Sustainable Solutions for Conservation: New Strategies for New Times

Soluciones Sostenibles para la Conservación: Nuevas Estrategias para los Nuevos Tiempos

IIC 2024, Lima Congress Proceedings



Studies in Conservation
SUPPLEMENT 1



Contributions to the Lima Congress
Aportes al Congreso de Lima

23–27 September 2022

Sustainable Solutions for Conservation: New Strategies for New Times
Soluciones Sostenibles para la Conservación: Nuevas Estrategias para los Nuevos Tiempos

Editors Editoras y editores

Isobel Griffin

Joyce H. Townsend

Barry Knight

Boris Pretzel

Published by Publicado por

The International Institute for Conservation (IIC)

1 Birdcage Walk

London SW1H 9JJ, UK

www.iiconservation.org

iic@iiconservation.org

Content is available at www.tandfonline.com/ysic

For 50+ years, Tru Vue® has been optically coating acrylic and glass to create highly specialized glazing products with a variety of protective and aesthetic characteristics. This advanced technology allows viewers to fully experience works as originally intended. With distribution in over 50 countries, TruVue glass and acrylic solutions, including Optium Museum Acrylic® and UltraVue® Laminated Glass, are used to protect and display fine art and cultural heritage throughout the world.

What makes Tru Vue the leading company used in museums is our museum experience. Our team of museum and conservation liaisons serve as consultants and technical points of contact and are available to advise, understanding the variety of situations artworks or heritage items are in. Zulfadhli Hilmi is our museum and conservation liaison for Southeast Asia and Oceania, including Singapore, Malaysia, Indonesia, Thailand, Australia, and New Zealand. Learn more about Hilmi and the rest of the Tru Vue Fine Art & Museum Team here.

TruVue and the Thoma Foundation are co-headline sponsors of the congress in Peru.

With special thanks to the Getty Foundation and the Getty Conservation Institute.

Copyright © The International Institute for Conservation of Historic and Artistic Works (IIC)

Responsibility for statements made in these papers rests solely with the authors.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without the written permission of the copyright holder. Requests for such permissions must be addressed to permissionrequest@tandf.co.uk.

ISSN (online) 2047–0584

Cover image courtesy of Rosanna Kuan (UTEC)

Studies in Conservation
Volume 69 Number S1 September 2024

CONTENTS

Supplement 1: Contributions to the Lima Congress 2024

Suplemento 1: Aportes al Congreso de Lima 2024

Sustainable Solutions for Conservation: New Strategies for New Times

Soluciones Sostenibles para la Conservación: Nuevas Estrategias para los Nuevos Tiempos

Foreword
Julian Bickersteth

Preface
Jane Henderson

Acknowledgements
Sarah Stannage

Articles

S1 Sustainable Conservation Solutions in a Hostile Environment: The Historic Huts of Antarctica: Soluciones de Conservación Sostenibles en un Entorno Hostil: las Cabañas Históricas de la Antártida
Julian Bickersteth, Gordon Macdonald and Lizzie Meek

S12 Fire Risk Assessment in Museums on the HERIe Web-based Decision-supporting Platform: Evaluación del Riesgo de Incendio en Museos en la Plataforma Web de Apoyo a la Toma de Decisiones HERIe
Łukasz Bratasz and Łukasz Berger

S18 Reconsidering Museums' Climate and Seasonal Adjustment for Vulnerable Artifacts: Reconsiderar el Clima y el Ajuste Estacional de los Museos para los Artefactos Vulnerables
Sonia Bujok, Alexandra Bridarolli, Michał Łukomski and Łukasz Bratasz

S25 The GREENART Project: Environmentally Friendly and Low Impact Materials for the Conservation of Cultural Heritage: El Proyecto GREENART: Materiales Ecológicos y de Bajo Impacto para la Conservación del Patrimonio Cultural
David Chelazzi, Giovanna Poggi and Piero Baglioni

S35 International Cooperation between Korea and Cambodia to Conserve and Manage Angkor Stone Heritage using Non-destructive Technology: Cooperación Internacional entre Corea y Camboya para Conservar y Gestionar el Patrimonio de Piedra de Angkor utilizando Tecnología no Destructiva
Myoungju Choie, Myeong Seong Lee, Sineth Oum and Sovann In

S44 Uplifting Community and Incorporating Reuse in Conservation Planning for the Noah Purifoy Outdoor Desert Art Museum of Assemblage Sculpture: Inspirando a la Comunidad e Incorporando la Reutilización en la Planificación de la Conservación del Museo de Arte de Escultura Ensamblaje al Aire Libre del Desierto Noah Purifoy
Anya Dani, Jennifer Kim, Joe Lewis, Robin Meyer-Lorey, Jill Moniz and Laleña Vellanoweth

S55 Materials Analysis of Two Nineteenth-century Brazilian Polychrome Sculptures to Reveal Their History and Significance: Análisis de Materiales de dos Esculturas Policromadas Brasileñas del Siglo XIX para Revelar su Historia y Significado
Dâmia Carina Dias Do Carmo, Marcus Vinicius de Oliveira Andrade, Marcelo Carvalho Lasmar, Caio Tadao Joko, Karen Santos Silva, Karla Balzuweit, Marcelo Azevedo Maffra, Alessandra Rosado and Luiz Antonio Cruz Souza

S63 Learning from the Past: Rediscovering Traditional Medieval Wood Tar Adhesives for Sustainable Stone Conservation and Built Heritage: Aprendiendo del Pasado: Redescubriendo los Adhesivos de Alquitrán de Madera Medievales Tradicionales para la Conservación Sostenible de la Piedra y el Patrimonio Construido
Bettina Ebert

S72 Sustainable and Beneficial: Pollutant Absorption and Relative Humidity Control in Display Cases by Saturated Salt Solutions: Sostenible y Beneficioso: Absorción de Contaminantes y Control de la Humedad Relativa en Vitrinas Mediante Soluciones de Sales Saturadas
Gerhard Eggert, Oliver Brieger, My Sa Marschibois, Daniel Becker, Christian Bur, Katja Franziska Siebel and Heiner Grieb

S81 UK Museums and Heritage Sustainable Packing Group: Exploring Sustainable Strategies for Soft Wrapping Paintings: Grupo de Embalaje Sostenible de Museos y Patrimonio del Reino Unido: Exploración de Estrategias Sostenibles para Pinturas de Embalaje Suave
Rebecca Ellison, Rebecca Hellen, Alice Tate-Harte, Alexandra Gent, Kim Kraczon, Victoria Ward and Clare Richardson

S91 Reducing Energy Use Through Behavioural Change: Carbon Literacy Training for Archives in the UK: Reducción del Uso de Energía Mediante Cambios de Comportamiento: Alfabetización sobre Carbono para Archivos en el Reino Unido
Lorraine Finch, Tim Powell and Helen Wilson

S98 Data Collection for Cultural Heritage Risk Management: the *Damage Map through Heritage Building Information Modeling (HBIM*) Project Applied to the Façade of St Francis of Assisi, Ouro Preto, Brazil: Recopilación de Datos para la Gestión de Riesgos del Patrimonio Cultural: el Proyecto *Mapa de Daños Mediante el Modelado de Información de Edificios Patrimoniales* (HBIM) Aplicado a la Fachada de San Francisco de Asís, Ouro Preto, Brasil
Yacy Ara Froner, Willi de Barros Gonçalves, Luiz Antônio Cruz Souza, Antônio Gilberto Costa, Alessandra Rosado, Ana Regina Mizrahy Cuperschmid, Guilherme de Oliveira Walter, Ana Carolina Neves Miranda, Guilherme Michelin, Ana Carolina Montalvão and Tiago Hardy

S108 Greenwashing Revelations through Revision: Re-evaluating Sustainability Claims for Bioplastics: Revelaciones de Lavado Verde a Través de la Revisión: Reevaluación de las Afirmaciones de Sostenibilidad de los Bioplásticos
Bianca Gonçalves, Daisy Green, Kim Kraczon and Talia Weiss

S117 Amplifying Indigenous Australian Voices in the Conservation and Management of Rock Art: Ampliando las Voces de los Indígenas Australianos en la Conservación y Gestión del Arte Rupestre
Darren Griffin, Michael Douglas, Stuart Harradine, Janine Coombs, Chrystle Carr, John Clarke, Billy Briggs, Nathalia Guimaraes, Emily Corris, Bill Bell, Troy Lovett, Leigh Malseed, Jake Goodes, Wendy Luke, David Lucas, Charlie Richardson, Dylan Clarke, Melissa Marshall, Lloyd Pigram and Cissy Gore-Birch

S127 Nothing Lasts Forever? Considering Lifespans in a Contemporary Collection: ¿Nada dura para Siempre? Considerando la Esperanza de Vida en una Colección Contemporánea
Isobel Griffin, Lorraine Maule and Jacqueline Ridge

S135 A Study of Protective Coatings for Archaeological Silver: Estudio de Revestimientos Protectores para Plata Arqueológica
Stephanie Guidera, Emily Kaplan, Caitlin Mahony, Thomas Lam and Gwénaëlle M. Kavich

S146 Strengthening Training in the Conservation of Cultural Heritage Through Academic Collaboration: Fortaleciendo la Formación en Conservación del Patrimonio Cultural a través de la Colaboración Académica
Tanushree Gupta and Gabriela Krist

S153 Salvaging Art Collections in the Face of Natural Disasters: Challenges and Outcomes: Salvamento de Colecciones de Arte Frente a Desastres Naturales: Desafíos y Resultados
Suati Rojas Gutierrez, Adam Godijn and Bianca Gonçalves

S161 Hygrothermal Performance of Enclosures in a Storage Room and Energy Efficiency in Environmental Control: Comportamiento Higrotérmico de Cerramientos en un Almacén y Eficiencia Energética en el Control Ambiental
Bo Han, Fan Wang, Julie Bon, Linda MacMillan and Nick Taylor

S169 Dissociation and Loss: a Challenge for Sustainable and Inclusive Conservation: Disociación y Pérdida: un Desafío para la Conservación-restauración Sostenible e Inclusive
Jane Henderson and Robert Waller

S176 Towards a National Heritage Climate Change Risk Assessment Hacia una Evaluación del Riesgo de Cambio Climático del Patrimonio Nacional
Paul Lankester and Ruth Knight

S190 Sustainable Preservation of Photographs in a Hot and Humid Climate: Dry Cabinets and Metal–Organic Framework Paper Composites: Preservación Sostenible de Fotografías en un Clima Cálido y Húmedo: Gabinetes Secos y Compuestos de Papel con Estructura Organometálica
Bertrand Lavédrine, Anne-Laurence Dupont, Pierre Tignol, Christian Serre, Vanessa Pimenta, Moisés L. Pinto and Abeer Al Mohtar

S198 From Lima to Canton and Beyond: Mobile and Digital Research Infrastructure for Closing the Gap Between Resource-rich and Resource-poor Organisations: De Lima a Cantón y más allá: Infraestructura de Investigación Móvil y Digital para Cerrar la Brecha entre Organizaciones con y sin recursos científico-técnicos propios
Haida Liang, Luke Butler, Sotiria Kogou, Marcus Burke, Lynn Lee, Lucia Pereira Pardo, Lora Angelova, Fenella France and Blythe McCarthy

S208 Making It Last: Training Conservators in Sustainable Solutions for Treating Outdoor Painted Sculpture: Haciendo que Dure: Capacitar a Conservadores-restauradores en Soluciones Sostenibles para el Tratamiento de Esculturas Pintadas al Aire Libre
Rosa Lowinger, Abigail Mack, Ellen Moody, Flavia Perugini, Rachel Rivenc and Stavroula Golfomitsou

S218 Sustainable and Collaborative Solutions for the Long-term Care of Heritage Earthen Sites in Seismic Areas in Peru: Soluciones Sostenibles y Colaborativas para el Cuidado a Largo Plazo de Sitios Patrimoniales de Tierra en Regiones Sísmicas del Perú
Elena Macchioni, Paulo B. Lourenço, Georgios Karanikoloudis, Nuno Mendes, Rafael Aguilar and Claudia Cancino

S227 Updating Environmental Guidance: the British Museum Approach: Actualización de la orientación medioambiental: el enfoque del Museo Británico
Tatiana Marasco and Louisa Burden

S235 Building on Successful Mechanical and Passive Environmental Controls for Preventive Conservation Through Data Analysis at National Museum Cardiff, Wales: Aprovechamiento de Controles Ambientales Pasivos y Mecánicos Exitosos para la Conservación Preventiva mediante Análisis de Datos en el Museo Nacional de Cardiff, Gales
Kelly McCauley, Robert Pearce and Diane Gwilt

S245 Improving Sustainability for the Conservation of the Eravimangalam Subramanyaswamy Temple: Virtual Reconstruction and Greener Formulations as a Means of Involving the Community: Mejorar la Sostenibilidad de la Conservación del Templo Eravimangalam Subramanyaswamy: Reconstrucción Virtual y Formulaciones más Ecológicas como Medio para Involucrar a la Comunidad
Moupi Mukhopadhyay and Chiara Biribicchi

S256 Pleasing the Wrathful Deities: Ethical Approaches to the Care of Tibetan Skull Drums: Complacer a las Deidades Iracundas: Enfoques Éticos para el Cuidado de los Tambores de Calaveras Tibetanos
Richard Mulholland and Rachael Durkin

S263 Fostering Inclusive Management and Community Participation: Lessons from the Field: Fomento de la Gestión Inclusiva y la Participación Comunitaria: Lecciones del Campo
Stephanie D. Ortiz

S270 Green Alternatives for Archaeological Iron Stabilization: Alternativas Verdes para la Estabilización del Hierro Arqueoló
Patrycja Petrasz, Sami Zhioua, Sarah James, Saskia Bindschedler, Pilar Junier and Edith Joseph

S281 The Application of Remote Sensing in the Conservation of the Archaeological Site of Pachacamac (Second–Sixteenth Century, Peru) La Aplicación de la Teledetección en la Conservación del Sitio Arqueológico de Pachacamac (siglos II-XVI, Perú)
Denise Pozzi-Escot, Maria Ilaria Panaccione Apa, Guido Ventura, Luigi Magnini, Arturo Peralta, Hernán Chipana, Janet Oshiro and Rommel Angeles

S291 From Paper Fibers to Practical Conservation Experiences: The *International Paper Conservation Seminars* in Latin America: Desde las fibras del papel a las experiencias prácticas de conservación: El *Seminario Internacional de Conservación de Papel* en América Latina
Yerko Andrés Quitral

S298 Development of Starch Nanoparticles as a Green Consolidant for Paper-based Objects: Synthesis and Design: Desarrollo de Nanopartículas de Almidón como Consolidante Verde para Objetos de Papel: Síntesis y Diseño
Ashna Rawat and Satish C. Pandey

S305 Interrogating Pollutants in Collecting Institutions During the Implementation of HVAC Energy-Saving Strategies: Lessons Learned and Practical Implications for Optimizing Sustainable Environmental Control: Interrogación de Contaminantes en Instituciones Recolectoras durante la Implementación de Estrategias de Ahorro de Energía en HVAC: Lecciones Aprendidas e Implicaciones Prácticas para Optimizar el Control Ambiental Sostenible
Emma Richardson, Kelly McCauley Krish, Marvin Cummings, Martin Schooping, Philip Hopke and Jean Tétreault

S314 Defining Sustainable Priorities and Actions for Storage of a Public Archive: A UK Case Study: Defin ición de Prioridades y Acciones Sostenibles para el Almacenamiento de un Archivo Público: un Studio de Caso en el Reino Unido
Yuki Russell

S323 Calculating the Carbon Footprint of Interventive and Preventive Conservation at English Heritage, UK: Calculando la Huella de Carbono de la Conservación Interventiva y Preventiva en English Heritage, Reino Unido
Alice Tate-Harte and David Thickett

S333 The Positive Role of Trees in Protecting Outdoor Painted and Engraved Rock Sites: El Papel Positivo de los Árboles en la Protección de Sitios Rocosos Pintados y Grabados al Aire Libre
Andrew Thorn

S341 *Fotográfica en Red:* A Working Group for Latin American Photographic Heritage: *Fotográfica en Red:* Un Grupo de Trabajo sobre el Patrimonio Fotográfico Latinoamericano
Natalia Ulloa and Isabella Gama

S345 Introducing a Risk-, Value- and Collection Lifetime-Based Lighting Policy at the Victoria and Albert Museum in London: Presentación de una Política de Iluminación Basada en el Riesgo, el Valor y la Colección en Función de la Vida Util en el Victoria and AlbertMuseumde Londres
Sarah VanSnick and Pedro Gaspar

S352 Implementing an Adaptive Climate Control Strategy: Collection Monitoring and Sustainability Outcomes: Implementación de una Estrategia de Control Climático Adaptativo: Monitoreo de Colección y Resultados de Sostenibilidad
Michael Varcoe-Cocks, MaryJo Lelyveld, Caitlin Breare, Alexandra Bridarolli, Vincent Laudato Beltran, Youkyoung Kim, Cecilia Winter and Michał Łukomski

S360 Conservation as a Tool for Cultural Rights in the Democratic Republic of the Congo: The *We have gaps* Project: La conservación como herramienta para los derechos culturales en la República Democrática del Congo: el proyecto *Tenemos brechas*
Muriel Verbeeck and Israel-Prince Wingenga

S369 Sustainable Cultural Preservation in Central Asia – Involving Local Communities as Caretakers of Archaeological Sites: Preservación Cultural Sostenible en Asia Central: Involucrar a las Comunidades Locales como Cuidadoras de Sitios Arqueológicos
Maruchi Yoshida, Natascha Bagherpour Kashani, Abolfazl Aali, Hamed Zifar, Shahrzad Amin Shirazi and Hasan Ahmed Qasim

S376 APOYOnline: A Sustainable Approach to Heritage Preservation Across the Americas: APOYOnline: Un enfoque sostenible para la preservación del patrimonio en las Américas
Beatriz Haspo, Amparo Rueda, Nathália Pamio Luiz, Gabriela Lúcio, Cristina Lara Corrêa, Irene Delaveris and Sarah Sequeira

Technical Committee

Isobel Griffin, UK (chair)
Jo Kirby Atkinson, UK
Jimena Blasco, Uruguay
Caitlin Breare, Australia
Duygu Çamurcuoğlu, UK
Jane Colbourne, UK
Yacy-Ara Froner, Brazil
Angélica Isa-Adaniya, Canada
Katy Lithgow, UK
Clare Meredith, UK
Sarah Staniforth, UK
Marcos Tascon, Argentina

Editorial Committee

Joyce H Townsend, UK (chair)
Isobel Griffin, UK
Barry Knight, UK
Boris Pretzel, UK

Organising Committee in South America

Juan Carlos Rodriguez, Perú (chair)
Claudia Barra Collazo, Uruguay
Mariana Carulla, Colombia
Valentina Castillo Pinaud, Chile
Yacy-Ara Froner, Brazil
Camilla Henriques Maia de Camargos, Brazil
Rosanna Kuon, Perú
Tom Learner, USA
Fernando Marte, Argentina
Adriana Páez Cure, Colombia
Lorice Sivira, UK
Luiz Souza, Brazil
Maria Ines Verlarde, Perú

IIC
Routledge
Taylor & Francis Group

Foreword

A very warm welcome to IIC's 30th Biennial Congress being staged at the Universidad de Ingenieria & Tecnologia (UTEC) in Lima, Peru.

