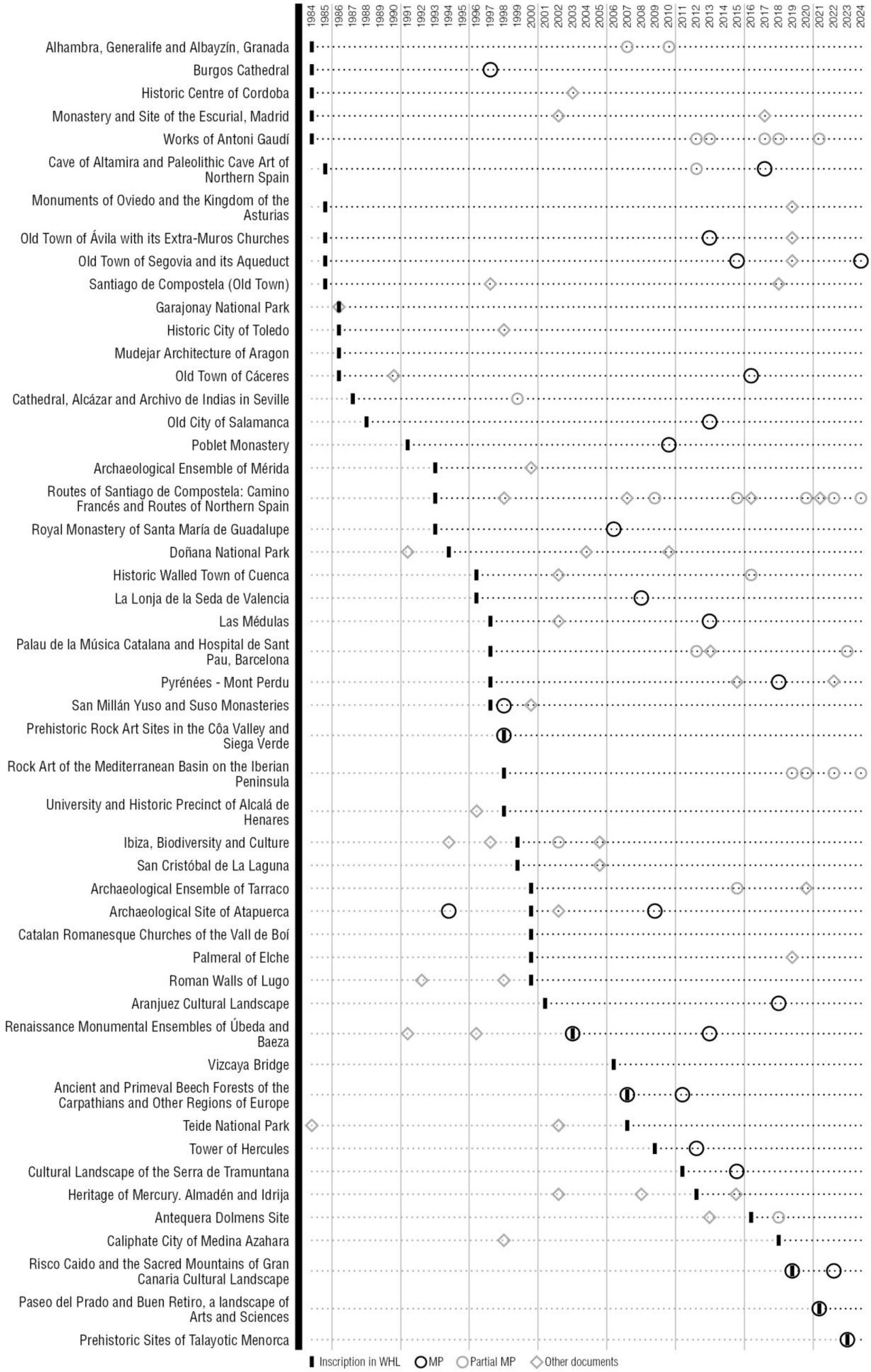

Figure 9. World Heritage in Spain. Documents for heritage management through time.

However, if we consider the drafting date of the management documents we have counted (Figure 8), over 60 % are older than the five-year implementation span recommended by UNESCO, some of them being elaborated in the 1990s. The oldest documents belong mostly to church properties that developed their MPs after the approval of the National Plan for Cathedrals (1990) and the National Plan for Abbeys, Monasteries and Convents (2004) developed by the Ministry of Culture.

The momentum experienced in the drafting of these documents from 2005 onwards is remarkable, when the need for their drafting was included in the WHOPs, the properties grouped in the Spanish World Heritage Cities Group were the first to respond to the request. If we also consider the MPs with partial affection, this effect is even more evident.

Moreover, if we consider those documents which at some point in time are reported to have begun drafting work (notwithstanding whether it has been possible to verify if this work has been abandoned at some point), their proliferation in recent decades is also notable. In 2023, a peak appears directly related to the most recent inscriptions, especially the Landscape of Arts and Sciences (2021) and Talayotic Menorca (2023) which not only incorporated a MP in their nomination documents but announced the beginning of the processes of revision and further development of new plans immediately after inscription.