This is the first IIC Congress in South America, and its choice reflects one of the Council's priorities in ensuring that IIC truly represents and supports conservators around the globe. All of Latin America, has, of course, incredibly rich and ancient cultural heritage and a long tradition of training conservators to care for them. IIC seeks to do more to foster interaction with our fellow Latin American conservators. So much can be learnt from sharing our experiences, and we trust that the IIC Lima Congress will enable this, and will act as a catalyst to improve IIC's visibility and relevance to the region, as well as creating a lasting legacy of connected professionals and training programmes globally.

The theme is *Sustainable Solutions for Conservation: New Strategies for New Times*. Sustainability is another priority for the IIC Council, to ensure it is a core part of our professional work and, more broadly, that we are playing our part in sustaining the planet. The field of conservation has not developed equally and equitably around the world, and it is not uncommon for countries with some of the richest heritage to be among the least developed. These discrepancies are widely recognized to have become more extreme with climate change. Sustainable conservation strategies are needed to create safer and more affordable approaches that will increase protection for the world's heritage and provide greater resilience to future world events and crises.

The quality, depth and range of the papers and posters on this theme is outstanding. They have all been through rigorous peer review by the Technical Committee, and I sincerely thank its chair Dr Isobel Griffin and IIC's Director of Publications Dr Joyce Townsend for their expert leadership and for the many hours that they and their Committee members have put into this Congress.

So IIC welcomes you to our 30th Congress, and the next milestone in our profession's development.

Julian Bickersteth AO FIIC FRSA
President, IIC
President@iiconservation.org

Prefacio

Una muy cálida bienvenida al 30° Congreso Bienal del IIC que se lleva a cabo en la Universidad de Ingeniería y Tecnología (UTEC) en Lima, Perú.

Esta es la primera vez que el Congreso del IIC se realiza en América del Sur y su elección refleja una de las prioridades del Consejo para garantizar que el IIC realmente represente y apoye a los conservadores de todo el mundo. Toda América Latina tiene, por supuesto, un patrimonio cultural increíblemente rico y antiguo y una larga tradición de formación de conservadores para cuidarlo. El IIC busca hacer más para fomentar la interacción con nuestros compañeros conservadores latinoamericanos. Se puede aprender mucho al compartir experiencias compartidas, y confiamos en que el Congreso del IIC en Lima lo permitirá y actuará como catalizador para mejorar la visibilidad y relevancia del IIC en la región, además de crear un legado duradero de profesionales y capacitación conectados. programas a nivel global.

El tema del congreso es *Soluciones Sostenibles para la Conservación: Nuevas Estrategias para los Nuevos Tiempos*. La sostenibilidad es otra prioridad para el Consejo de el IIC. Para garantizar que sea una parte central de nuestro trabajo profesional y, en términos más generales, que estemos desempeñando nuestro papel en el sostenimiento del planeta. El campo de la conservación no se ha desarrollado de manera equitativa y igualitaria en todo el mundo, y no es raro que países ricos en patrimonios se encuentren entre los menos desarrollados. Se reconoce ampliamente que estas discrepancias se han vuelto más extremas con el cambio climático. Se necesitan estrategias de conservación sostenible para crear enfoques más seguros y asequibles que aumenten la protección del patrimonio mundial y proporcionen una mayor resiliencia ante futuros eventos y crisis mundiales.

La calidad, profundidad y variedad de los artículos y posters sobre este tema son sobresalientes. Todos han pasado por una rigurosa revisión por pares por parte del Comité Técnico, y agradezco sinceramente a su presidenta, la Dra. Isobel Griffin, y a la Directora de Publicaciones del IIC, la Dra. Joyce Townsend, por su liderazgo experto y por las muchas horas que ellos y los miembros de su Comité han dedicado a este Congreso.

Así es que el IIC les da la bienvenida a nuestro 30° Congreso y al próximo hito en el desarrollo de nuestra profesión.

Julian Bickersteth AO FIIC FRSA
President, CII
Presidente@iiconservation.org

Welcome

The IIC Lima conference is not just an event, but a platform for us to listen to and learn from the global expertise and perspectives of conservators. This year, we are privileged to be led by conservators from Latin America, showcasing the truly global impact of our community.

IIC is fortunate to have so many engaged, imaginative, and efficient members, supporters, and staff. Our executive director has offered our thanks to everyone working to make this conference a success. As an organization, we are committed to providing multiple avenues for engagement, and we are always open to your valuable feedback on how we can further enhance these opportunities.

Listening is not just a passive act, but a powerful tool for sustainable practice. The conference has identified inequity in the distribution of resources to care for cultural heritage as a significant theme. I encourage those of us operating in countries that are major consumers of global resources to seek out and benefit from the approaches of those living within a more sustainable footprint. Our actions, whether big or small, can make a significant difference in our collective approach to conservation worldwide. To learn lessons, we seek knowledge and expertise that is embodied in people. To protect knowledge, we must protect people and their ways of life and accordingly sustainable conservation is a human rights issue. As the challenges facing the world mount, we can be under no illusion that continuing to practice as we have is neither neutral nor effective conservation. I am so grateful that IIC has worked to increase availability of knowledge worldwide, to actively empower new voices and to share perspectives, the challenge to us as individuals is to listen, learn, and act.

Professor Jane Henderson FIIC ACR
Secretary-General, IIC
secgen@iiconservation.org

Bienvenido y bienvenida

La conferencia de la IIC Lima no es solo un evento, sino una plataforma para que escuchemos y aprendamos de la experiencia y las perspectivas globales de los conservadores. Este año, tenemos el privilegio de contar con la dirección de conservadores de América Latina, mostrando el impacto verdaderamente global de nuestra comunidad.

El IIC tiene la suerte de contar con tantos miembros, partidarios y personal comprometidos, imaginativos y eficientes. Nuestro director ejecutivo ha ofrecido nuestro agradecimiento a todos los que trabajan para que esta conferencia sea un éxito. Como organización, estamos comprometidos a brindar múltiples vías de participación y siempre estamos abiertos a sus valiosos comentarios sobre cómo podemos mejorar aún más estas oportunidades.

Escuchar no es sólo un acto pasivo, sino una poderosa herramienta para una práctica sostenible. La conferencia ha identificado la inequidad en la distribución de recursos para cuidar el patrimonio cultural como un tema importante. Animo a quienes operamos en países que son grandes consumidores de recursos globales a buscar y beneficiarnos de los enfoques de quienes viven dentro de una huella más sostenible. Nuestras acciones, ya sean grandes o pequeñas, pueden marcar una diferencia significativa en nuestro enfoque colectivo hacia la conservación en todo el mundo. Para aprender lecciones, buscamos conocimientos y experiencia que se materializan en las personas. Para proteger el conocimiento, debemos proteger a las personas y sus formas de vida y, en consecuencia, la conservación sostenible es una cuestión de derechos humanos. A medida que aumentan los desafíos que enfrenta el mundo, no podemos hacernos ilusiones de que continuar practicando como lo hemos hecho no es una conservación neutral ni efectiva. Estoy muy agradecido de que el IIC haya trabajado para aumentar la disponibilidad de conocimiento en todo el mundo, empoderar activamente nuevas voces y compartir perspectivas; el desafío para nosotros como individuos es escuchar, aprender y actuar.

Profesora Jane Henderson FIIC ACR
Secretario General, CII
secgen@iiconservation.org

IIC
Routledge
Taylor & Francis Group

Acknowledgements

On behalf of IIC Council, I would like to extend a heartfelt thank you to everyone who has made this congress possible, from the technical and editorial committees chaired by Dr Isobel Griffin and Dr Joyce Townsend respectively, to the IIC staff and volunteers, including Digital Engagement Volunteers coordinated by Sharra Grow and translations managed by Mariana Escamilla Martínez.

A special mention must go to the Local Organising Committee members, namely Juan Carlos Rodriguez (Chair), Rosanna Kuon, Maria Ines Verlarde and Lorice Sivira, and to UTEC - Universidad de Ingeniería y Tecnología for hosting IIC's first major international congress in Latin America. We also acknowledge the various leads for all our regional in-person hubs: Fernando Marte (Argentina), Camilla Henriques Maia de Camargos and Luiz Souza (Brazil), Valentina Castillo Pinaud (Chile), Adriana Páez Cure and Mariana Carulla (Colombia) and Claudia Barra (Uruguay).

We are grateful to Tru Vue Inc. and the Thoma Foundation as co-headline sponsors, and to the Getty Conservation Institute (GCI) and Getty Foundation for their unwavering support in helping to provide opportunities that help connect and bring together the conservation community globally. Through this kind support, and with donations from members to the IIC Brommelle Memorial Fund, we have been able to fund in-person as well as online attendance internationally for over 40 students and early career professionals from previously underrepresented regions globally.

We must also pay a special tribute to our global conservation community, thank you for your contribution to this global congress and to the important role you have in helping to create a more sustainable and resilient world.

Dr Tom Learner FIIC
IIC Director, Chair of Congress
tlearner@getty.edu

Agradecimientos

En nombre del Consejo del IIC, me gustaría agradecer de todo corazón a todos los que han hecho posible este congreso, desde los comités técnico y editorial presididos por la Dra. Isobel Griffin y la Dra. Joyce Townsend respectivamente, hasta el personal y los voluntarios del IIC. incluyendo Digital Engagement Volunteers coordinados por Sharra Grow y traducciones gestionadas por Mariana Escamilla Martínez.

Una mención especial debe ir a los miembros del Comité Organizador Local, a saber, Juan Carlos Rodríguez (Presidente), Rosanna Kuon, María Inés Verlarde y Lorice Sivira, y a UTEC - Universidad de Ingeniería y Tecnología por albergar el primer gran congreso internacional del IIC en América Latina. También reconocemos a los distintos líderes de todos nuestros centros regionales presenciales: Fernando Marte (Argentina), Camilla Henriques Maia de Camargos y Luiz Souza (Brasil), Valentina Castillo Pinaud (Chile), Adriana Páez Cure y Mariana Carulla (Colombia) y Claudia Barra (Uruguay).

Agradecemos a Tru Vue Inc. y a la Fundación Thoma como patrocinadores co-principales, y al Instituto de Conservación Getty (GCI) y la Fundación Getty por su apoyo inquebrantable para ayudar a brindar oportunidades que ayuden a conectar y unir a la comunidad conservacionista a nivel mundial. A través de este amable apoyo, y con donaciones de los miembros al IIC Brommelle Memorial Fund, hemos podido financiar la asistencia presencial y en línea a nivel internacional para más de 40 estudiantes y profesionales que inician su carrera de regiones que anteriormente estaban subrepresentadas a nivel mundial.

También debemos rendir un homenaje especial a nuestra comunidad conservacionista global, gracias por su contribución a este congreso global y por el importante papel que tiene para ayudar a crear un mundo más sostenible y resiliente.

Dr Tom Learner FIIC
Director del CII, Presidente del Congreso
tlearner@getty.edu

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S1–S11
https://doi.org/10.1080/00393630.2024.2350286

ORIGINAL RESEARCH OR TREATMENT PAPER

Sustainable Conservation Solutions in a Hostile Environment: The Historic Huts of Antarctica

Soluciones de Conservación Sostenibles en un Entorno Hostil: las Cabañas Históricas de la Antártida

Julian Bickersteth [1], Gordon Macdonald [2] and Lizzie Meek [3]

[1]International Conservation Services, Chatswood, New South Wales, Australia; [2]Gordon Macdonald, Heritageworks Ltd, Victoria, British Columbia, Canada; [3]Antarctic Heritage Trust, Christchurch, New Zealand

ABSTRACT

Since 2003 the four surviving Ross Sea huts of the Heroic Era (1899 –1917) of Antarctic exploration have been the subject of a major programme of conservation by the Antarctic Heritage Trust of New Zealand, the Ross Sea Heritage Restoration Project (RSHRP). This paper describes how the RSHRP came to be and the key components which were identified and put in place for the project at its outset. It then explores the learning from and challenges of this significant project, and it critically considers the way in which the programme has been developed and delivered. The example of Scott's memorial cross is used to illustrate the innovative approach of the RSHRP, and through the case study, the authors share both the successes (and in some cases the lack of success) of treatments, and the learning which has come from this.

Desde 2003, las cuatro cabañas sobrevivientes de la Era Heroica (1899–1917) de exploración antártica en el Mar de Ross han sido objeto de un importante programa de conservación por parte del Fondo del Patrimonio Antártico de Nueva Zelanda, el Proyecto de Restauración del Patrimonio del Mar de Ross (RSHRP). El artículo describe cómo surgió el RSHRP y los componentes clave que fueron identificados e implementados para el proyecto desde sus inicios. Subsecuentemente se explora el aprendizaje y los desafíos de este importante proyecto y considera críticamente la forma en que se desarrolló y entregó el programa. El ejemplo de la cruz conmemorativa de Scott se utiliza para ilustrar el enfoque innovador del RSHRP y, a través del estudio de éste caso, los autores comparten tanto los éxitos (y en algunos casos la falta de éxito) de los tratamientos así como del aprendizaje que se ha obtenido de estos.

ARTICLE HISTORY
Received November 2023
Accepted April 2024

KEYWORDS
Antarctic exploration; cold climate conservation; heritage; conservation management plans

Exploración Antártica; conservación del clima frío; patrimonio; planes de gestión de conservación

Introduction

The Ross Sea Heritage Restoration Program (RSHRP) is an ongoing conservation project undertaken by the Antarctic Heritage Trust of Aotearoa New Zealand to conserve the tangible legacy of the early Antarctic explorers in the Ross Sea region of Antarctica. The focus of the project has been the conservation of the four expedition bases (collectively referred to as 'the huts') which survive from the so-called Heroic Era of Antarctic exploration (1899–1917), and the approximately 21,000 artefacts which survive in and around the huts. As a conservation project it is unusual in both its longevity of delivery and its consistency of staff and focus.

Throughout its 20-year history, the RSHRP has overcome extraordinary logistical and physical challenges to deliver the necessary resources and materials required. In response to the hostile Antarctic environment in which the huts and artefacts are situated, the programme has developed a range of innovative solutions for cold climate conservation.

Conceived in 2002, over 20 years later the RSHRP has achieved almost all its aims in ensuring the ongoing preservation of the huts and artefacts. While significant work remains to be done at Cape Adare, work at the Ross Island sites (Cape Evans, Cape Royds, and Hut Point) is substantially complete and has now moved from the delivery of active on-site treatment and a year-round presence of conservators in Antarctica to a summer-only programme of monitoring and maintenance. However, this maintenance programme is necessarily an active one, given the harsh nature of the polar environment, which has challenged the long-term efficacy of a range of traditional conservation treatment methodologies and materials.

This paper explores the RSHRP as a useful model for the planning and execution of a major conservation programme, resulting in much learning particularly relating to conservation works in logistically challenging locations and a harsh environment. The authors have all been involved from the early days of the project with expertise both in the conservation of the

CONTACT Julian Bickersteth j.bickersteth@icssydney.com International Conservation Services, Chatswood, New South Wales, Australia
© The International Institute for Conservation of Historic and Artistic Works 2024

built fabric and the artefacts. The RSHRP's aims and early experiences, and the history of the sites, were covered in an paper delivered at the IIC London 2008 Congress (Bickersteth, Clayton, and Tennant 2008).

Background

To understand the success of the RSHRP, it is useful to look at the various components which fed into its establishment and the framework under which it has been executed. After the end of the Heroic Era of exploration in the Ross Sea, generally recognised as 1917 with Shackleton's *Endurance* expedition, for which the Ross Sea huts played a support role, there was minimal interaction with the huts until 1956 (Harrowfield 2007). At this stage Scott Base was established with the support of the New Zealand Government to plan and oversee New Zealand's involvement in the Commonwealth Trans-Antarctic Expedition and the first International Geophysical Year (IGY, lasted 1 July 1957 to 31 December 1958) (Lintott 2016). Despite Antarctica thereafter being controlled by the International Antarctic Treaty, an outcome of the IGY was the responsibility for the care of the huts being transferred to New Zealand, thus maintaining the country's right of sovereignty over the Ross Dependency since 1923.

Recognising this responsibility, New Zealand began a programme of care for the historic sites and buildings at

- Cape Adare (Carsten Borchgrevink's 1899–1900 British Antarctic Expedition)
- Hut Point (Scott's 1901–1904 *Discovery* expedition)
- Cape Royds (Shackleton's 1907–1909 British Antarctic expedition)
- Cape Evans (Scott's 1911–1913 British Antarctic Expedition and also the Ross Sea Party of Shackleton's Imperial Trans-Antarctic Expedition 1914–1917).

Care for the historic huts was initially undertaken by the NZ National Historic Places Trust (NZNHPT) in 1957, and there followed a period of clean-up and repair culminating in the Hut Restoration Project led by Quartermain during the period 1959–1961 (Lintott 2016; Quartermain 1963). In 1987 the Antarctic Heritage Trust (AHT) of NZ was established, as its founding deed made clear (McElrea 1987): 'To further the conservation and preservation of the historic huts and historic sites and the artefacts contained in or associated with such historic huts and historic sites, in the Ross Dependency'.

Over the next few years works at the huts concentrated on understanding and stabilising the condition of the artefacts and ensuring the huts themselves were weatherproof. However, under a new chair of the AHT board in 2000 there was impetus for the creation of a long-term plan for the conservation and maintenance of the huts. Thus was conceived the RSHRP, the success of which can be significantly attributed to three components, described below.

Long-term vision, stable staff structure, and funding

The board of AHT recognised that if the aims of the RSHRP were to be achieved, then a strategic vision was required around which to focus the support and commitment of stakeholders. The first step was to appoint a CEO with the necessary drive, and then support that leadership with a team of experts prepared to commit for the lengthy duration of the project. It was recognized that the success of the project would partly depend upon continuity of execution and for that, continuity of staff would be vital. As the project planning developed, it was apparent the scale of investment required was significant. A substantial effort was therefore made to raise the necessary funds from government, corporate, not-for-profit and individual sources both in New Zealand and around the world.

Closely aligned parallel programmes for the conservation of the fabric of the huts and the artefacts were developed. Beginning in 2005–2006, the RSHRP involved both on-site works which took place in the narrow three-month summer period when the huts are accessible each year, and off-site works throughout the winter months. The latter was undertaken at Scott Base, where a conservation laboratory was built, and at the Canterbury Museum in Christchurch, New Zealand. Over 80 conservators have been involved in the programme to date, many of them over-wintering at Scott Base between 2006 and 2022.

Internationally peer-reviewed conservation management plans

A strategic management plan had been created prior to the establishment of the AHT, under the control of New Zealand Historic Places Trust. Shortly after the creation of the AHT in 1987 a heritage management plan for the four huts was written. This proved to be a useful document for managing the early interventions in the care of the huts in a coordinated way. However, with the establishment of the RSHRP, there came a recognition that much more substantive plans were acquired to guide the conservation works in disciplined and consistent ways. Developed by a team of heritage experts from New Zealand, Australia and the UK, individual conservation plans (CPs) for each of the four sites were peer reviewed by over 50 individuals and organizations around the world. These were progressively signed off by the AHT board and

published across the period 2002–2015, the most recent being for Hillary's 1957 TAE/IGY hut at Scott Base, for which the Trust became conservation manager in 2015 (Cochran 2003; Cochran 2004a; Cochran 2004b; Morrison 2004; Cochran et al. 2014).

The plans have proved to be an invaluable reference point for all decision-making over the last 20 years. Most of the philosophies and guidelines have worked well. Some criticism received during peer review on the topic of re-creation (that is, the re-establishment in part or whole of a lost feature based on available physical and documentary evidence) was ultimately not reflected in the printed version of the conservation plans. The challenges faced by project personnel in responding to the circumstances encountered on site were not always helped by the tension between the printed guidance and an unwritten understanding of how the conservation philosophy had moved on. The inevitable evolution of philosophies and approaches is one reason conservation plans must be regularly reviewed, however a lesson learned here was that where change is critical to underpin consistent work, it is worth investing in an update, or shorter review period, for the sake of long-term efficiency. In 2023, 20 years on from the initial writing of the conservation plans, AHT commenced a review and updating of their content.

In summary, despite these shortcomings, these plans endorsed agreement with the international heritage community with what was being undertaken, ensured the ownership by the board of the process being followed and provided invaluable guidance and support for the staff in decision-making for the implementation of the conservation works.

Challenges of cold climate conservation

It was recognized from the early days of the conservation of the huts and their artifacts that the extreme external environment and the lack of ability to control the internal environment in the huts created some unique challenges for their conservation. Accordingly detailed methodologies were developed for every aspect of the conservation works of both the built fabric and artefacts. These were underpinned and guided by the internationally peer reviewed published conservation plans which had been written for the huts prior to work commencing. However, inevitably there were many aspects of the conservation works which required interpretation and debate, and an expert steering group was established to work through and resolve these matters.

The development of the process

As the project progressed it became apparent that knowledge transfer was crucial to enabling consistent conservation and interpretation across the sites. It was similarly recognized that no amount of off-site preparation and specification could fully prepare for the circumstances which would be encountered during the brief and intense periods of subsequent fieldwork. Macdonald and Morrison (2021) capture the spirit of this challenge in the introduction to their *Carpentry Methodology* where they state the success of the work:

> 'is dependent upon the good judgement of skilled conservators who must practice their craft within the context of many (often competing) objectives which may include:
>
> i Aesthetics and/or interpretation of the site
> ii Program restrictions (e.g. schedule, available resources, etc.)
> iii National and international conservation charters and policies
> iv Cost
> v Environmental policies
> vi Practicality of the proposed repairs and/or specifications
> vii Health and safety considerations
> viii On-site conditions (e.g. weather, snowpack, etc.)
> ix Permit restrictions'.

A system and suite of project manuals and templates was developed for recording known approaches and treatments, and for enabling staff to step through decision-making processes in a manner which tied back to the conservation plans.

The documents provide context and references to the bigger picture of the site, but their key focus is the objective of quality assurance and control for the project. By defining key criteria to enable informed decision making by each conservator, they provide practical tools for decisionmaking, and ensure that interventions conform to international standards in so far as this is practicable in the Antarctic situation. The documents ensure a level of consistency across the project and identify circumstances where external advice is appropriate or required. As each seasonal team was brought on board, the documents formed a key part of the induction and training programme, allowing the twice-yearly handovers to be conducted with consistency and efficiency.

The practical section of the artefact conservation manual covers six volumes:

- administration and reporting
- practical methodologies
- Vernon database
- relevant research and reports
- hut locations plans[1]
- reference images of condition ratings 1–5, and examples of previous treatments.

The methodologies manual recorded practical information on treatments within the context of Antarctica and Scott Base, as well as the preferred treatment

approaches for different material types. Reviewed and updated by each subsequent team, the manual also recorded the rationale behind some preferred treatments and included illustrative case studies. Topics covered include (for example):

- methods for removing paper linings from corroded tins
- the requirement to keep evidence of historic use, especially the presence of soot from blubber fires
- limitations around the use of certain chemicals and processes in the restricted environment of an Antarctic scientific base
- the collection interpretation preference for low-gloss coatings within an original historic building context.

The *Carpentry Methodology* likewise documents the practical application of on-site repairs to historic timber buildings. Under the framework of investigation, appraisal, specification and action, further criteria for materials, fixings, and adhesives are outlined. Of critical importance is the protection of the hut and artefact collection whilst on-site works are conducted – this and the careful approach to waste minimisation, and process for the retention and recording of historic building fabric, also form key components of the manual.

All works involving the huts, both on and off site, are underpinned by the AHT *On-Ice Health and Safety Manual*, which includes risk assessments and site-specific safety plans.

The artefact and carpentry conservation manuals provide sufficient guidance for much of the work of the project. However, more complex sub-projects arise on a regular basis, so to assist with consistent decision making, AHT has developed a field methodology template. Completed by the AHT's programme managers or lead heritage personnel, the template steps through a sequence of information gathering, including known history, description, condition and hazard assessments. A values assessment is completed, then an options analysis, beginning with the option of non-intervention, leading through increasing orders of intervention. The author(s) make a recommendation, and the document is then reviewed, discussed, and evolved by the Trust's panel of heritage experts. A consensus decision being reached, the document is signed off and an implementation plan developed.

Some field methodologies have been active and evolving across a period of years, as the conservation work required goes through an iterative and reactive response to changing circumstances. In the uncontrolled conditions of Antarctica, many treatments have a much shorter lifespan than conservators expect or hope for before renewal is required. When



Figure 1. Detail of Scott's Memorial Cross on Observation Hill. Image: Antarctic Heritage Trust of NZ.

treatment approaches fail, the field methodology template provides a useful way of tracking and dissecting the original approach, the failures, and the discussions and alternative solutions arising.

Observation Hill cross case study

A core challenge for the team has been to preserve the material culture of the Heroic Era in the context of its harsh polar environment. This has necessarily meant grappling with complex issues related to the managed decline of some large and immovable objects, and the decision to relocate/dissociate some smaller objects to preserve them. The carved timber cross which sits atop Observation Hill is emblematic of these challenges: this is the memorial to Scott and his companions who famously perished on their return journey from the South Pole. Erected by the surviving members of the 1910–13 expedition, the memorial stands today between Scott Base, operated by Antarctica New Zealand, and McMurdo Station, the principal base of the United States Antarctic Program.

The cross (Figure 1) is made from Jarrah (*Eucalyptus marginata*), an Australian hardwood which was presumably carried south on board the *Terra Nova*. The planks are laminated together (i.e. built up) with 14 decorative bronze dowels, the ends of which are peened over iron washers (a process during which the ends of the soft metal rods are repeatedly hammered to create a flared or 'upset' head) to provide the clamped connections (although only eight of the original dowels survive). The base of the memorial consists of a rock cairn which conceals a modern cast concrete footing which was installed in 1994 after the cross was blown down for a second time, this having occurred at least once previously, in 1974. The whole of the cross was originally painted white. The footing is set into the ground and socketed to receive the post of the cross, thus shortening the overall height of the memorial by approximately one meter compared with its original 1913 configuration. One face of the cross bears an incised inscription (originally painted black) which includes lines from Tennyson's *Ulysses*, chosen by Apsley Cherry-Garrard, the expedition

Table 1. Potential interventions considered and their associated impacts. Those in green are considered the most favourable outcomes, those in red the least.

Potential interventions and their associated impacts						
Treatment option	**Impact on significance**	**Potential risk to object**	**Predictability of outcome**	**Effectiveness of solution**	**Longevity of solution**	**Difficulty of implementation**
Temp covers	High	Low	High	High	Moderate	Low
Surface treatment: reversible	Low	Low	Low	Low	Low	Low
Surface treatment: non-reversible	Low	Moderate	Moderate	Moderate	Low	Low
Change orientation of object	High	Low	Moderate	Moderate	Unknown	Moderate
Temporary removal	High	Low	High	High	n/a	Moderate
Remove and replace with reproduction	High	High	High	High	High	High
Permanent shelter	High	Low	High	High	High	high

assistant zoologist, and close friend of both Wilson and Bowers:

IN MEMORIAM

CAPT R. F. SCOTT R.N.

Dr E.A. WILSON CAPT L. E. G. OATES INS.
DRGS Lt H.R. BOWERS R.L.M

PETTY OFFICER E. EVANS R.N

WHO DIED ON THEIR

RETURN FROM THE

POLE MARCH

1912

TO STRIVE, TO SEEK

TO FIND

AND NOT TO

YIELD

The memorial is situated on the extremely exposed summit of Observation Hill, where winter storms can result in winds exceeding 250 kilometres per hour. These circumstances have contributed to the erosion, by wind and windborne ice crystals, of the carved inscription. Concern for the potential loss of the inscription has been a topic of discussion for the past 50 years, and indeed this was the reason for turning the cross through 180° when it was re-erected in 1974. As the RSHRP gathered momentum, the AHT undertook a detailed condition assessment of the memorial in 2006 for the purpose of exploring options for its long-term conservation. Concurrent to these investigations, an initial attempt was made to consolidate the carved wooden surfaces using Paraloid® B-67, and an emergency repair was made to replace two of the missing bronze dowels using materials which exactly matched the originals.

A review by the AHT's expert steering group determined that the development of a stand-alone conservation plan for the memorial was unwarranted

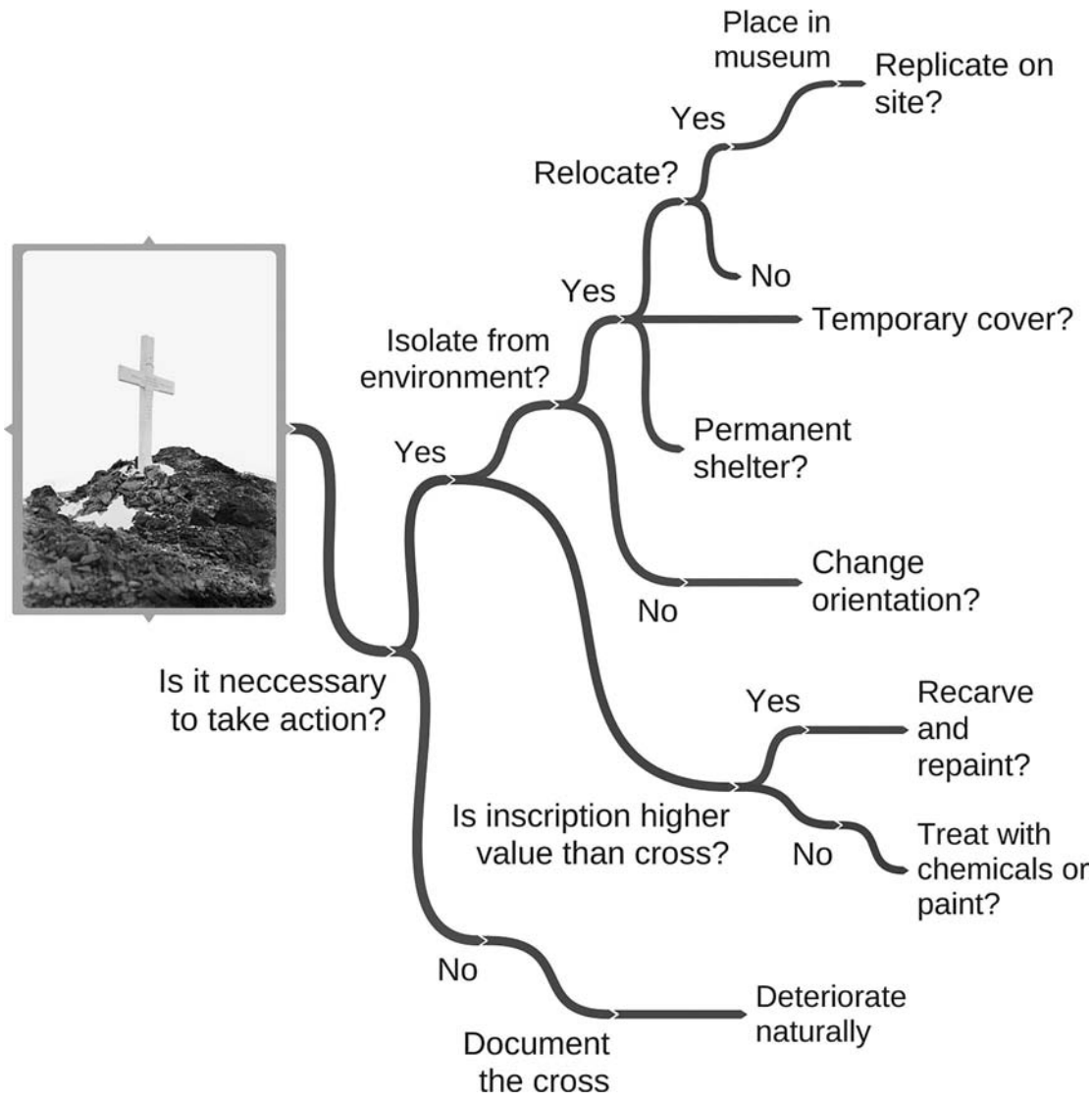


Figure 2. Decision-making flowchart for various treatments based on the deterioration of the Observation Hill Cross. Image: Gordon Macdonald.

given the suitable platform for decision-making provided by the existing and related plans for Scott's Discovery Hut at nearby Hut Point, and the Terra Nova Hut at Cape Evans. While these plans should form the philosophical basis for determining the preferred conservation approach, all options were to be considered.

From the onset it was recognised that the values associated with the memorial were complex and multi-faceted. The cross is an iconic symbol of the Heroic Era, a memorial to the lives of five of its most significant actors, and a tangible connection to the tragedy associated with their achievements. The living descendants of Scott and his expedition companions are deeply invested in the conservation and long-term survival of the memorial as a place of memory, and this is true for many others around the world as well. The site has significance for its selection as a viewpoint overlooking the historic Discovery Hut, its views south towards the Pole, and relationships to both McMurdo Station and Scott Base. When AHT conservators surveyed the memorial

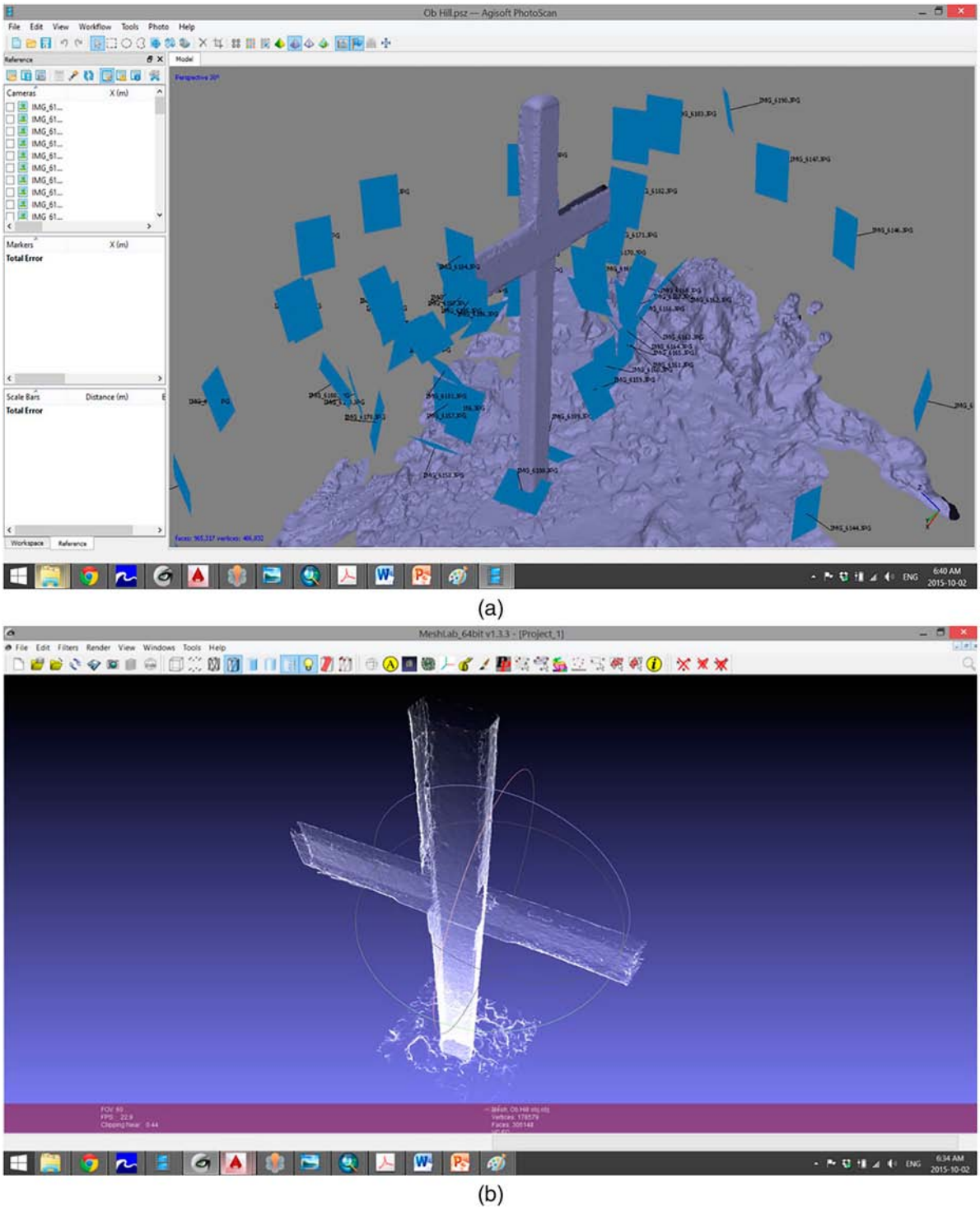


Figure 3. (a) Screen shot of digital images used to create the photogrammetry model of the cross. (b) 3D surface model developed from photogrammetry. Images: Gordon Macdonald.