Finally, a chronogram has been drawn up for the development of these various documents for each of the 50 Spanish properties (Figure 9), a summary of the research, and a graphic reflection of the progressive evolution from the first inscriptions that spent years without a MP to the latest inscriptions that incorporate the plan in the nomination document itself.

Discussion and conclusions

From the earliest charters, the discourse around heritage has evolved within the international community while UNESCO's programmatic development has set the tone for heritage conservation, generating a rich body of mechanisms and knowledge around WH that is no less applicable to other local heritages.

UNESCO's efforts to achieve a representative and balanced List have led to a progressive updating of the recognised categories, the reformulation of key questions in heritage conceptualisation and the generation of a vast network of knowledge to understand WH in an increasingly holistic and inclusive way. From updating the OUV to actively participating in monitoring processes, WH properties require constant work only to meet the ever-increasing complexity of international requirements.

In recent decades, important progress has been made in recognising the role of heritage in ensuring social cohesion, environmental sustainability and the sustainable cultural and economic development of communities, with the adoption of the World Heritage and Sustainable Development Policy in 2015 as a key milestone. This translates into the progressive adoption of a people-centred approach to conservation, where communities gain an important role in the governance of their heritage, instead of the more traditional exclusively experts-based management. It is an international challenge that each State Party must strive to adapt to its own operational context.

Spanish efforts to implement the international guidelines on the identification, definition and conservation of WH have been particularly noteworthy in the last two decades, but it is still necessary to persist on pressing issues such as implementing the tools for sustainable and comprehensive management, where there is a lack of unity in the models used. Having analysed the different sources available, and within the limitations of this study, we can conclude that while almost all properties have a sufficiently clarified and effective management system, the documents used for WH management in Spain are still insufficient in most cases, either because of their content, age, or because they cover only part of the property inscribed. The preference for solutions contained in the corpus of Spanish legislation, considered more practical, is still notable, leaving the MP to act as a complement to other legally valid instruments, establishing a strategic basis for protection, but leaving the rest of the issues addressed by the plan without legal support.

The different financial and administrative models affecting each property generate a heterogeneous picture in which finding common criteria and searching for models that can provide legal capacity are of paramount importance. The impact of the efforts developed within the heritage alliances is proof that this is the right way forward.

Furthermore, the complexity of these properties often implies coordinating diverse administrations, owners or communities, making real-time management difficult. This is one of the current challenges facing heritage: the integration of participation in the drafting, approval, monitoring and sustainable management of heritage projects, achieving transversal and inclusive cooperation of all the actors involved. Efforts in this direction are increasingly visible in the policies developed internationally in recent decades, and it is the responsibility of State Parties and managers of WH properties to continue along this path, setting an example for the rest of the heritage community.

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ARTICLE / ARTIGO

Notes on the display of the *Hall of the Expansion of Christianity* in the Museu Biblíc Tarraconense: between copies, reconstructions and didactics

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Notas sobre a exposição da *Sala da Expansão do Cristianismo* no Museu Biblíc Tarraconense: entre cópias, reconstruções e didácticas

Abstract

This article presents historical and critical reflections on the display of the Hall of the Expansion of Christianity in the Museu Biblíc Tarraconense. In the first part it recalls the history of the museum and its cultural background; then it describes the hall and its composition. It ends with comparisons with other cases of similar museum displays between the 1850s and the 1950s, and a reflection on copies and authenticity in museum. The aim is to focus on this example of museum recreation of early-Christian burial and cult settlements, to contribute to the study of casts and reproductions and their role in European historical museum displays for Christian archaeology.

KEYWORDS
Museum exhibitions
Replicas
Authenticity
Religious museums
Early Christian art

Resumo

Este artigo apresenta reflexões históricas e críticas sobre a exposição da Sala da Expansão do Cristianismo do Museu Bíblìc Tarraconense. Na primeira parte apresenta a história do museu e o seu contexto cultural e, em seguida, descreve-se a sala e a sua composição. Termina com algumas comparações com outros casos de exposições museológicas semelhantes entre as décadas de 1850 e 1950, e uma reflexão sobre cópias e autenticidade nos museus. O objetivo é centrar-se neste exemplo de recriação museológica de assentamentos cristãos primitivos e cultos funerários, contribuindo para o estudo de moldes e reproduções e do seu papel para a arqueologia cristã em exposições em museus históricos europeus.

PALAVRAS-CHAVE
Museologia
Reproduções
Autenticidade
Museus religiosos
Arte cristã primitiva

Introduction

Many European museums still preserve or re-create display modes and museographic concepts developed in past centuries, but which are still valid or interesting today due to their historical importance, didactic usefulness, and their particular aesthetics. It is, for example, the case of the extensive use of copies and reproductions in museum displays. The tradition of copies and reproductions in museums is long and important, and much analysed in the international context [1]: although the museum is the place of material transmission, hence the place of originals, copying is appreciated for aesthetics, and educational purposes, from the middle of the nineteenth century with the emergence of historical museums everywhere [2]. Copies are therefore admitted into museums over the centuries as a means of better understanding, especially in the archaeological field where artefacts need more protection or need to be deeply explained for their better understanding in the museum [3]. Moreover, casts and copies begin to appear in museums, as we shall see in the specific case of this essay, when the originals are inaccessible or are located in places to which not everyone could travel [4]. In this sense, from the mid-nineteenth century onwards, the permanent presence of copies and casts in museum displays became the main instrument to promote education, artistic training and museum narration [5]. Indeed, starting with the *Convention for the universal promotion of reproductions of works of art for the benefit of the museums of every country* signed at the Universal Exhibition in Paris in 1867 and the creation of important museums that make copies the core of their collections (e.g. the Victoria & Albert Museum or even the Metropolitan Museum in New York), throughout the twentieth century casts became desirable for the creation of "universal" museums of arts and archaeology throughout the western world.

Museum displays thus always reflect the choices of their society. In contemporary times, with the recent central role of the museum in the development of communities and in the formation of a common identity, copies and reproductions of high technical quality play a heartfelt and beneficial role in engaging visitors in museum discourse. They also appeal to an emotional sphere of private experience, of preserving and understanding objects: copies are more approachable and visible, they allow a more direct contact with the past. Today, integrating copies and reproductions into the exhibition still may also mean giving didactic tools to a wider public, as well as allowing direct experience of access to works and contexts at risk or otherwise impossible to reach, creating relationships between objects, filling gaps and creating more complex archaeological discourses.

In the latest years, the interest on the "historical culture" and social aspects of the collections has been at the very basis of a wider inclusion of visitors' experience in the presentation of history and have been leading to new ways of staging exhibitions [6]. Focus of art has been shifting from the single piece to the historical background [7] and it reflects on restaging exhibitions. There is increased attention to the individual and on the creation of different exhibition mode based on the fact that objects are historically significant only if seen together. Contemporary museums believe in the importance of visual information and are everyday more interested in displaying objects collectively to present larger history and create connections beyond the single textual aids and written information. These collective displays can be created even without authentic objects, aiming at providing "experience" as an opportunity to learn [6]. Sometimes, collections and objects are almost irrelevant to the social and didactic purpose and to the institutional mission: when museums are linked to education, they can decide that objects are not necessary for their didactic purposes [8]. Reimagining the museum experience of the visitors beyond the traditional focus on physical objects today can lead to a greatly impactful visit, a deeper connection with object history. The reframing of museum experience is therefore a very contemporary issue that challenges the central role of museum artefacts [9].

At the same time, these are issues that involve every time more the concept of interpretation in museum. After the emerging of new need of heritage access and understanding, heritage interpretation led on heritage sites, visitor centres and museums are becoming a key tool for access and understanding, information sources, context and setting, authenticity, tangible and intangible values [10]. Over the years, the interest on heritage interpretation in museums has been growing [11] and interpretation has been developing as a working method both for presentation and public use of heritage, using many presentation resources based on cultural evidence and promotion of original contexts. Heritage interpretation has been proved to answer to public needs of education and leisure, understanding and experience of the site. Interpretation tools bring visitor closer to the site, with numerous presentation forms and techniques both in interpretation centres (to support visitor in exploration and interaction with heritage) and museums (where do not aim only to collect, conserve and study objects, but to offer a better communication of meanings and interrelationships of cultural heritage [12]. In contemporary debate, interpretation serves as a management tool for communicating with the public [13], especially when it focusses on the context of the collections, promoting its use for cultural, educational, social and tourism purposes [14].

The development hinted at here can be clearly seen in the case we are going to examine, namely the Hall of the Expansion of Christianity in the Museu Biblíc Tarraconense, and in the critical reflections related to it. This museum was created at the beginning of the twentieth century with a clear didactic intent and, therefore, based mostly on copies.

In this sense, this study focusses on issues of museum display and aims to disseminate a case of a type of museum display and curatorship activity, that is effective from a communicative point of view and also belongs to a long museum tradition.