Figure 4. (a) Installing an early version of the covers in 2015. (b) Installing the current soft-shell version of the temporary covers in 2022. Images: Antarctic Heritage Trust of NZ.

ANTARCTIC HERITAGE TRUST

Conservation Specification – Observation Hill Memorial Cross

Rev M – Updated 3 Mar 2024

Specification & References:

Conservation Worksheet, 12 Jan 2023 (Appendix 5)

Conservation Methodology, 2 Mar 2022 (Appendix 4)

Carpentry Worksheet, 15 Dec 2015 (Appendix 3)

Carpentry Worksheet GM01 2009- Rev F- Field event K170

Locations:

HSM 20: Observation Hill Cross - Observation Hill, Ross Island

77°50′60″ S, 166°40′60″ E

Key Dates/Revisions:

2024 – Laser scan of memorial and approach trail; reconstruction of cairn; straps of winter cover altered.

2023 – Follow-up repair to vandalism; new site interpretation sign proposed (not installed).

2022 – Winter cover altered to improve fit/fastening, and ground valence reduced; repair to vandalism (graffiti); installation SOP updated.

2021 – PVC cover prototype tested.

2019 – SOP developed for installing wood covers.

2018 – Carbon fiber option abandoned; soft shell options proposed (neoprene, PVC, other).

2016 – Carbon fiber cover proposed.

2015 – Repair to vandalism (graffiti); new wood covers made.

2014 - Repair Specification approved by Design Team; prototype wood covers tested.

2013 – Repair Specification proposed.

2012 – Laser scan of memorial.

2010 – Missing bronze rods replaced.

2006 – Excavation of cairn and documentation of memorial including footing.

2005 – Initial inspection of memorial.

Figure 5. Excerpt from current draft specification showing chronology of interventions and key dates. Image: Gordon Macdonald.

in 2006, they discovered multiple tokens concealed within the cairn at the base of the cross, providing evidence of its modern use and further distinction of the values associated with Observation Hill as a place of pilgrimage for many of those people who work in the Ross Sea Region of Antarctica. How best then to protect these many values, when they were so intrinsically related to the physical location of this inhospitable site?

The AHT's first concern was to develop a range of viable *in situ* and *ex situ* conservation options for consideration by the advisory team, and likewise to rule out those options that were determined to be impractical or ineffective. For example, a series of offsite tests was undertaken to explore the relative durability of 12 chemical consolidants, and their capacities to withstand the effects of wind scouring and abrasion. Dry ice blast media was used to simulate the effects of the Antarctic environment on surface treated wooden test blocks with a Janka hardness rating matching that of Jarrah. While these tests were underway, a literature review was made to identify whether any potential solutions might exist beyond the realm of polar conservation. It was during this period that the team first contemplated the use of temporary winter covers as a means to slow/retard, if not to resolve, the effects of erosion. For example, the fitting of temporary covers as a means of winter protection has been used by Historic Environment Scotland to protect 1,300-year-old stones featuring Pictish carving at various sites throughout eastern Perthshire. Such soft and porous stones are particularly vulnerable to the impacts of frost (Agnew 2002; Berry et al. 2005; Ruedrich et al. 2011; Milchin, Haselberger, and Krist 2020)

After a period of approximately eight months of investigation and experimentation, the team compiled a range of potential options and presented these to the advisory team together with a matrix outlining the associated anticipated impacts (Table 1). A flow chart was also developed to identify key points in the decision-making process (Figure 2).

Upon review of the various options, the advisory team decided that the development of temporary winter protection should be regarded as a high priority action and recommended this to the AHT executive as an acceptable interim solution for the care of the memorial. With the AHT's support, a work programme was developed in 2012 to field test an initial set of covers. However, as is so often the case with conservation interventions in Antarctica, the work had only just begun.

During the ten-year period since the adoption by AHT of the 'temporary winter covers' strategy, several prototypes have been developed and tested. The first of these consisted of interlocking, foam-lined plywood cases forming a hard-shell carapace. The design and dimensions of these cases were developed using a photogrammetric model (Figure 3).

The first version of the temporary plywood covers was tested during the winter of 2013–14. This was replaced by an updated and improved wooden version (this included more effective gaskets to seal the joins between case sections, and an improved latching system to secure the sections) during 2014 which remained in use until 2021 (Figure 4a).

As Berry and associates observed, 'close-wrapping involves close physical contact', and this is one of the factors which must be considered alongside environmental conditions, cost, summer storage and aesthetics when designing temporary covers (Berry et al.

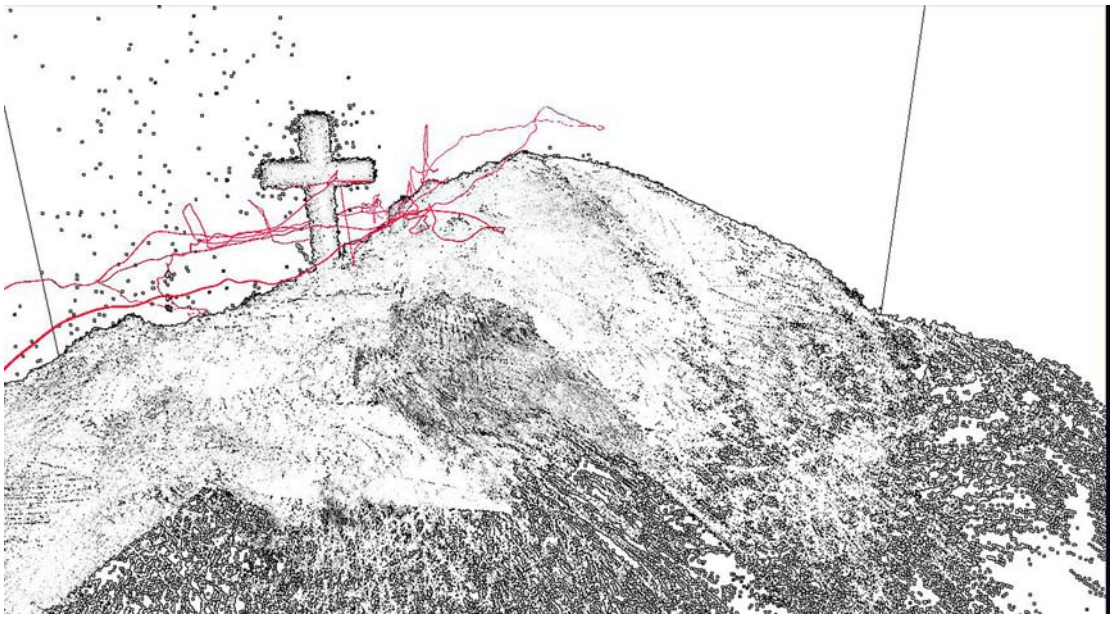


Figure 6. Screen capture from the point cloud resulting from a SLAM portable laser scan made during the 2023–2024 Antarctic season. Red line indicates travel path of scanner. Image: Gordon Macdonald.

2005). Concerns about the weight of the wooden covers (these being challenging to carry up and down Observation Hill) and the potential for accidentally scratching/damaging the cross during installation or removal, led to the exploration by the project team of several lightweight alternatives including a carbon-fibre shell, neoprene 'sock', and other variants of soft covers. The first of these to be fabricated was a soft-shell composite cover consisting of PVC fabric with nylon lacing cord and Velcro fastenings, manufactured in New Zealand, and installed during 2021. The PVC covers are impermeable, and while this might permit challenges in a more temperate climate (e.g. condensation, mould growth, etc.) the covers are only employed during the cold, dry, Antarctic winters from March to August. Further modifications were made in 2022 to reduce the size of the ground valance and improve the fit (Figure 4b).

Such modifications are recorded during each field event for the purpose of quality control. At the end of each on-ice season these worksheets are reviewed and approved by the advisory team and the field methodology is updated accordingly to reflect any changes made to the object (Figure 5).

If, during their review, the advisory team identifies a deficiency in the work (e.g. incomplete task) this is recorded in the annual sign-off documents as an action for the upcoming season. The conditions of the object are observed and recorded each season as part of the AHT's ongoing Maintenance and Monitoring Program. Recording methods have evolved during the project, and now include simultaneous localization and mapping (SLAM) type portable laser scanning. Figure 6 shows a screen capture from the point cloud resulting from a portable laser scan made during the 2023–2024 Antarctic season.

This case study highlights how many conservation treatments in Antarctica are iterative processes, interpreting the way in which artefacts have responded to treatments, and seeking to adapt and innovate to produce a better outcome where this is considered achievable.

Conclusion

This paper has described the process undertaken to deliver the RSHRP. For the delivery of multi-year conservation projects of this complexity, it has highlighted the critical value of:

- establishing sound staff resourcing and financial footing
- ensuring a peer-reviewed conservation management plan is in place
- recognising the conservation challenges of the project and putting in place appropriate methodologies in response
- encouraging collaboration between field event staff and advisory team members, to enable the iterative development of conservation treatments over time.

Using the experience of the RSHRP, the paper has detailed the response to the conservation challenges encountered in cold climate conservation in Antarctica, and the methodologies which were developed in the process. A case study using the Scott Memorial Cross has then been used to illustrate the way in which these processes have played out.

It is hoped that learning from this project can help inform similar multi-year complex conservation projects, irrespective of whether these are undertaken in challenging environments.

Note

1. Each hut has a series of floor and elevation plans created by Cheshire Architects, Canterbury Museum and Lizzie Meek, with codes for each area, shelf, hook, or other surface, allowing accurate location information for each object to be recorded in the Vernon database.

Acknowledgements

We thank the following for their physical and intellectual contributions to the project: Antarctic Heritage Trust (NZ), Antarctica New Zealand, Pip Cheshire, Win Clark, Chris Cochran, Al Fastier, and Ben Gourley,

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Julian Bickersteth http://orcid.org/0000-0002-2280-5913
Gordon Macdonald http://orcid.org/0009-0000-0061-8378
Lizzie Meek http://orcid.org/0000-0002-5831-1536

References

Agnew, N. 2002. "Methodology, Conservation Criteria and Performance Evaluation for Archaeological Site Shelters." *In Conservation and Management of Archaeological Sites* 5 (1–2): 879–887.

Berry, J., F. David, S. Julien-Lees, B. Stanley, and D. Thickett. 2005. "Assessing the Performance of Protective Winter Covers for Outdoor Marble Statuary: Pilot Investigation." In *ICOM-CC 14th Triennial Meeting The Hague* 12–16 September 2005, edited by J. Bridgland. https://www.icom-cc-publications-online.org/2148/Assessing-the-performance-of-protective-winter-covers-for-outdoor-marble-statuary–pilot-investigation.

Bickersteth, J., S. Clayton, and F. Tennant. 2008. "Conserving and Interpreting the Historic Huts of Antarctica." *Studies in Conservation* 53 (supp.1): 218–223. https://doi.org/10.1179/sic.2008.53.Supplement-1.218.

Cochran, C., ed. 2003. *Conservation Report: Shackleton's Hut, British Antarctic Expedition 1907–1909, Cape Royds, Ross Island, Antarctica*. Christchurch, New Zealand: Antarctic Heritage Trust.

Cochran, C., ed. 2004a. *Conservation Plan: Scott's Hut, Cape Evans, British Antarctic Expedition 1910-1913, Ross Island, Antarctica*. Christchurch, New Zealand: Antarctic Heritage Trust.

Cochran, C., ed. 2004b. *Conservation Plan: Discovery Hut, Hut Point, National Antarctic Expedition 1901-1904, Hut Point, Ross Island, Antarctica*. Christchurch, New Zealand: Antarctic Heritage Trust.

Cochran, C., A. Fastier, L. Meek, D. Harrowfield, and N. Watson. 2014. *Conservation Plan: Hillary's Hut, Scott Base*. Christchurch, New Zealand: Antarctic Heritage Trust.

Harrowfield, D. 2007. *Call of the Ice: Fifty Years of New Zealand in Antarctica*. Auckland, New Zealand: David Bateman.

Lintott, B. J. 2016. *Scott's and Shackleton's Huts: Antarctic Heritage and International Relations*. Unpublished PhD dissertation. Christchurch, New Zealand: University of Canterbury.

Macdonald, G., and M. Morrison. 2021. *RSHRP Carpentry Methodology*. Christchurch, New Zealand: Antarctic Heritage Trust.

McElrea, R. 1987. *Declaration in Support of Amendment to Trust Deed 2*. Christchurch, New Zealand: Duncan Cotterill Solicitors.

Milchin, M., M. Haselberger, and G. Krist. 2020. "Preventive Conservation Measures for Stone Statuary in the Outdoor Environment: Three Case Studies from Austria." *Studies in Conservation* 65 (supp.1): 233–236. https://doi.org/10.1080/00393630.2020.1757879.

Morrison, M., ed. 2004. *Conservation Plan: The Historic Huts at Cape Adare, Borchgrevink's British Antarctic Expedition 1898–1900; Northern Party of Scott's British Antarctic Expedition 19101913, Cape Adare, Antarctica*. Christchurch, New Zealand: Antarctic Heritage Trust.

Quartermain, L. B. 1963. *Two Huts in the Antarctic*. Wellington, New Zealand: R. E. Owen.

Ruedrich, J., Y. Rieffel, S. Pirskawetz, H. Alpermann, U. Joksch, C. Gengnagel, F. Weise, R. Plagge, J. Zhao, and S. Siegesmund. 2011. "Development and Assessment of Protective Winter Covers for Marble Statuaries of the Schlossbrucke, Berlin (Germany)." *Environmental Earth Sciences* 63: 1823–1848. https://link.springer.com/article/10.1007s12665-010-0765-2.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S12–S17
https://doi.org/10.1080/00393630.2024.2369830

ORIGINAL RESEARCH OR TREATMENT PAPER

Fire Risk Assessment in Museums on the HERIe Web-based Decision-supporting Platform

Evaluación del Riesgo de Incendio en Museos en la Plataforma Web de Apoyo a la Toma de Decisiones HERIe

Łukasz Bratasz and Łukasz Berger

Jerzy Haber Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences, Kraków, Poland

ABSTRACT

Fire statistics indicate that fire, despite significant technical progress in the field of fire protection, is a significant risk to the long-term preservation of cultural property. Management of the risk requires tools which quantitatively relate the risk of fire to the characteristics of buildings and collections and the effectiveness of fire protection measures. Such tools must be accessible to, and useful for, conservation professionals and related decision-makers. To address the challenge, a module assessing fire risk for collections in museums has been developed on the HERIe online digital decision-supporting platform using the methodology proposed by Jean Tétreault transformed into a mathematical algorithm. It takes into account building characteristics and the proportion of the collection stored in showcases, as well as the vulnerability of the collection materials to heat, combustion, smoke, and water. This information is used to forecast loss to collection value over a selected time horizon. Fire likelihood is estimated from the fire statistics available in the user's country, area, or organization. Risks to collections associated with correct and unwanted activation of automatic fire suppression systems are also considered.

Las estadísticas indican que, a pesar de los importantes avances técnicos en el campo de la protección contra incendios, estos aún representan un riesgo importante para la preservación a largo plazo de los bienes culturales. La gestión del riesgo requiere herramientas que relacionen cuantitativamente el riesgo de incendio con las características de los edificios y colecciones y con la eficacia de las medidas de protección contra incendios. Estas herramientas deben ser accesibles y útiles para los profesionales de la conservación y los tomadores de decisiones relacionados. Para afrontar este desafío, se ha desarrollado un módulo que evalúa el riesgo de incendio de las colecciones de los museos en una plataforma digital de apoyo para la toma de decisiones en línea HERIe. La plataforma utiliza la metodología propuesta por Jean Tétreault transformada en un algoritmo matemático. Tiene en cuenta las características del edificio y la proporción de la colección almacenada en vitrinas, así como la vulnerabilidad de los materiales de la colección al calor, la combustión, el humo y el agua. Esta información se utiliza para pronosticar la pérdida del valor de cobranza durante un horizonte temporal seleccionado. La probabilidad de incendio se estima a partir de las estadísticas de incendios disponibles en el país, área u organización del usuario. También se consideran los riesgos para las colecciones asociados con la activación correcta e indeseada de los sistemas automáticos de extinción de incendios.

ARTICLE HISTORY
Received October 2023
Accepted June 2024

KEYWORDS
Fire risk assessment; fire protection; museums; HERIe

Evaluación del riesgo de incendio; protección contra incendios; museos; HERIe

Introduction

In recent years, there has been a noticeable change in the approach to the protection of museum and library collections. The heuristic approach based on simplified reasoning without defining measurable goals is increasingly being replaced by comprehensive risk management. Risk assessment involves identifying the most significant processes affecting the collection value and estimating quantitatively its loss at a given time horizon. This allows priorities in the long-term preservation of a collection to be identified (Waller 2003, 2008, 2019; Michalski and Pedersoli 2016) and measures to be selected based on an analysis of benefits understood as reducing loss of collection value and costs of these measures (Michalski and Karsten 2018).

Fire, despite significant technical progress in the field of fire protection, is one of the greatest risks to the long-term preservation of collections (Maxwell 2010). A significant loss of collection value caused by fire is primarily due to the potentially catastrophic consequences of combustion as well as heat, smoke, and

CONTACT Łukasz Bratasz ncbratas@cyf-kr.edu.pl, lukasz.bratasz@ikifp.edu.pl Jerzy Haber Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences, ul. Niezapominajek 8, 30-239 Krakow, Poland

© The International Institute for Conservation of Historic and Artistic Works 2024

water used during fire extinguishing. Frequently, the selection of fire protection measures follows applicable legal regulations and standards which primarily aim at protecting human life and health, not preserving collections. European Standard EN 16893:2018 (European Committee for Standardization 2018) provided specifications and guidance for the assessment of fire risk in a building or space housing collections to formulate a policy for fire prevention and protection. Measures should protect the contents and structure of the building both from the fire itself and from damage caused by firefighting operations. Fire compartments preventing fire, smoke and water from spreading, measures minimizing fire hazards in the ventilation equipment and electrical systems, planning for automatic fire detection, alarm and fire-fighting systems are key elements of such policy. The scope for any alterations or achievement of conditions suitable for collections may, however, be limited in protected historic buildings that contain collections as such alterations could cause damage to the historic fabric. Therefore, an appropriate methodology and reliable, detailed statistical data are required for the selection of the optimal and most cost-effective strategy for the preservation of collections.