Museu Biblíc Tarraconense

The history

The city of Tarragona has an archaeological museum tradition of considerable importance, starting with the collection of the antiquities of the sixteenth-century scholar Anton Augustí. The rising of the city's museums dates back to the beginning of the nineteenth century, when the museums of the Comissió Provincial de Monuments de Tarragona and the Reial Societat Arqueològica Tarraconense were founded [15]. The collections of these institutions were brought together in 1860 in the Provincial Archaeological Museum, which, from its first location in Plaça de la Font in what is now Ayuntamiento, collects finds from all the archaeological discoveries in the province. The museum still exists today as the National Archaeological Museum of Tarragona (MNAT), whose historical headquarter in Plaça del Rei is currently undergoing major restoration and refurbishment work that will hopefully end in 2025 [16]. The main pieces of the permanent collection are now on display in a temporary installation in a structure in the city's port area, the Tinglado 4: this is a museographic experiment that follows in the successful trend of the exhibitions of antiquities hosted in industrial and contemporary venues and represents an excellent example of exhibition and didactic synthesis of a rich collection with a strong historical background. Other important institutions to define Tarragona's museum richness are the house-museums (i.e. Casa Museu Castellarnau or Casa Canals), the Diocesan Museum and the Museum of the Roman-Christian Necropolis. The Museum of the Roman-Christian Necropolis is perhaps one of the jewels of museology on the Iberian Peninsula: although today it is in a state of disrepair, in 2022 it was selected as a recipient of funds from the Plan de Modernización y Competitividad Turística, paid for with the Next Generation EU Plan for its restoration, refurbishment and reopening to the public [17]. It is a museum inaugurated by Joan Serra Vilaró in 1930 on the very site of the Roman-Christian necropolis to keep the artefacts found there, thus preventing their dispersion outside Tarragona [18]. It is a very interesting museum, both for its history and subject (after all, it is one of the very few cases in the Iberian Peninsula of a museum that housed an exclusively early Christian collection at the beginning of the twentieth century), and for its museological layout.

In the basement, excavated burials and other architectural finds and large amphorae could be seen at close quarters. On the first floor, the outer corridor housed sarcophagi displayed in a gallery, while the central hall, the heart of the museum, was decorated with numerous funerary inscriptions on the walls and large wooden showcases in the centre with the smaller finds [19] (Figure 1).

Figure 1. Postcard of the inner room of museum of the Necropolis in Tarragona (1930s, private collection).

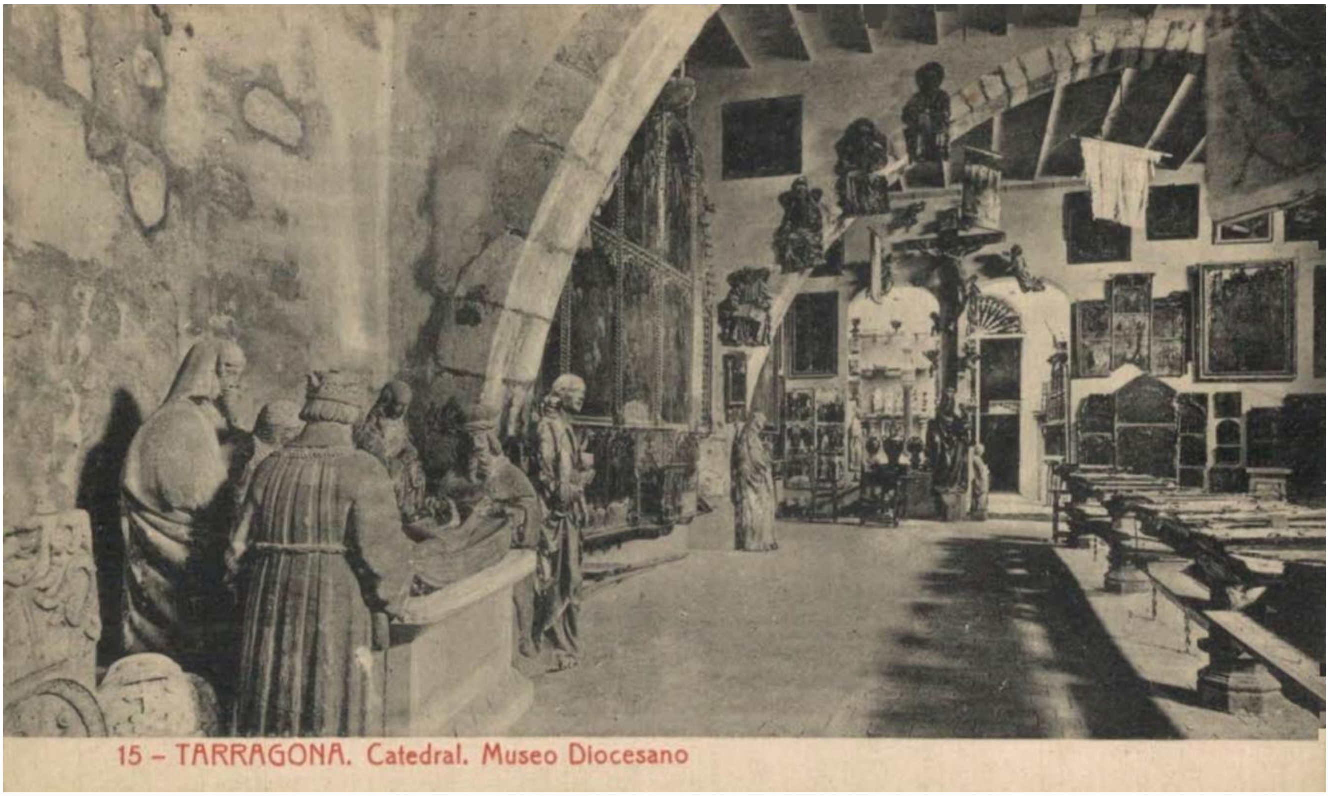

Figure 2. Postcard of the Diocesan Museum in Tarragona (1930s, private collection).