To address the challenge, a module assessing fire risk for collections in museums has been developed on the HERIe web-based decision-supporting platform freely available at herie.pl to anyone involved in the preservation of collections. The platform contains several modules corresponding to other agents of change (deterioration): incorrect temperature or relative humidity (RH), air pollutants, or light. The HERIe platform is currently used by more than 2000 users to support decisions in the area of preventive conservation. It was found that approximately 50% of users are educators, exploiting the platform for lectures, classes, and professional development courses.

A general approach to the fire risk assessment

Tétreault (2008) proposed a method for a quantitative assessment of the risks caused by fires in museums considering the statistical frequency of fires in Canadian museums and their estimated effects. Tétreault proposed six control levels (CL) for fire risk. Reaching given CL in a building depends on meeting several requirements in six areas: avoiding, blocking, detecting, responding, training, and procedures. CL1 to CL3 apply to buildings without automatic extinguishing systems (AES), CL4 applies to buildings where AES is installed in rooms with large fire loads, and CL5 and CL6 apply to buildings where AES is installed in all rooms.

In the quantitative assessment of fire risk, the occurrence of fires and their estimated effects should be considered. Mathematically, fire risk is expressed as the product of the expected number of fires in the assumed time horizon and its effects, which in memory institutions are understood as the fraction of the collection value lost.

The impact of a fire depends on:

- sensitivity of materials from which objects are made to combustion and heat, smoke, and water used during fire extinguishing
- the size of a fire, which may be confined to a single material, room, floor, or spread through the building
- parts of the collection affected by the fire.

Therefore, the magnitude of risk for a given group of objects can be estimated using a simplified formula:

$$MR = \sum_{i}^{\text{Fire size}} Pi \cdot \sum_{j}^{\text{combustion, smoke, water}} MC_{ij}$$

$$MC_{ij} = \sum_{i}^{\text{fire size}} EF_i \sum_{j}^{\text{combustion, smoke, water}} PM_{ij} \cdot ML_{ij} \cdot PC_{ij}$$

Where, MR is the magnitude of risk to a collection due to fire, P is the expected number of fires in the time horizon, i is summation index for fires of various extents, j is summation index for three agents of change: – combustion and heat (aggregated into one agent), smoke, and water released during extinguishing action, MC_j expresses material consequences of a fire event in terms of impacts of the individual agents of change on the expected loss of collection value. It is assumed that the value of the collection is originally 1, EF_i represents fractional shares of fires of various extents – in terms of fire spread – in the total number of fires, PM_{ij} represents part of the material (collections and other museum equipment) affected by fires of various extents and various agents of change, ML_{ij} represents loss of material value caused by fires of various extents and various agents of change, PC_{ij} – the probability that it is the collection, not other materials, that will be affected by fires.

The expected number of fires is estimated as a ratio of the chosen time horizon and the average meantime between fires per museum in the analysed region or country. In an unlikely situation where the estimated mean time between large fires is shorter than the typical time horizon used in the risk assessment (30, 50, or 100 years), mitigation of the risk should be a 'catastrophic priority'.

The distribution of the extent of fire and loss of material value ML resulting from the three agents of change for materials of medium sensitivity to damage, depending on the size of the fire, control level CL, and the expected number of fires in the

Table 1. Fractional shares of fires of various extents in the total number of fires EF_i and loss of material value ML caused by combustion/heat (c/h), smoke (s), or water used in the fire suppression action (w), estimated for fires of various extents.

		Extent of fire															
		Material				Room				Floor				Building			
			ML_j				ML_j				ML_j				ML_j		
CL	P [1/year]	EF	c/h	s*	w**	EF	c/h	s*	w**	EF	c/h	s*	w**	EF	c/h	s*	w**
1	$7.1*10^{-3}$	0.28	0.8	0.1	0.02	0.29	0.7	0.1	0.05	0.17	0.8	0.1	0.1	0.26	0.8	0.1	0.2
2	$7.1*10^{-3}$	0.28	0.8	0.1		0.34	0.5	0.07		0.19	0.7	0.1		0.19	0.5	0.07	
3	$6.3*10^{-3}$	0.42	0.5	0.07		0.56	0.4	0.06		0.02	0.4	0.06		$7*10^{-4}$	0.4	0.06	
4	$1.4*10^{-3}$	0.53	0.3	0.04		0.46	0.3	0.04		0.01	0.3	0.04		$1*10^{-4}$	0.4	0.06	
5	$6.7*10^{-4}$	0.68	0.1	0.01		0.31	0.2	0.03		0.01	0.3	0.04		$6*10^{-5}$	0.4	0.06	
6	$3.6*10^{-4}$	0.99	0.1	0.01		0.01	0.2	0.03		$2*10^{-4}$	0.3	0.04		$1*10^{-5}$	0.4	0.06	

*It is assumed that the material damage resulting from smoke is proportional to that from combustion and heat because the amount of smoke produced during a fire depends on its size and the speed at which the fire is extinguished. The proportionality factor selected was 2/14.

**It is assumed that regardless of how the fire is extinguished (using AES or by fire brigade units) the time of wetness is similar and, therefore, material damage resulting from the extinguishing action does not depend on extinguishing method.

time horizon P, were taken from Tétreault (2008) (Table 1).

The damaging effect of fire also depends on the sensitivities of materials to heat and combustion, and water – it is assumed that all objects are equally sensitive to soiling associated with the deposition of smoke particles. The material vulnerabilities were quantified following Tétreault (2008) as relative sensitivities V_j in Table 2 and the correction of loss of material value ML in the form $ML_{\text{medium-sensitivity}}^{\left(\frac{1}{\sqrt{V_j}}\right)}$ was applied. The proposed correction formula approximates the expected trends in material damage, that is to say, loss of value for materials with high sensitivity to an agent of change is 1, and for decreasing sensitivity will asymptotically approach 0.

When considering the effect of fire, it is necessary to estimate what part of the material PM in the museum (objects and equipment) will be affected by combustion and high temperature. This estimation depends on the size of the building, the number of floors, and the number of rooms. When estimating the consequences of fire covering the entire building, PM is 1. Assuming a simple building layout, one can estimate the PM for the fire covering one floor by dividing 1 by the number of floors, and for a room by the number of rooms. In the case of a fire confined to the material of origin, it is assumed that the PM estimate for a room is divided by 10.

In addition, the effect of fire depends on the probability PC that heritage objects will be within its range. Tétreault reports that only 3% of all fires in Canadian museums begin in rooms containing collections. In consequence, when a fire is confined to a room, the probability that the objects will be within the fire range is 3%. A PC of 0.15 was adopted for fires confined to the material of origin to reflect a significant decrease in the probability that a museum object will be within a small fire range. When a fire covers one level, PC is calculated by dividing the number of floors with the collection present by the number of floors in the building. When a fire covers the entire building, the PC is 1.

Material loss due to the impact of smoke and water

In the model, Tétreault reasonably assumes that water or smoke cannot destroy objects damaged by combustion and heat. Therefore, the material loss resulting from the impact of water or soot deposition is estimated after deducting the part of the material affected by combustion. In the case of a fire covering the entire building:

$$PM_{\text{building,water}} \text{ or } PM_{\text{building,smoke}} = 1 - ML_{\text{building,combustion}}$$

However, in the case of a fire covering one floor, smoke will also spread over the upper floors, and water will flood the lower floors. For simplicity, it is assumed that for a museum, smoke and water will affect half of the building, including the floor covered by the fire.

$$PM_{\text{floor,water}} \text{ and } PM_{\text{floor,smoke}} = \frac{1}{2}\left(1 - ML_{\text{floor,combustion}} PM_{\text{floor,combustion}}\right)$$

where $PM_{\text{floor,combustion}} = \dfrac{1}{\text{number of floors}}$.

In the event of a fire confined to a room, it is assumed that the water effect will be limited to that room. However, the impact of smoke will depend on CL. In CL4 to CL6, a smoke-proof door or an automatic air-conditioning cutoff will confine smoke to the room of fire origin:

$$PM_{\text{room,water}} \text{ and for CL4 to CL6 } PM_{\text{room,smoke}} = \left(PM_{\text{room,combustion}} - ML_{\text{room,combustion}} \cdot PM_{\text{room,combustion}}\right)$$

For CL1 to CL3, smoke will spread throughout the entire floor:

$$PM_{\text{room,smoke}} = \left(PM_{\text{floor,combustion}} - ML_{\text{room,combustion}} \cdot PM_{\text{room,combustion}}\right)$$

where $PM_{\text{room,combustion}} \dfrac{1}{\text{number of rooms}}$

Table 2. Relative sensitivities of materials to combustion/heat and water after Tétreault (2008).

	Combustion and heat		Water	
Material sensitivity to the agents of change	Typical materials	Relative sensitivity V_{fire}	Typical materials	Relative sensitivity V_{water}
Very low	Stone, ceramics, plaster, large metal objects (except for lead)	0.1	Stone, ceramics, plaster, metal objects, plastics	0.01
Low	Glass, thin metal objects	0.5	Textiles, leather	0.1
Medium	Boards, thick books	1	Wood covered with material of low permeability to water, panel paintings, glass*	1
High	Paper, textiles, paintings, plastics	10	Bare wood, paper, canvas paintings	5
Very high	Nitrocellulose	1000	Soluble salts, pastels, watercolours	10

Finally, it is assumed that during a fire confined to a material of origin, smoke, and water will affect the whole room:

$$PM_{material,water} \text{ or } PM_{material,smoke} = (PM_{room,combustion} - ML_{material,combustion} \cdot PM_{material,combustion})$$

where

$$PM_{material,combustion} = \frac{1}{10 \cdot \text{number of rooms}}$$

Material damage is additionally limited by systems and methods of storing objects. The estimated material damage resulting from the effects of water and smoke will be significantly smaller if it is considered that some objects are placed in cabinets or showcases or protected by water resistant packaging.

It is also assumed that the probability PC that heritage objects will be affected by smoke or water has the same values as given in the previous section for combustion.

It was verified that the developed model gives losses similar to those reported by Tétreault. For a museum with CL2 and a collection of medium sensitivity to water and combustion, the losses caused by water and smoke are 0.2 and 0.14 relative to the combustion/heat, respectively.

Negative consequences of fire suppression action using AES

Undoubtedly, equipping a building with AES significantly reduces fire risk for a typical museum collection as illustrated by the data shown above. However, an important element in rational decision-making regarding the installation of AES and the selection of its type is the assessment of risk associated with correct and unwanted activations. Some museum institutions have in the past chosen not to install AES as they feared the consequences of unwanted activation.

According to a report by Ahrens (2017) prepared for the American Fire Protection Association, various types of sprinklers were present in 25,440 fires in buildings other than homes in 2014, and, at the same time, there were 51,000 unwanted activations. Therefore, it can be estimated that the frequency of unwanted sprinkler activations relative to the fire frequency in buildings with sprinklers is 2:1. Due to a lack of data for museums, this value is used to estimate risk related to unwanted activations. Tétreault estimated that the likelihood of fires in museums with AES, expressed as the average meantime between fires per museum, is between 720 and 2800 years. Hence, the average meantime between unwanted activation is 360–1400 years. In this work, 360 years is used as a more cautious representation of the risk. Therefore, a P value of $3*10^{-3}$ is used to calculate the related MR, whereas ML corresponds obviously to local water damage limited to the material of origin.

It is even more difficult to estimate the effects of physical forces caused by the activation of gaseous AES systems (AES-G) due to the lack of statistical data. According to interviews with staff of institutions equipped with AES-G who have experienced gas discharges in storage spaces, the risk of damage to objects is small but occasionally some objects can be damaged. It was estimated that the risk associated with gas discharge causes damage to a much smaller number of objects and the related damage will be smaller than when water-based AES is activated. Therefore, it was considered that the expected loss of collection value for CL4 to CL6 will be equivalent to that caused by water-based AES calculated for objects of low sensitivity to water.

Fire risk assessment for an example storage facility

The comparison of loss of collection value due to fire for various control levels was done using the fire risk assessment module of the HERIe platform to inform the selection of optimal control measures in a large, shared storage facility for several museums being built near Warsaw which will combine high standards of collection care with very low energy consumption. The following parameters were used in determining the risk of fire for the facility:

- the time horizon chosen was 50 years,
- the storage building has 1 floor,
- there are 10 storage compartments,
- none of the objects are framed or in showcases.

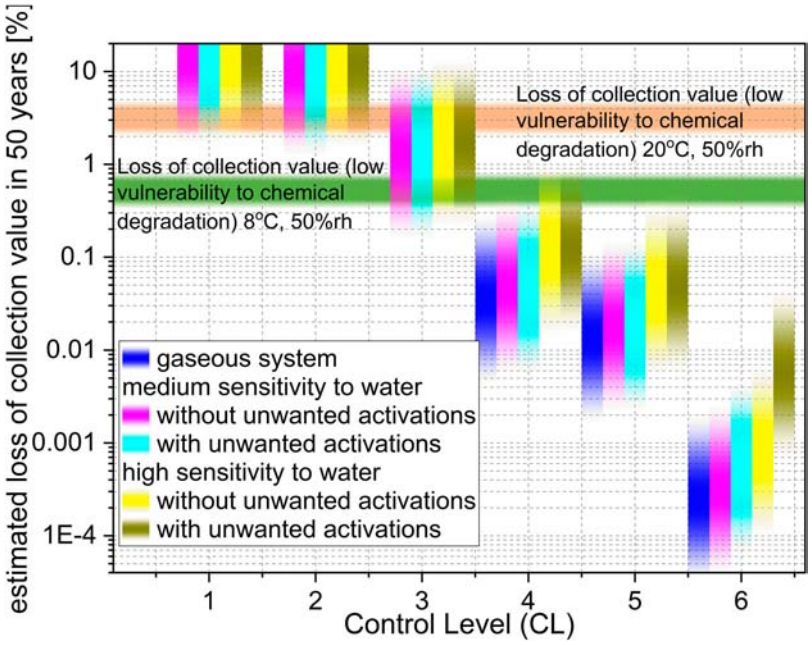


Figure 1. The predicted loss of collection value for objects of medium sensitivity to combustion and heat, and medium and high sensitivity to water including, or not, unwanted AES activations. The calculations were performed for a storage facility in the perspective of 50 years. For comparison, loss of collection value due to chemical degradation of materials of low vulnerability to such degradation is shown for room temperature and for cool storage. The uncertainty of the estimation is large, at least one order of magnitude, and therefore, presented data illustrate trends, not exact numbers.

As one can see from the results presented in Figure 1, the risk decreases approximately by one order of magnitude if the CL increases by one, except for the transition from CL1 to CL2, when the reduction of risk is insignificant. Naturally, as CL increases, the relative significance of damage caused by water increases as losses caused by heat and combustion are reduced due to the effective action of AES. Generally, the impact of unwanted AES activation on the aggregated risk is insignificant – the positions of pink and cyan as well as yellow and khaki bars are similar. The highest CL is the exception, in this case the risk increases by 60% (from $3*10^{-4}$ to $5*10^{-4}$) or 600% (from $8*10^{-4}$ to $6*10^{-3}$) for materials of medium or high sensitivity to water, respectively. The risk for materials of high sensitivity decreases 3.5–22 times for CL4 and CL6, respectively, when a gaseous system is used instead.

The above method can be helpful when comparing various risks and choosing the most cost-effective measures for the protection of the collection. If one assumes that the collection under consideration contains a significant amount of organic materials of reasonable chemical stability, such as good quality paper, textiles, and wood, which have a lifetime of approximately 1000–3000 years at 20°C and 50% RH, the loss of value of the collection due to chemical degradation is approx. 2–5% per 50 years assuming a linear relation between loss of collection value and chemical degradation (see https://www.canada.ca/en/conservation-institute/services/agents-deterioration/temperature.html). In the case of cool storage at a temperature of about 8°C, the chemical degradation is about 6 times slower when compared to 20°C (Strlič et al. 2015). Therefore, the loss of value of the collection due to chemical degradation is 0.2–0.5% per 50 years. The losses caused by fire are significantly larger than losses caused by chemical degradation for CL1 to CL2. But the risks become comparable for CL3, and for CL higher than CL3, chemical degradation would, in the long term, cause significantly larger losses than fire. Using this information, it was decided that the facility would not be equipped with any AES but additional measures minimizing the likelihood of fire initiation were identified and implemented. Although the above analysis does not give a definite and universal answer about the optimal CL, it indicates that investing in CL higher than 4 might not be effective for typical museums from a cost–benefit point of view.

Conclusions

The presented model is conceptually and formally significantly simplified. Further simplifications occur when evidence-based statistical data which populate the model are collected to represent the 'average museum'. In practice, such a museum does not exist. In consequence, the extrapolation of available information and extending the outcome of modelling to a particular museum building is questionable. Also, statistical data collected for Canada might not be

valid for other countries. Data for any single country will be based on such a small sample size that random uncertainty will be large. Unfortunately, the use of more comprehensive methods like the one proposed by Harmathy et al. (1989) is limited due to a lack of statistical data. Similarly, the lack of representative data for unwanted sprinkler activations makes the presented analysis a rough approximation of their impact on collections. However, general conclusions from the analysis remain valid even if the likelihood of the unwanted activation would be underestimated by a factor of 10. Despite the shortcomings, the model proposed by Tétreault was implemented and made available as the fire risk assessment module on the HERIe platform to provide perspective and guide decisions as illustrated in Figure 1. However, although the calculated risk is presented showing two significant numbers, one must keep in mind that the uncertainty of the estimation is large, at least one order of magnitude. Change of the distribution of fire sizes *EF* in Table 1 for CL1 to 0.65, 0.2, 0.1, 0.05 which better reflects fire statistics in Poland, reduces the magnitude of risk fourfold for that class. In general, risk magnitude is dominated by the likelihood of the largest fires for low CLs. The situation changes for higher CLs for which risk magnitude is determined by fires confined to room and level. Change in the likelihood of fires P in higher CL classes, for which statistical data are scarce, can also significantly change the magnitude of risk.