The last crucial place to briefly define the panorama of museums in Tarragona is the Diocesan Museum, founded in 1914 from the union of various collections of different provenances, and which became the convergence point of antiquities and sacred art materials from private collections and from churches and buildings in the diocese [20]. There are numerous pictures testifying the heavy juxtaposition of objects, displayed on all walls according to the accumulation canons typical of the period (Figure 2).

The museum is part of a flourishing Catalan tradition of museums of archaeology and sacred art, which has its roots in the well-known case of the Diocesan Museum of Vic and in the work of one of its main characters, Josep Gudiol i Cunill, who, inspired by contemporary Roman museology, published the first manual of sacred archaeology in Spain in 1902 [21]. The Tarragona Museum has always had the primary objective of preserving the historical and artistic treasures of the seat of the diocese, but it has had a turbulent life over time, with moves and rearrangements within the perimeter of the cathedral and in the buildings adjacent to it. Today, various rooms that open onto the cathedral cloister are being completely refurbished, according to the most modern canons of display and conservation (temperature and humidity control, proper supports, correct lights) [22].

The Museu Biblíc Tarraconense, the focus of this article, is perfectly inserted in this tradition.

The museum

The history of the Biblical Museum began when Josep Vallès, a canon and professor at the Pontifical Seminary of Tarragona, made a trip to the Near East, collecting archaeological pieces, map and reproductions of cult objects related to the Bible. On his return, he deposited these objects at the city's seminary to create a bible museum that would serve the education of seminary students and attract scholars and a more general public. This museum was well regarded by the ecclesiastical hierarchies of Tarragona, who wanted to reproduce, in the city, examples such as the Biblical Museum of Monserrat or the Diocesan Museum of Vic. The museum was opened in 1930 in the rooms of the Sacred Heart Cloister of the seminary of Tarragona. It had several nuclei of collections, from a varied archaeological section to a natural history one, and it housed some valuable pieces such as original medieval manuscripts from the cathedral treasury, but above all, many objects related to the Judaic religion and many didactic complements on religion, in particular maps, reproductions and manikins related to events in biblical history. For its founder, who was also inspired by the contemporary experiences of museums and pontifical institutes in Rome, this museum was to be a pedagogical museum at the service of culture and the history of religion, whose pioneering aim was to make people learn "by seeing, touching and creating" [23] (Figure 3).

The museum lived through ups and downs: with the civil war in 1937, it was moved to other locations in the archbishopric, only to return to its rooms in 1950. In 1968 it was dismantled, and the objects were only preserved thanks to the attention of the then diocesan archivist. In 1974, a reopening of the museum was approved with the intention of promoting the local dissemination of biblical studies, on the upper floor of the bishop's palace in 1995. In the last stage of its history, in the 2000s, the museum was once again thought of as a place to be renovated for initiation into religious history and the history of Christianity.

The new museum was inaugurated in the building of the Casa dels Concilis on the 10th of April 2006 in the presence of the then Archbishop Jaume Pujol. From the very first moment, it aimed at being a multidisciplinary pedagogical tool for a historical understanding of the Scriptures and their influence on universal culture, and was intended for the formation of the diocese and for bringing all areas of society closer to biblical culture [24]. The museum fulfils its educational task with a well-developed didactic system and by housing a wide variety of objects ranging from original archaeological and geological finds, to reproductions of sites and monuments and, above all, copies and casts of original objects, that allow visitors to see at the same time objects held in other museums or currently lost. A significant example is the cast of part of the forehead of the sarcophagus of Peter and Paul from the Necropolis of Tarragona, made and donated to the museum by Serra Vilaró himself. It is now placed at the entrance to the Hall of the Expansion of Christianity, highlighting how the casts and copies play a crucial role in the museum, both in its display and conservation choices, as can be seen in this particular room.

Figure 3. Photo of teaching activities inside the Museu Biblíc Tarraconense (1930s photography: Museu Biblíc Tarraconense).

Figure 4. Overview of the display of the Hall of the Expansion of Christianity in the Museu Biblíc Tarraconense.

The room is presented as a longitudinal space whose back wall has been chosen to reconstruct a kind of presbytery area, generically suggesting an early Christian basilica, which is explicitly linked to the history of the first Christian communities of Tarragona. By placing oneself in the centre of the room, in fact, the visitor can observe the reconstruction of four pillars that recall the presence of a nave and contribute to the reconstruction of an apsidal hall (Figure 4).