The module is an open tool. The user can freely modify fire likelihood, distribution of extent of fire in museums, and estimates of the loss of materials to analyse and better understand the uncertainty associated with the estimation. Alternatively, the fire statistics available in the user's country, area, or organization can be used to tailor the model to the specific features of a particular museum.

Therefore, there is an acute need to gather sound fire statistics and data on unwanted activations of automated fire extinguishing systems which would supply input into the algorithms modelling risk implemented on the HERIe platform. Such data can be collected effectively by an active community of professionals involved in the preservation of collections. One of the unexpected outcomes of implementing the HERIe platform has been a growing group of users interested in evidence-based decision-making. It is hoped that, with a growing understanding of key parameters needed for the evaluation of fire risk, the acute gap in the availability of high-quality data will diminish.

Acknowledgment

We are very grateful to Robert Waller for critical discussion and inspiring comments on the manuscript.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This research has been financially supported by the IPERION HS [project no. 871034] Integrating Platforms for the European Research Infrastructure ON Heritage Science, funded within the HORIZON 2020 programme.

ORCID

Łukasz Bratasz http://orcid.org/0000-0002-5277-2606

References

Ahrens, M. 2017. "US Experience with Sprinklers." National Fire Protection Association. https://www.nfpa.org/education-and-research/research/nfpa-research/fire-statistical-reports/us-experience-with-sprinklers.

European Committee for Standardization. 2018. *EN 16893:2018. Conservation of Cultural Heritage – Specifications for Location, Construction and Modification of Buildings or Rooms Intended for the Storage or use of Heritage Collections*. Brussels: European Committee for Standardization.

Harmathy, T. Z., K. H. Alrnand, V. R. Beck, D. W. Belles, I. A. Benjamin, C. L. Beyler, R. W. Bletzacker, et al. 1989. "A Decision Logic for Trading Between Fire Safety Measures." *Fire and Materials* 14 (1): 1–10. https://doi.org/10.1002/fam.810140102

Maxwell, I., ed. 2010. *COST Action C17: Built Heritage: Fire loss to Historic Buildings*. Edinburgh: Historic Scotland.

Michalski, S., and I. Karsten. 2018. "The Cost-Effectiveness of Preventive Conservation Actions." *Studies in Conservation* 63 (sup1): 187–194. https://doi.org/10.1080/00393630.2018.1471894

Michalski, S., and J. L. Pedersoli. 2016. *The ABC Method: A Risk Management Approach to the Preservation of Cultural Heritage*. Ottawa: Canadian Conservation Institute.

Strlič, M., C. M. Grossi, C. Dillon, N. Bell, K. Fouseki, P. Brimblecombe, E. Menart, et al. 2015. "2Damage Function for Historic Paper. Part III: Isochrones and Demography of Collections." *Heritage Science* 3: 1–11.

Tétreault, J. 2008. "Fire Risk Assessment for Collections in Museums." *Journal of the Canadian Association for Conservation* 33: 3–21.

Waller, R. 2003. *Cultural Property Risk Analysis Model: Development and Application to Preventive Conservation at the Canadian Museum of Nature*. Göteborg Studies in Conservation 13. Göteborg: Göteborg Acta Universitatis Gothoburgensis.

Waller, R. 2008. "Comprehensive Risk Assessment." In *Real-Time and Deliberative Decision Making. NATO Science for Peace and Security Series C: Environmental Security*, edited by I. Linkov, E. Ferguson, and V. S. Magar, 179–190. Dordrecht: Springer. https://doi.org/10.1007/978-1-4020-9026-4_10

Waller, R. 2019. "Collection Risk Assessment." In *Preventive Conservation: Collection Storage*, edited by L. Elkin, and C. A. Norris, 59–90. New York: Society for the Preservation of Natural History; American Institute for Conservation of Historic and Artistic Works; Smithsonian Institution; and The George Washington University Museum Studies Program.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S18–S24
https://doi.org/10.1080/00393630.2024.2375162

ORIGINAL RESEARCH OR TREATMENT PAPER

OPEN ACCESS Check for updates

Reconsidering Museums' Climate and Seasonal Adjustment for Vulnerable Artifacts

Reconsiderar el Clima y el Ajuste Estacional de los Museos para los Artefactos Vulnerables

Sonia Bujok [1], Alexandra Bridarolli [2], Michał Łukomski [2] and Łukasz Bratasz [1]

[1]Jerzy Haber Institute of Catalysis and Surface Chemistry Polish Academy of Sciences, Krakow, Poland; [2]Science Department, Getty Conservation Institute, Los Angeles, CA, USA

ABSTRACT

The paper provides new experimental evidence for vulnerable artifacts on the dependence of failure strain on the loading rate corresponding to typical environmental loads lasting between hours and months. Animal glue-based ground was chosen for this study as an easily available, hygroscopic and brittle material as well as due to its abundance in collections and its relevance when discussing the risk of mechanical damage to objects. Gesso specimens were tested using dynamic mechanical analysis and tensile testing at different frequencies, under a variety of loading rates and temperatures. The time-temperature superposition principle was used to predict the material response to slow deformations (lasting hours to months) that are otherwise inaccessible on laboratory timescales. The results demonstrate that brittle materials such as animal glue-based grounds do not benefit from longer cycles of applied loads as failure strain is not time-dependent within the investigated timescale.

El artículo proporciona nueva evidencia experimental sobre la dependencia de fallas de tensión para artefactos vulnerables, con la tension correspondiente al estrés causado por fluctuaciones ambientales típicas con duraciones entre horas y meses. Para este estudio se eligió un gesso a base de cola animal por ser un material fácilmente disponible, higroscópico y quebradizo, así como por su abundancia en las colecciones y su relevancia a la hora de discutir el riesgo de daño mecánico a los objetos. Las pruebas se realizaron en muestras de Gesso mediante análisis mecánico dinámico y pruebas de tracción a diferentes frecuencias, bajo una variedad de velocidades de carga y temperaturas. Se utilizó el principio de superposición tiempo-temperatura para predecir la respuesta del material a deformaciones lentas (que duran de horas a meses) que de otro modo serían inaccesibles en escalas de tiempo de laboratorio. Los resultados demuestran que los materiales frágiles, como el gesso a base de cola animal, no se benefician de los ciclos largos de cargas aplicadas, ya que la deformación por falla no dependió del tiempo dentro de las escalas investigada en este artículo.

ARTICLE HISTORY
Received October 2023
Accepted June 2024

KEYWORDS
Museum climate; seasonal change; time-temperature superposition; brittle cracking; failure strain

Clima de museo; cambio estacional; superposición tiempo-temperatura; agrietamiento frágil; deformación por falla

Introduction

It is generally accepted that hygroscopic materials in heritage collections are at risk of mechanical damage in unstable environments. For this reason, all museum climate guidelines published in recent decades discuss the ranges and the amplitudes of daily variations in relative humidity (RH) and temperature for collections containing artefacts made of hygroscopic materials. The origin and the evolution of environmental specifications for museum collections have been thoroughly analysed in several publications (Luciani 2013, Michalski 2014, Bickersteth 2016). They demonstrate a strong tendency present in the cultural heritage field to define environmental specifications based on evidence provided by scientific research and rigorous observations. One of the pivots for the change has been research performed at the Smithsonian Institutions by Mecklenburg et al. since the 1990s together with subsequent discussions on the rare but catastrophic damages to artifacts subjected to less controlled environmental conditions (Ashley-Smith et al. 1994; Michalski 1993; Pretzel 2014). They determined not only the critical mechanical parameters – the dimensional response of materials to environmental changes and the critical levels of strain at which the materials began to deform plastically or fracture – necessary for the

CONTACT Sonia Bujok sonia.bujok@ikifp.edu.pl Jerzy Haber Institute of Catalysis and Surface Chemistry Polish Academy of Sciences, Niezapominajek 8, 30–239 Krakow, Poland

Supplemental data for this article can be accessed online at https://doi.org/10.1080/00393630.2024.2375162.

© 2024 J. Paul Getty Trust. Published by Informa UK Limited, trading as Taylor & Francis Group
This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (http://creativecommons.org/licenses/by-nc-nd/4.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

evaluation of the risk of mechanical damage (Mecklenburg et al. 1998), but also demonstrated that mechanical testing performed in the laboratory is relevant for the analysis of stresses and strains engendered by fluctuating environments (Mecklenburg et al. 1996). It was also demonstrated that the mechanical properties of artists' paints are profoundly affected by the rate of load application (Mecklenburg et al. 1991, 137–171).

Equally important is the growing understanding that the preservation of art collections is associated with environmental costs which are becoming unacceptable to institutions or, more broadly, to society. These tendencies are clearly reflected in one of the most influential guidelines – the ASHRAE chapter on 'Museums, Galleries, Archives and Libraries' (ASHRAE 2023). It defines types of climate control (AA, A1, A2, B, C, and D) based on the current understanding of the risk of mechanical damage to 'unproofed objects' i.e. new objects (never exposed to broader climatic fluctuations) or recently restored objects (proofed only to the conditions they experienced after treatment). It should be noted that types of climate control were developed as a consensus among experts using the best available knowledge about the risks on one hand and *modus operandi* of climate control units on the other. Given its importance for the museum community, the ASHRAE chapter continues to be discussed and improved. The equivalence of the risk of mechanical damage in control types A1 and A2 is the most debated issue. Control type A1 allows a seasonal change in RH of 10% and short-term fluctuations of ±5%, whereas control type A2 recommends no seasonal change and short-term fluctuations of ±10%. The underlying concept of their equivalence is that slow environmental changes carry half the risk of fast ones. This is based on the observation that slow loading of materials leads to a decrease in material stiffness and an increase in failure strain. According to ASHRAE, control types A1 and A2 are safe for most collections, with only a small risk of mechanical damage to highly vulnerable artefacts that contain very brittle materials. The data used to equate the mechanical risk of control types A1 and A2 were obtained from testing wood and paints. Data obtained by Madsen (1975) for wood in the direction perpendicular to the grain showed a more than threefold increase of failure strain for loads applied within months compared to those applied within hours. The typical failure strain of wood in the direction perpendicular to the grain is around 0.01. Hagan (2017) measured changes in critical strain for acrylic and oil paints tested at different loading rates. For example, the critical strain for a lead white oil paint varies between 0.0088 and 0.0144 when the paint is stretched the same amount for one hour or 6 months, respectively. This suggests a risk reduction of approximately 65%. However, no quantitative data shows a similar tendency for very brittle materials having a failure strain of 0.002 or lower, such as animal glue-based grounds or old (historic) oil paints (Janas et al. 2022).

A similar conviction underpins other important international environmental guidelines – see the IIC and ICOM-CC Declaration (IIC 2014). The guidelines state that 'For many classes of object[s] containing hygroscopic materials … a stable RH is required in the range of 40–60%' but allows not more than ±10% RH variations within 24 hours.

The research presented aimed to provide new experimental evidence for very brittle materials on the dependence of failure strain on the rate of load application corresponding to typical environmental loads lasting between hours, days, and months. An animal glue-based ground, or traditional gesso, was chosen for this study because it is easily available, brittle and because of its abundance in museum and gallery collections and its importance when discussing risks of mechanical damage to objects (Bratasz et al. 2020, Mecklenburg et al. 1998, Rachwał et al. 2012).

The same method used by Hagan (2017) on oil paints to construct a master curve predicting the long-term behaviour of oil paints was applied to gesso. This method, which makes use of the principle of time-temperature superposition (TTS), allows data collected at different frequencies (or rate of measurement) and temperatures to be shifted along the time axis, thus giving access to large response times (months, years) which could not be accessed in a laboratory testing timescale. This is based on the assumption that as temperature increases, the rates of inter-/intra-molecular movements occurring within the material tested are increased. Thus, molecular rearrangements that would have taken months to occur can be observed in a few seconds or minutes when the temperature is raised. The method is commonly used in the polymers industry but was also introduced in conservation studies to investigate the mechanical behaviour of oil paints (Hagan 2017) and paper (Ding et al. 2007).

Materials and methods

Gesso was selected for the experiments presented in the current article as a material frequently used to design environmental specifications in museums and to determine safety bands of environmental variations; it is considered one of the most brittle materials in collections and at the same time of a very valuable category of heritage objects like paintings. Recent research showed that some oil paints dried for decades (Janas et al. 2022) as well as egg tempera paints (Poznańska et al. 2024) can have similarly low strain at break to gesso. It was also shown that oil paints become stiffer with time. The elasticity

modulus of some oil paints after 30 years of drying, like malachite, verdigris, zinc white, and lead white with litharge, as well as egg tempera paint, reach values of a few GPa similar to gesso at 50% RH. Due to the lack of large amounts of well-dried oil paint samples, it was assumed that gesso bearing similar mechanical properties right after preparation represents well the group of brittle materials in heritage collections.

The mechanical properties of the gesso are highly dependent on RH, the strength of the glue and the pigment-to-volume concentration (PVC = P/(P + B) where P and B are volumes of the pigment and the glue binder, respectively). PVC values ranging between 85 and 95% reflect typical recipes for usable grounds (Michalski 1991, Mecklenburg et al. 1991 p. 173-216) but in this study, a historical gesso recipe and procedure were adopted after Cennino Cennini (Thompson 1972). Bratasz et al. (2020) demonstrated that gessoes of PVC between 85 and 92% have similar resistance to cracking, dropping to zero for gessoes of PVC 96%. Thus, a PVC of approximately 92% was found to be a sweet spot for the mechanical properties of gesso. A 6.7 wt % solution was obtained by dissolving rabbit skin glue (Kremer-Pigmente GmbH) in the water at the temperature of 50 °C for 60 minutes. It was used to prepare a gesso with a PVC of ca. 92%. A 'chalk from Champagne' from the same supplier, which is a natural calcium carbonate, was slowly added to the glue solution until the liquid phase was completely absorbed. Wet gesso was sieved using a fine nylon fabric (15 DEN tights) and heated again to 50 °C. The gesso was poured into moulds, dried at room conditions for 30 days and machined to bars of dimensions $6 \times 6 \times 80$ mm^3. However, these specimens were used only for the investigation of the samples' geometry effect on the failure strain. For this, gesso strips of dimensions $1.5 \times 10 \times 150$ mm^3 were cut from the gesso layer cast on polyester sheets and allowed to dry under controlled environmental conditions of room temperature and a 40–50% RH range for 3 days and then detached from the polyester sheet. Due to the brittleness of the specimens and to prevent any risks of damage during mounting on the UTM, their edges were embedded in an epoxy resin. To do so, the specimen ends were placed in polysiloxane moulds into which the resin was poured and cured to create extended specimen ends. Specimens prepared in this manner were securely mounted in a Zwick/Roell Z2.5 TN Universal Testing Machine (UTM) with a 2.5kN load cell with Xforce P grade 1 accuracy.

The UTM was placed in the environmental chamber in which temperature could be stabilized between 20 and 48 °C and RH was fixed at 50%. During the tensile tests, the UTM operated in a displacement control mode with a constant crosshead rate varying between 0.02 and 2 mm/min. The displacement was measured using a video-extensometer from Messphysik Materials Testing GmbH synchronized with the UTM. The distance covered by the video-extensometer was ca. 250 mm and its resolution uncertainty was 5 µm.

Gesso specimens of $0.6 \times 8.6 \times 30$ mm^3 in dimension were also tested in a dynamic mechanical analyser Discovery DMA 850 (TA Instruments) with the RH unit at the non-destructive deformation of 0.0005 dynamic strain in tensile mode. Frequency sweep measurements in the 0.1–10 Hz range were performed at 5 °C intervals between 25 and 90 °C with a fixed RH of 50%. These data allowed the construction of a master curve and the calculation of the activation energy specifically associated with the glassy relaxation of gesso.

The effect of sample geometry (bars and strips) on the possible discrepancies between the failure strain values was investigated at 20 °C and 2 mm/min loading rate. The failure strain for gesso bars was 0.002 ± 0.001, whereas for strips a value of 0.0009 ± 0.0002 was obtained. Due to the significantly smaller experimental errors obtained for the tensile tests performed on gesso strips, this sample geometry was used for further experiments.

Results and discussion

In this paper, static and dynamic mechanical tests were performed to predict the long-term mechanical response of a gesso used as a representative of highly brittle materials commonly found in cultural heritage objects. Dynamic mechanical analysis (DMA) is used to determine the viscoelastic properties of the materials, i.e. storage E' and loss E'' moduli when tested under non-destructive sinusoidal (oscillatory) strain. The E' is related to the stiffness and reversible elastic contribution to the material's response (stored energy), whereas the E'' corresponds to the irreversible viscous contribution (energy dissipated as heat).

The standard static tensile test conducted until specimen failure provides information on the stiffness of the material or Young's modulus, (i.e. modulus of elasticity calculated from the slope of the linear part of the stress–strain curve) as well as conditions at which material breaks (i.e. failure strain and failure stress). In addition, the shape of the stress–strain curve indicates whether the material response reflects elastic or ductile behaviour. If the stress–strain curve follows the linear trend until rupture, the material behaves elastically (Figure 1: blue, red, and green curves obtained for gesso strips at 50% RH). On the contrary, the response of the ductile material follows a linear trend only at the beginning of the stress–strain curve. Above the so-called yield point, the curve significantly deviates from linearity (Figure 1: black curve for gesso strip at 70% RH).

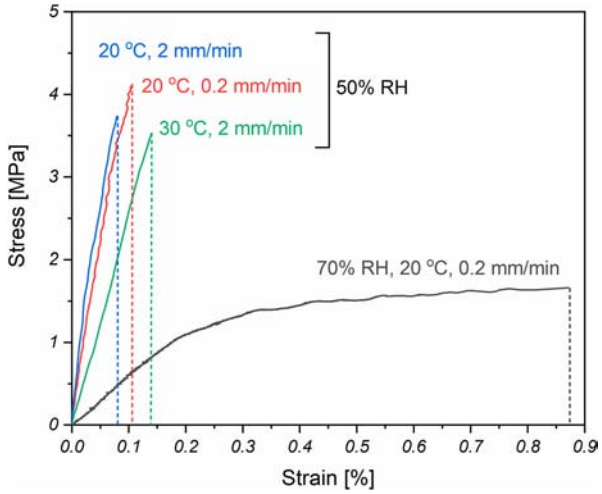


Figure 1. Examples of the stress-strain curves obtained for gesso at various conditions of temperature, relative humidity, and loading rate.