The reconstruction of the apsidal basin is completed by a painted decoration with stars, a gem-studded cross and palms on a blue background. The appearance explicitly recalls the typical mosaic decoration of the apses of large Roman churches, referring to an aesthetic immediately recognisable to the visitor as Christian and ancient. A similar Roman inspiration can also be found in the reconstruction of the altar in the centre of the apsidal area, with the aim of enhancing the fragment of an inscription with the name of Saints Fructuosus and Augurus found in the city's Necropolis [25, pp. 131-150], reconstructing a possible location in an altar mensa. The type of altar chosen for this reconstruction is perhaps the best known and best-preserved example of an early Christian altar from the 4th century with a system for direct access to the relics of a saint, the one placed on the tomb of Alexander and Eventius in the Catacombs of St Alexander on the Via Nomentana in Rome. The inscription added above this altar reproduction is the exact copy of the very fragment of the inscription with the names of the martyrs of Tarragona, the original of which is kept in the museum of the Necropolis, which also appears reconstructed in the edge of the canteen. Another copy made of an early Christian artefact found in the necropolis and preserved there is that of the floor mosaic that closed the tomb of Optimus [26, pp. 321-345]. The copy is placed in the floor in the centre of the room, in front of the altar, recalling the presence in early Christian basilicas of floor tombs of various kinds. A small mosaic with a Eucharistic theme of fish and loaves, a copy of a detail from the floor of the Church of Multiplication in Tabgha (Cafarnao), has been placed in the floor near the altar. On either side of the apsidal area there are two small rooms. The room on the right was used as a reconstruction of a small polygonal immersion baptistery, mosaic-covered on the inside, copying North African examples. On the wall, a scene of Adam and Eve is reproduced that clearly recalls a catacomb (Figure 5).

Figure 5. Reconstruction of: *a)* the baptismal font and *b)* a catacomb painting of Adam and Eve (right) in the Hall of the Expansion of Christianity in the Museu Biblíc Tarraconense.

The room on the left is the most interesting, because the entire long wall is occupied by the reproduction of an arcosolium of a Christian catacomb in Rome, including the reconstruction of the tomb with the body of the deceased, closed by a glass panel to allow the visitor to look inside. The wall decoration reproduces, with some modifications, the upper part of the painted wall of the so-called cubiculum of the five saints found in the mid-nineteenth century in the catacombs of San Callisto in Rome. Here, around the arch of the burial, the five praying saints that appear in the original painting have been reproduced and, on either side of the arcosolium, the two peacocks with painted inscriptions. On the back wall of the arcosolium, a painting of the Good Shepherd from the same catacomb has instead been reproduced (Figure 6).

Following the archive research carried out at the museum, and especially after having directly contacted the authors of the reproductions (Figure 7), it is possible to offer some technical indications on the composition of these reproductions.

The copies were requested by the then Archbishop, Jaume Pujol Balcells, to two English artists contacted by an English collaborator of the museum. The copy of the Optimus mosaic was produced mainly in the United Kingdom by Lawrence Payne, a mosaic artist trained in Ravenna. The panels were then installed into the floor of the room (Figure 8). A similar procedure was followed for the mosaic of the fishes and loaves and the inside of the baptismal font, which was an eclectic composition of general early Christian motifs, fishes and birds [27]. The paintings were also commissioned by the Archbishop in 2005 to the painter Ria Teunisse, expert in copies of ancient paintings. The Archibishop provided examples in photos and pictures with the permission of the Vatican Pontificia Commissione di Archeologia Sacra. The techniques used were fresco and secco: fresco for the paintings above the tomb with the copy of the Arcosolio of the five Saints, while an old secco technique was used for the other ones, using a natural gesso and paint with egg tempera [28].

Figure 6. Reconstruction of the catacomb arcosolium in the Hall of the Expansion of Christianity in the Museu Biblíc Tarraconense.

Figure 7. The authors of the copies posing with the Archbishop of Tarragona on the opening day (10.04.2006) (photography: Museu Biblíc Tarraconense).

Figure 8. Installation of the mosaic panel at Museu Biblíc Tarraconense (photography: Museu Biblíc Tarraconense).

The hall was inaugurated together with the museum on the 10th of April 2006, and the press of the time reminds us how, from that day onwards, it served as a helpful tool of approaching ancient practices such as immersion baptism and burial in catacombs. In this sense, the room also became a new setting for events of theatrical reconstructions of early Christian rites and celebrations as part of "open days" or re-enactments of antiquity such as Tarracoviva [29].

Critical reading

After this formal description, some reflections are necessary as that are the focus of this article. From the point of view of museum display, this apparently naive and simplified layout draws attention to important precedents. In fact, in the history of archaeological museology the effect of an exposition clearly depends also on the history of the displayed objects [30]. Between the nineteenth and twentieth century, there were several cases of displays reproducing the interiors of catacombs [31], which were linked to the development of period rooms and the widespread use of exact copies and facsimile reproductions for the study and conservation of archaeological and artistic heritage. The high regard in which copies and reproductions were held for both display and conservation purposes is clearly expressed by one of the pioneers of cultural heritage conservation and preservation in Europe, right between the nineteenth and twentieth century, the art historian Alois Riegl (1858-1905):

> *In view of the increasing development of art-technical means of reproduction, one can be confident that in the foreseeable future (especially after the discovery of absolutely convincing colour photography and its combination with facsimile copies) it will be possible to find as perfect replacements as possible for the documentary originals*. [32, p. 38, translation from German by the author]

The increasing use of reproductions was linked as much to their value in replacing the originals and telling the story of the objects [4] as to the interest of critics. It has been recalled [33] how in the German context of the 1920s the problem of copies and reproductions for conservation and museology was strongly raised, at a time when the spread of photography and mechanical reproduction for restoration and reproduction pervaded the debate on the perception of the original. The art historian Erwin Panofsky (1892-1968) discussed, in terms that are still valid for our case, how facsimile reproduction could convey the effect and meaning of the original with little loss, effectively allowing people to come into direct contact with objects, and these objects of the past to have an impact on life in the present [34]. In the same years, Alexander Dorner (1893-1957) had already established exhibition criteria for reproductions to bring the spirit of artistic creation to the wider public: original cultural materials are better enhanced in an environment recreated to approximate their original atmosphere [35], and if the virtue of the museum is to educate, then it is the facsimile that allows it to reach many more people.

In the same early decades of the twentieth century, there were of course discussions about reproductions (and not only in museums) with the introduction of photography, and its role in the diffusion of art imaginary and social use [36]. This allowed for a very wide and inexpensive dissemination of visual knowledge both in the international network of scholars and museums as well as in all social classes.

Museums of Christian archaeology and catacomb studies between nineteenth and twentieth century were not excluded from this debate and from the use of reproductions, copies and facsimile. The first institution to make systematic and official copies of the paintings of the catacombs was the papacy: in the Christian Museum in the Lateran Palace, opened in 1854, Pope Pius IX had an entire room set up with copies of the paintings of the Roman catacombs in order to give visitors (in a pre-photographic period) a clear view of the underground paintings, which were very difficult to visit *in situ* [37]. These included a largescale copy of the painting of the cubicle of the five saints from the Catacombs of Callisto, which we can identify as the main antecedent to the one in the Museu Biblíc.

In the following years many museums, both public and private, were decorated "like a catacomb" with educational, edifying and didactic purposes and with a strong focus on the promotion of cultural heritage and archaeology. With regard to the dissemination of religious and Christian knowledge, for example, in 1884 two rooms of the Museum of the Campo Santo Teutonico in the Vatican were set up. There, materials from excavations in the catacombs were exhibited in an arrangement that reproduced the pictorial decorations of the catacombs themselves [38]. Then, in 1898, a small museum was opened next to the ancient early Christian basilicas in Salona, Croatia: the museum's library and guest room were decorated in ancient style, reproducing catacomb themes [39]. In 1912, a Dutch entrepreneur opened an entire facsimile catacomb in the countryside of Valkenburg with papal authorisation. It is a still-existing, accurate reproduction of the most important sites of the Roman catacombs, built following a "bringing back to life" concept and with the aim of "reviving interest in the lives, sufferings and deaths of the oldest Christians", to provoke a "warm Christian ecstasy" in Holland [40]. The museographic choices for reconstructing early Christian environments in museum displays are therefore very interesting and also varied, as the Byzantine rooms of the Bode Museum in Berlin show us. Here, in a famous case of re-contextualization, of the nineteenth century, the sixth-century apsidal mosaic of the Ravenna church of San Michele in Africisco was transferred and re-installed, arranged in a room together with other late antique architectural pieces arranged as in a basilica [41].

The reproduction of catacombs for museum purposes declined in various ways, some much less faithful to the reconstructions of the setting and with no clear educational intention in a religious sense. This is the case of the reconstructions in wax museums such as the Grevin Museum in Paris where, in 1904, Léopold Bernhard Bernstamm created and exhibited mannequins of Christians performing their rites and funeral ceremonies in hypogeal settings totally inspired by Roman catacombs (Figure 9).

Figure 9. Postcard of the catacomb reproduction at the Grevin Museum in Paris (1930s, private collection).

Figure 10. Postcard of the catacomb reproduction at the Musée Historique Canadien in Montreal (1940s, private collection).

In 1935, the sculptor Albert Chartier reproduced similar settings for the Musée Historique Canadien in Montreal (Figure 10), contributing to the intercontinental diffusion of these reconstructions for the purpose of amusement through the recreation of sacred scenes. This purpose was then further enriched by the desire to educate in the Christian faith in various other American cases, ranging from the facsimile catacombs reproduced under the Franciscan monastery of the Holy Land in Washington D.C., to the sacred theme amusement park with reproductions of places of the Jewish and Christian tradition (including the catacombs) in Holyland, in Connecticut since 1995. In these latter examples, far from the scientific and museographic rigour of the older cases, the need for religious education went hand in hand with that of offering a vast public the experience of getting to know very sacred but also very distant places, where they could hardly go in person in the course of their lives.