Tensile tests performed at various loading rates and temperatures provide information on the rate – and temperature-dependent mechanical response of the material. The stress–strain curves of the gesso strips (Figure 1) show that the stiffness (slope of the stress–strain curve) of the gesso decreases at slower loading rates, higher temperatures, and most significantly at higher RH. The temperature dependence shown in Figure 1 therefore allows TTS to be performed on the gesso data collected by DMA and tensile testing. This will be presented in the following sections.

The mechanical response of the material to the changing deformation rate (frequency) is commonly investigated using DMA in frequency ranges corresponding to fast (0.01 s) and slow (up to ca. 15 min) non-destructive deformations. The choice of the lower limit of the frequency range is limited by the time allocated to the experimentation. This can however be overcome using TTS and time-temperature dependency to access longer experimentation times. The long-term mechanical behaviour of gesso (master curve) was determined on the basis of short-time experiments performed in a narrow frequency range at several temperatures. Multiple frequency sweeps at various temperatures (from 25 °C to 90 °C) were measured (Figure 2, right plot – original data) and shifted towards lower frequency values with reference to the curve obtained at 25 °C (Figure 2, left plot). Due to less pronounced changes in E' of the gesso over the frequency and temperature ranges tested, to avoid overestimating the possible frequency range, the master curve was constructed based on E''. The resulting master curve for gesso shows that no significant change in modulus is observed over the frequency range investigated which indicates that the material is in a glassy state.

On the basis of DMA results, the experimental horizontal shift factors a_T used for the shift of the E'' frequency scans at different temperatures were obtained (Figure 3). The linear fitting of the shift factors plotted against temperature was performed using the Arrhenius equation (1):

$$log\ a_T = \frac{E_a}{2.303R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right) \quad (1)$$

where E_a is the activation energy of the thermally-induced transition, R is gas constant, T is the temperature in kelvin at which measurement was performed and T_{ref} is the reference temperature, herein 25 °C (i.e. 298 K). The results show that the shift factors measured for gesso follow the Arrhenius equation ($R^2 = 0.95$) and allow the calculation of an activation energy of 88 ± 6 kJ/mol. This value is comparable to previously obtained E_a for gelatine films (ca. 77 kJ/mol) reported by Zsoldos et al. (2017) confirming the validity of the fitting performed. Equation 1 was used to calculate a set of new shift factors a_T at a new

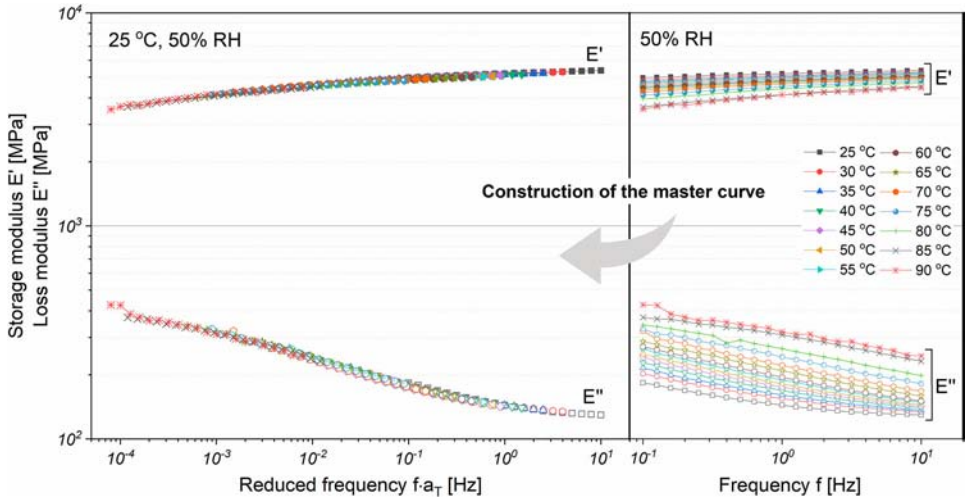


Figure 2. Frequency sweeps at the temperature range of 25–90 °C and 50% RH (right plot) and resulting master curve (left plot) for gesso valid for 25 °C and 50% RH.

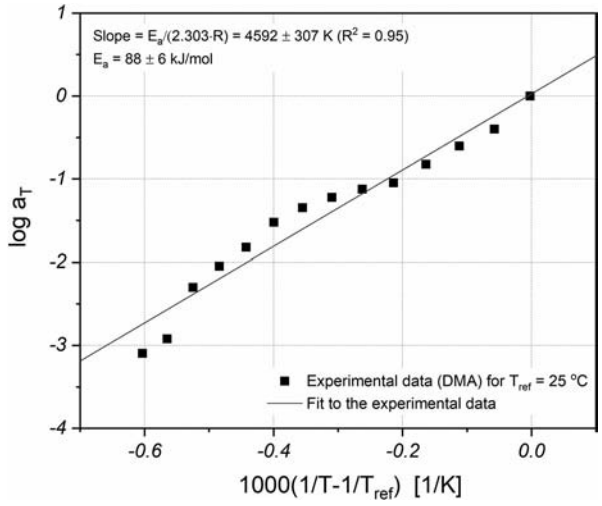


Figure 3. Arrhenius plot showing the dependence of horizontal shift factors a_T on temperature.

Table 1. Horizontal shift factors a_T for gesso calculated for 20 °C (293 K) reference temperature.

Temperature (K)	log a_T	a_T
293	0.000	1.000
303	−0.517	0.304
313	−1.001	0.100
321	−1.367	0.043

reference temperature of 20 °C, using experimentally determined activation energy. These shift factors (Table 1) were then used to construct the TTS curve using failure strain data. The justification for using DMA-based shift factors on failure strain data will be clearly demonstrated in the next section.

Based on the tensile tests performed at different loading rates and temperatures, failure strains were determined for each test. For example, for the gesso sample measured at 20 °C and 0.2 mm/min, a failure strain of 0.11% was measured (Figure 1). In Figure 4 (right plot), the failure strains for all tests were plotted in function of strain rate (i.e. failure strain divided by time at break). Usually, two repeat measurements were performed for each temperature and loading rate, and the variability in the results obtained is highlighted by the experimental error shown for each point of the plot. Using the shift factors previously calculated for a reference temperature of 20 °C at 50%RH (Table 1), the failure strain data points were shifted to lower strain rates according to the TTS principle and the failure strain master curve of gesso at 20 °C and 50% RH was obtained (Figure 4, left plot).

As seen in the data plot with unshifted data (Figure 4, right plot), the scattering of the results did not allow for a clear shift to be performed initially by simple visual inspection (additional statistical evaluation related to the data scattering is included in the supplementary information). The need for reliable horizontal shift factors which were obtained via DMA testing, proved to be necessary to process the failure strain data resulting in the construction of the corresponding master curve of gesso.

To predict the long-term failure strain (failure strain under slow load increase) of the materials, it is necessary to find the correlation between failure strain and time to failure. With reference to the previously investigated oil paints (Hagan 2017), a linear correlation was also assumed for the gesso data presented in Figure 5 within the time frame ranging from minutes to months. The slope of the linear fit was used to estimate the potential benefit of slow load application, i.e. the larger the slope the larger the critical deformation at a long-time scale (slow processes). Due to the scattering of the data observed in Figure 5 for MH zinc white, MH flake white, and gesso, a statistical evaluation of the results was applied. The *p*-values were calculated to verify if the fitted slope values were significantly different from 0 (horizontal line). The relation of the *p*-value for the slope fitted using linear regression to the

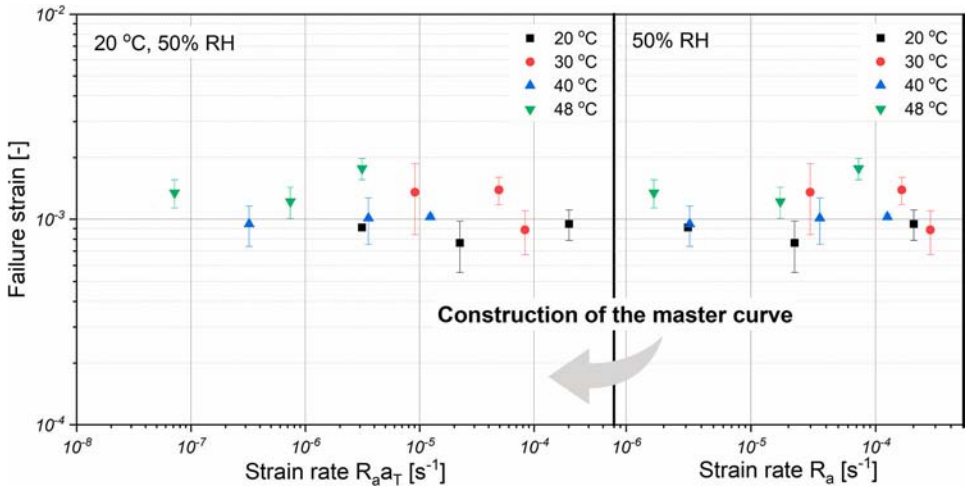


Figure 4. Failure strain dependence on the strain rate at different temperatures (right plot) and resulting failure strain master curve (left plot) for gesso valid for 20 °C and 50% RH.

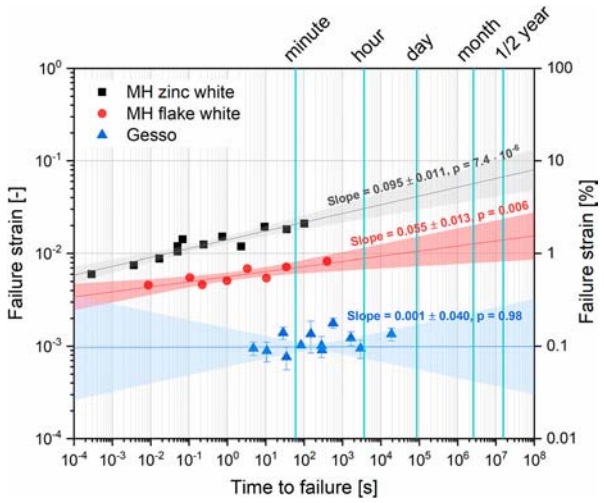


Figure 5. Time evolution of failure strain for gesso (blue curve) in comparison with Michael Harding flake (red curve) and zinc (black curve) white paints (adopted from (Hagan 2017)). The confidence bands are related to the scattering of the data and do not affect the significance of the linear fitting slope.

significance level, α, determines whether the slope is significantly different from zero ($p<\alpha$). The value of the significance level is usually assumed as 0.05, which corresponds to the 5% risk of the wrong assumption (that the slope of the fitted curve is significantly different from 0 when it is not). In the case of zinc white and flake white oil paints, the p-values of 7.4×10^{-6} and 0.006 indicate that the slopes of 0.095 and 0.055, respectively, are significantly different from zero. On the contrary, the p-value for gesso (0.98) indicates that the slope of the fitted curve is not statistically different from zero. It means that the failure strain of oil-based paints increases with loading time, whereas the failure strain of the gesso is not time-dependent.

Based on the results, and assuming linear extrapolation as shown in Figure 5, it can be estimated that the failure strain of the oil paints subjected to a similar load applied over one hour or half a year, would increase by 120% and 57% for the zinc white and flake white, respectively (Table 2). This indicates a reduction in the risk of oil paint failure over long periods, making slow environmental changes advantageous in practice. However, the risk reduction for some paints like lead white is smaller than suggested in the ASHRAE chapter (2023). Contrary to oil paints, the rate of climate variations becomes irrelevant for gesso. This supports the choice made for this study to use a glue-based ground with a PVC of 92% as an example of a material of high brittleness that does not benefit from slow deformations. Therefore, this result is of practical relevance because gesso is one of the most brittle materials and constitutes vulnerable artifacts found in museum collections. Materials like these are particularly susceptible to physical damage due to deformation caused by unstable climatic conditions.

Table 2. Failure strain values for zinc and flake white in periods of hour, day and half of the year.

Time to failure	Failure strain for MH zinc white [-]	Failure strain for MH flake white [-]
1 h	0.0308	0.0088
1 d	0.0411	0.0105
½ year	0.0677	0.0138

Conclusions

The new experimental evidence shows the lack of equivalence of risk of mechanical damage for the A1 and A2 control types defined by the ASHRAE chapter (2023), for the most vulnerable objects in museum collections that contain gesso. On the contrary, the results demonstrated that animal glue-based grounds do not benefit from longer cycles of applied loads as failure strain is not time-dependent within the investigated time scale. Thus, the research indicates that the amplitude of the RH variations is decisive in terms of risk induced by environmental variations, not the rate of this change. One of the commonly used thresholds proposed by the IIC/ICOM-CC Declaration of allowable ranges of ±10% RH variations occurring over an hour or a day brings about the same risk as seasonal variations of the same amplitude. Consequently, the obtained data also do not justify a limit for maximal variation of ±10% RH per 24 hours accepted by the IIC/ICOM-CC Declaration.

Since no other data to date has shown that any other brittle materials benefit from such change, equating A1 and A2 types of control for all brittle materials is not supported by solid evidence. Therefore, gesso is proposed to be used as representing worst-case material for defining stringent environmental specifications until additional experiments on other brittle materials could refine these conclusions.

Obviously, the above conclusions apply only to unproofed objects which constitute a very small, if any, fraction of museums' collections. Therefore, the risks associated with A1 or A2 types of controls are negligible in practice.

Acknowledgements

This work is part of the research of the GoGreen project (*Green strategies to conserve the past and preserve the future of cultural heritage*; project no.: 101060768) funded by the European Commission Horizon 2020 Programme. The authors would like to thank Eric Hagan for providing original data on oil paints and Naoki Fujisawa for discussion.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Declaration of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This work was supported by European Commission [grant number: 101060768].

ORCID

Sonia Bujok http://orcid.org/0000-0001-8962-4271
Alexandra Bridarolli http://orcid.org/0000-0002-0114-751X
Michał Łukomski http://orcid.org/0000-0001-7942-9026
Łukasz Bratasz http://orcid.org/0000-0002-5277-2606

References

Ashley-Smith, J., N. Umney, and D. Ford. 1994. "Let's be Honest — Realistic Environmental Parameters for Loaned Objects." *Studies in Conservation* 39(sup.2): 28–31. https://doi.org/10.1179/sic.1994.39.Supplement-2.28.

ASHRAE 2023. "Museums, Galleries, Archives and Libraries". *ASHRAE Handbook, Chap. 24*. Peachtree Corners: American Society of Heating and Air-Conditioning Engineers.

Bickersteth, J. 2016. "IIC and ICOM-CC 2014 Declaration on Environmental Guidelines." *Studies in Conservation* 61: 12–17. https://doi.org/10.1080/00393630.2016.1166018.

Bratasz, Ł, K. G. Akoglu, and P. Kékicheff. 2020. "Fracture Saturation in Paintings Makes Them Less Vulnerable to Environmental Variations in Museums." *Heritage Science* 8 (1): 1–12. https://doi.org/10.1186/s40494-020-0352-0.

Ding, H. Z., and Z. D. Wang. 2007. "Time–Temperature Superposition Method for Predicting the Permanence of Paper by Extrapolating Accelerated Ageing Data to Ambient Conditions." *Cellulose* 14 (3): 171–181. https://doi.org/10.1007/s10570-007-9114-3

Hagan, E. W. S. 2017. "Thermo-mechanical Properties of White oil and Acrylic Artist Paints" *Progress in Organic Coatings* 104 (3365): 28–33. https://doi.org/10.1016/j.porgcoat.2016.10.019

IIC. 2014. *Declaration on Environmental Guidelines*. Accessed October 2023. https://www.iiconservation.org/sites/default/files/static/6972-2014-iic-icom-cc-environmental-guidelines.pdf.

Janas, A., M. F. Mecklenburg, L. Fuster-López, R. Kozłowski, P. Kechiche, D. Favier, C. Krarup Andersen, M. Scharff, and Ł. Bratasz. 2022. "Shrinkage and Mechanical Properties of Drying oil Paints", *Heritage Science* 10: 181. https://doi.org/10.1186/s40494-022-00814-2.

Luciani, A. 2013. *Historical Climates and Conservation Environments. Historical Perspectives on Climate. Unpublished Doctoral Thesis*. Milan.: Politecnico di Milano.

Madsen, B. 1975. "Duration of Load Tests for Wood in Tension Perpendicular to Grain." *Forest Products Journal* 25: 48–53.

Mecklenburg, M. F., and C. S. Tumosa,. 1991. "An Introduction Into the Mechanical Behavior of Paintings Under Rapid Loading Conditions." In *Art in Transit: Studies in the Transport of Paintings*, edited by M. F. Mecklenburg, 137–171. Washington D. C.: National Gallery of Art.

Mecklenburg, M. F., and C. S. Tumosa. 1991. "Mechanical Behavior of Paintings Subjected to Changes in Temperature and Relative Humidity." In *Art in Transit: Studies in the Transport of Paintings*, edited by M. F. Mecklenburg, 173–216. Washington D. C.: National Gallery of Art.

Mecklenburg, M. F. and C. S. Tumosa. 1996. "The Relationship of Externally Applied Stresses to Environmentally Induced Stresses." In *Fiber Composites in Infrastructure (Proceedings of the First International Conference on Composites in Infrastructure)*, edited by H. Saadatmanesh and M. R. Ehsani, 956–971. Tucsan: University of Arizona. Accessed May 2024. https://repository.si.edu/bitstream/handle/10088/35959/Mecklenburg%2c%20Tumosa%20-%201996%20-%20The%20Relationship%20of%20Externally%20Applied%20Stresses%20to%20Environmentally%20Induced%20Stresses.pdf?sequence=1&isAllowed=y.

Mecklenburg, M. F., C. S. Tumosa, and D. Erhardt. 1998. "Structural Response of Painted Wood Surfaces to Changes in Ambient Relative Humidity." In *Painted Wood: History and Conservation*, edited by V. Dorge, and F. C. Howlett, 464–483. Los Angeles: Getty Conservation Institute.

Michalski, S. 1991. "Crack Mechanism in Gilding." In *In Gilded Wood: Conservation and Histor,y*, edited by D. Bigelow, E. Come, G. J. Landrey, and C. van Horne, 171–181. Madison: Sound View Press.

Michalski, S. 1993. "Relative Humidity: A Discussion of Correct/Incorrect Values." In *In ICOM Committee for Conservation 10th Triennial Meeting Washington DC*, edited by J. Bridgland, 6246–6229. Paris: ICOM.