The Museu Biblíc Tarraconense fits in perfectly in this tradition, and we can indeed say that the 'Hall of the Expansion of Christianity' represents the latest example in chronological order of a museum display trend of more than a hundred years old. In this case, the museum uses a museological expedient to respond to the main objective of the institution itself, i.e. the dissemination of archaeological knowledge about the early Christians, not only in a local sense. The pieces are thus a small part around which a large display project with a broader objective revolves. The main reconstruction of the room intends to provide a plausible original positioning of some very important finds for the ancient history of the city, but these are also declined in a Roman key to link the experience of the martyrs and Christians of Tarragona to that of the Christians of the eternal city. The very decision to link the finds from Tarragona's early Christian history to international examples (again, to Rome for the reconstruction of the catacomb's arcosolium, and to Africa for that of the baptistery) identifies a clear desire to stitch together the narrative of the local past, using a display that can ennoble it, and above all help the visitor to link Tarragona's past events to much clearer and generically more recogni sable examples for all. The use of casts and copies that do not require attention in the museum, nor those conservation practices required of archaeological works, has allowed the curators to freely dispose of the space both in its display and in its didactic and promotional use.

Copies, reproduction and authenticity

Recalling the history of the Museu Biblic and that of the facsimile catacombs is not idle, but rather represents well how the issue at the heart of the museum and its mission is precisely that of creating educational and evocative places, especially in interpretative centres and museums, whose first focus is to tell stories and generate questions in the visitor [42].

In history and archaeology museums, balancing curatorial and educational aspects is of paramount importance, as collections alone are not always sufficient for fruitful use for scientific purposes [43]: objects can only be truly understood when they are embedded in complex didactic frameworks that make the exhibition a composition of multiple documents [30].

Objects are primary documents that impact on the visitor, and the museum is the place of originality and respect for it, as indicated by the ICOM guidelines. Material authenticity continues to be considered a vehicle of truth, always with a great physical and emotional impact on the visitor, and can be compromised by any human action on the object. But when it is the museum itself that replaces the original and creates displays of reproductions, it certainly does so with other intentions of heritage conservation and promotion. This is indeed the case at the Museu Biblíc, which was created precisely with the intention of using a mixture of originals, copies and reproductions to create a coherent storytelling on the Bible and the history of Christianity. Visitors (always guided through the museum by museum staff) are immediately made aware of the copies and reproductions, which are used by the guides for contextualisation. In fact, visitors are led on a journey through the geography and history of the Holy Land from the Judaic era to the Christian era, and then on to Christianity in Europe and Spain. This journey takes place among original artefacts, copies of cult objects of Judaic-Christian archaeology, models (such as the one of the Temple of Jerusalem in Phase II), reconstructions (such as the one of the trial of Pontius Pilate), videos and photographs of the sites. Such a wealth of material of different types greatly aids the overall understanding of the themes presented in the museum.

In this case, if it is not the object itself that is authentic, the experience created by the museum reconstruction becomes so. We can see, in fact, how the concept of the "aura" of the authentic object on display, of the physical and emotional attraction of the visitor to an object due to its antiquity and being a relic of the past, is overcome in order to focus on its position in a broader panorama. In the case recounted here, we go beyond the entirely subjective concept of credibility and value linked to authenticity. The Museu Biblíc aims to answer to the issues of the object in the museum seen as incomplete and uprooted, and of the cultural experience in the museum as something that does not reveal the authentic context of origin of these objects. It is often the reproduction and facsimile It is often the reproduction and facsimile arrangement that can serve the visitors to open an eye to the past and reveal how archaeological finds had a presence in the ancient world and society, how they could be used, produced and perceived as a social representation [44].

It is chosen to give up a purely authentic set up in order to create a new display of copies, reproductions, casts and models, which can illustrate the past and be useful to museum discourse. The atmosphere created by these replicas, without any intention to deceive, is certainly not “authentic” as commonly intended, but has the merit of being able to link the object to its origin [34].

If, therefore, the museum does not exhibit originals, but exhibits an idea, a path, an educational choice, it is the reconstructions that are to be thought of as “creative originals”. The exhibition choices presented here are themselves authentic objects, an artistic reconstruction for archaeological interpretation and education, a new form of scientific creation [43]. This therefore makes them worthy of study: in the "Hall of the Expansion of Christianity", the archaeological objects (whether originals or copies) make sense because they are placed in a space that recalls the original context (which cannot be visited because it has been lost under the modern city), in a credible architectural arrangement (even if hypothetical, which is unknown due to the lack of archaeological excavations), and in a broader international context (which the individual visitor cannot know or recall all together when visiting the museum).
Such an arrangement, in its albeit obvious “inauthenticity”, has a distinct educational and social function. It is a clear exhibition choice that underlines very well the idea of the founders and curators: the Museu Biblíc serves education, and it is to this therefore that all its exhibition tactics must aim. The aim of this article was in fact to analyse the display of a room in the Museu Biblíc of Tarragona from the perspective of its educational interest for Christian antiquities. It seemed important to place it, in a broader museum tradition, and therefore to contribute to analysing it as the latest development in a century-long trend of the use of reproductions and copies at the service of the dissemination of Christian archaeology. The aim was thus to enter in the debate on the role of the copy in the museum and of the museum in society through the presentation of a single case that is little known but was created precisely for to the cultural development of the community.

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