Michalski, S. 2014. "Climate Guidelines for Heritage Collections: Where We Are in 2014 and How We Got Here". In *Proceedings of the Smithsonian Institution Summit on The Museum Preservation Environment*, edited by S. Stauderman and W. G. Tompkins, 7–22. Washington D. C.: Smithsonian Institution.

Poznańska, K., A. Hola, R. Kozłowski, M. Strojecki, and Ł Bratasz. 2024. "Mechanical and Moisture-Related Properties of Selected Dried Tempera Paints." *Heritage Science* 12 (25): 1–12. https://doi.org/10.1186/s40494-024-01147-y.

Pretzel, B. 2014. "[Un:]Reasonable – broadening acceptable climate parameters for furniture on open display". In *ICOM-CC 17th Triennial Conference Preprints, Melbourne,* ed. J. Bridgland, art. 1507. Paris: ICOM.

Rachwał, B., Ł Bratasz, M. Łukomski, and R. Kozłowski. 2012. "Fatigue Damage of the Gesso Layer in Panel Paintings Subjected to Changing Climate Conditions." *Strain* 48: 474–481. https://doi.org/10.1111/j.1475-1305.2012.00844.x

Thompson, D.V. (ed.). 1972. Cennino Cennini's *Il Libro Dell'arte*. 3rd Edition. New Haven, CT.

Zsoldos, G., K. Szoda, and K. Marossy. 2017. "Combined Mechanical and Electrical Study of Polymers of Biological Origin" *IOP Conference Series: Materials Science and Engineering* 175: 012028. https://doi.org/10.1088/1757-899X/175/1/012028

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S25–S34
https://doi.org/10.1080/00393630.2024.2342656

ORIGINAL RESEARCH OR TREATMENT PAPER

The GREENART Project: Environmentally Friendly and Low Impact Materials for the Conservation of Cultural Heritage

El Proyecto GREENART: Materiales Ecológicos y de Bajo Impacto para la Conservación del Patrimonio Cultural

David Chelazzi, Giovanna Poggi and Piero Baglioni

Department of Chemistry 'Ugo Schiff' and CSGI, University of Florence, Florence, Italy

ABSTRACT

While some green solutions and advanced materials have been proposed in recent decades to improve on traditional conservation processes, conservation practice still uses petroleum-based compounds and procedures that lack time- or energy-efficiency, and are not sustainable. Tackling these issues, the GREENART project (GREen ENdeavor in Art ResToration, Horizon Europe, 2022–2025) is developing green and sustainable systems for the remedial and preventive conservation of works of art, following a 'safe and sustainable by design' approach where green components are firstly screened and then used to formulate new materials. This contribution reviews traditional and state-of-the-art materials used in protective coatings, foams and packaging materials, consolidants, cleaning systems, and monitoring tools, and introduces the novel solutions the GREENART project is developing for each of these classes. Some of the new products are already being assessed, and the main processes in the formulation of the solutions are outlined. Life cycle assessment will be carried out before the commercial production of the new systems to demonstrate their full sustainability. Finally, perspectives are discussed, highlighting the role of GREENART in promoting a green transition for cultural heritage preservation.

A pesar de que algunas soluciones ecológicas y materiales avanzados para mejorar las metodologías de restauración tradicionales has sido propuestas en las últimas décadas, la práctica de conservación-restauración todavía utiliza compuestos y procedimientos a base de petróleo que carecen de eficiencia de tiempo o energía y no son sostenibles. Para abordar estas cuestiones, el proyecto GREENART (GREen ENdeavor in Art ResToration, Horizon Europe, 2022–2025) está desarrollando sistemas ecológicos y sostenibles para la conservación remedial y preventiva de obras de arte, siguiendo un enfoque 'seguro y sostenible por diseño'. Este enfoque indica que los componentes deben examinarse primero y luego utilizarse para formular nuevos materiales. Esta contribución revisa los materiales tradicionales y de última generación utilizados en recubrimientos protectores, espumas y materiales de embalaje, adhesivos, sistemas de limpieza y herramientas de monitoreo, e introduce las soluciones novedosas que el proyecto GREENART está desarrollando para cada una de estas clases. Algunos de los nuevos productos ya están siendo evaluados. Los procesos principales en la formulación de las soluciones han sido descritas. La evaluación del ciclo de vida se llevará a cabo antes de la producción comercial de los nuevos sistemas para demostrar su total sostenibilidad. Finalmente, se discuten las perspectivas, destacando el papel de GREENART en la promoción de una transición verde para la preservación del patrimonio cultural.

ARTICLE HISTORY
Received October 2023
Accepted March 2024

KEYWORDS
Green materials; sustainable conservation; cleaning; consolidation; protection

materiales ecológicos; conservación sostenible; limpieza; consolidación; proteccion

Introduction

Green chemistry and sustainable practices have been gaining, over the past decades, growing importance in numerous scientific, technological, and industrial fields (Mulvihill et al. 2011; Zimmerman et al. 2020). Current approaches range from low-toxicity and environmentally friendly chemicals, to low energy production and application routes with reduced carbon emission, to materials or processes based on renewable sources. In particular, the development of 'safe and sustainable by design' criteria (SSbD) and standards for the classification of materials, are coupled with the use of analytical tools for the 'cradle-to-grave' evaluation of practices (Menegaldo et al. 2023). Current recommendations are pointing to the adoption of cost-effective materials and methodologies to yield circular economies (Awan et al. 2021), fostering the 're-growth' of socioeconomic systems. Biomimicry is a key concept, since biomimetic materials can exhibit remarkable functional properties, safety, and durability (Fratzl 2007; Rodriguez-Navarro et al. 2023).

CONTACT Piero Baglioni baglioni@csgi.unifi.it Department of Chemistry 'Ugo Schiff' and CSGI, University of Florence, via della Lastruccia 3-Sesto Fiorentino, Florence I-50019, Italy

Supplemental data for this article can be accessed online at https://doi.org/10.1080/00393630.2024.2342656.

© The International Institute for Conservation of Historic and Artistic Works 2024

These fundamental concepts can and should be applied to the preservation of cultural heritage (CH), a strongly multi-disciplinary field with high socioeconomic relevance, where the green transition can bring significant advancement and benefit. Conservation practice still partly relies on fossil-based solvents or polymers with low sustainability, and on classical solvent/polymer chemistry with poor selectivity, durability, and safety to the works of art or the end-users (Casini et al. 2023). Crucial advances have been made over the last decades in preventive and remedial conservation, based on soft matter and colloids (Baglioni and Chelazzi 2021; Baglioni, Carretti, and Chelazzi 2015; Leona et al. 2021), biopolymers and composite materials (Baglioni et al. 2021a; Baglioni and Chelazzi 2021; Passaretti et al. 2021; Rosciardi et al. 2022; Boccaccini et al. 2022). However, it is necessary to develop the best-performing systems to maximize their sustainability, and design completely new systems according to SSbD criteria.

In recognition of this, the European Union has recently funded three such projects for CH, namely MOXY, GOGREEN and GREENART. Here, we will illustrate the main objectives of the GREENART project (GREen ENdeavor in Art ResToration, Horizon Europe, 2022–2025, https://cordis.europa.eu/project/id/101060941/it). The inter-disciplinary consortium for GREENART consists of 13 research centers, four large high-tech and three micro/small-enterprises (including conservation professionals), one national ministry and seven important museums and collections across Europe, the Americas and Asia (China, Japan). The authors belong to the Center for Colloid and Surface Science (CSGI) at the University of Florence, Italy, which is the coordinating unit for the project.

Partners with different expertise in science, technology, and social sciences and humanities (SSH) cooperate in GREENART in a holistic approach to the preservation of CH through the development, assessment, life cycle assessment/ life cycle cost analyses (LCA/LCC), exploitation and dissemination of green solutions for remedial and preventive conservation, as summarized in Figure 1.

In this contribution the five main classes of materials developed in the project will be introduced by giving fundamental but comprehensive overviews of traditional solutions and the state-of-the-art, and then commenting on the main strategies and applications generated thus far. Finally, perspectives will be given on current trends in the green transition for CH.

Green materials in conservation: state-of-the-art and the GREENART project

Protective coatings

Surface protection had been carried out for centuries by artists and restorers using natural compounds, until the post-WW2 polymer boom introduced synthetic formulations that were affordable, easy to use, and produced desirable aesthetic effects in the short term (Chércoles Asensio et al. 2009). Polyesters, ketone and epoxy resins, siloxanes or polyolefins have been traditionally employed since the 1970s to treat works of art ranging from stone to canvas paintings, murals, wood, leather, metal, glass, and others (Mariani and Malucelli 2023). However, more than five decades of field evidence and scientific studies have shown that synthetic polymer coatings can be

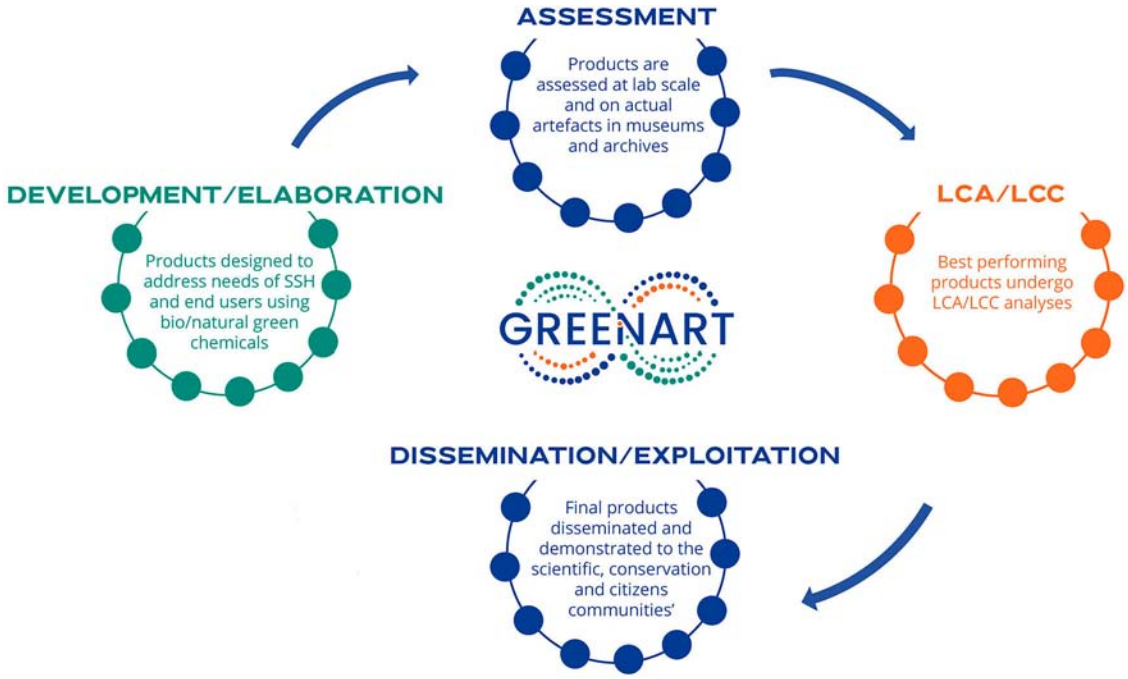


Figure 1. The fundamental methodology of GREENART, linking an inter-disciplinary partnership through an iterative and interactive loop.

detrimental. For instance, acrylate or vinyl acetate copolymers undergo yellowing, cracking or changes in molecular weight caused by photo-oxidation, temperature, and pollutants, resulting in changes in appearance and the loss of adhesive power, and can also be attacked by micro-organisms (Chiantore and Lazzari 2001; Cappitelli et al. 2021; Bagniuk et al. 2019). In addition, when polymer coatings are applied onto porous surfaces, they can seal the substrate, enhancing the damage caused by salt crystallization and spalling of the surface (Baglioni et al. 2016). Polyvinyl acetate (PVA)-based coatings can also undergo deacetylation during aging (Chelazzi et al. 2014), releasing acetic acid that threatens metal, canvas, paper, and wood.

To overcome these limitations and improve sustainability, novel coatings have evolved toward biopolymers such as chitosan (Giuliani et al. 2018), nanocellulose and nanolignin (Camargos et al. 2022), polylactic acid (Giuntoli et al. 2014), and geopolymers (Giacobello et al. 2022), targeting safety and durability as fundamental features (Artesani et al. 2020). These approaches have been augmented by innovative coatings that have introduced hybrid polyfunctional materials, such as silane/siloxane combined with chitosan (Eyssautier-Chuine et al. 2018), TiO_2 nanoparticles encapsulated in epoxy-silica resins (Gómez-Laserna et al. 2019), mesoporous silica nanoparticles functionalized with benzoyl chloride and included in an acrylic matrix (Olivieri et al. 2023a), and layered double hydroxides functionalized with carboxylic moieties (Giuliani et al. 2020) or loaded with corrosion inhibitors and included in polyvinyl alcohol (PVAl) (Salzano de Luna et al. 2018).

In this context, the GREENART project is involved in the development of 'smart coatings' such as multifunctional protective coatings able to act as active, passive, or combined multi-layer active/passive barriers against moisture, degradation and corrosion agents. The main target is the conservation of objects made of copper or silver alloys, or iron, while other possible substrates include ceramics, stone, and canvas. For the formulation of the coatings, the focus is on bio-based sustainable/renewable polymers, such as lignin, vegetable oils, sugar bioconversion, and agricultural residues. The biopolymers are also blended with functional additives to yield transparency, reversibility (by thermal or chemical stimuli), antimicrobial/antifungal activity, self-cleaning or hydrophobicity. Modified mesoporous silica nanoparticles represent an optimal candidate to provide the coatings with nanoreservoirs (Olivieri et al. 2023a) able to release green anticorrosive agents (e.g. from vegetable biomass) as

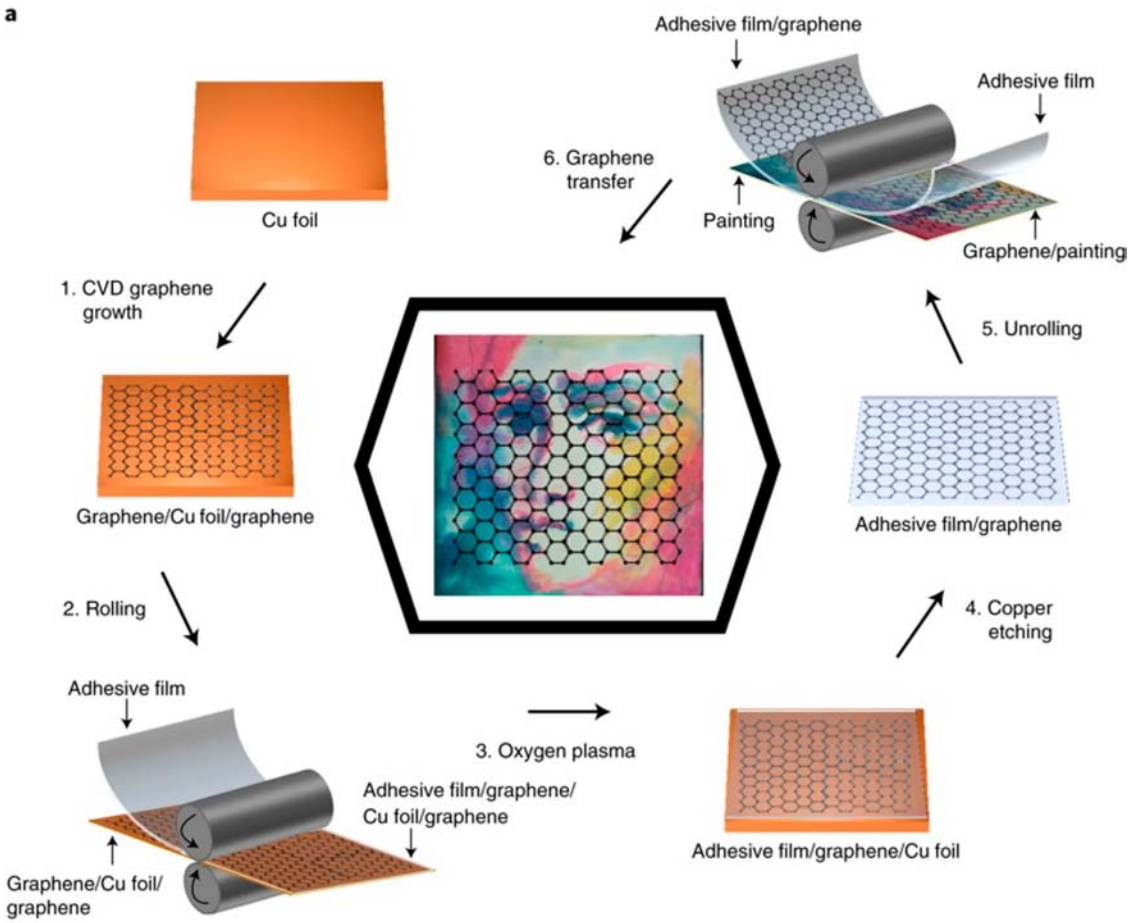


Figure 2. The roll-to-roll process to transfer graphene onto mock-ups and real artworks as proposed by Kotsidi et al. (2021). ©Authors 2021, under exclusive license to Springer Nature Limited.

alternatives to petroleum-based and toxic commercial products. Another class of additives proposed in GREENART includes graphene-related materials (GRMs), which were recently shown to impart ultraviolet (UV) shielding to artworks, potentially reducing the fading of dyes, through either the placing of transparent graphene membranes made with chemical vapor deposition (CVD) onto an artwork (Figure 2), or the inclusion of graphene flakes into artists' paints (Kotsidi et al. 2022). Challenges include the treatment of rough surfaces and reversibility.

GRMs can also be combined with PVA in composite films to produce self-buffering archive boxes (Gorgolis et al. 2023). GREENART will evaluate the use of GRMs prepared by CVD, also considering recycled/waste materials as sources for the materials. Green processes, e.g. solvent-free or using water-based dispersions, are also under evaluation for the incorporation of GRMs in biopolymer coatings. These materials could provide alternative protection for objects, or their enclosures (cases, crates, boxes).

Foams and packaging materials

Foams and packaging materials can act as effective preventive conservation tools in the exhibition, storage, and transport of works of art. For instance, increased loan activity to promote access leads to extensive use of packing materials (Nunberg et al. 2016). Archives store large volumes of documents that need boxes able to protect against biological agents of deterioration, and environmental damage including that from volatile organic compounds (VOCs) (Mai et al. 2022). For instance, composite PVA/GRM films have been recently integrated into storage boxes to buffer environmental fluctuations, and to absorb VOCs (Gorgolis et al. 2023) (Figure 3). This use calls for effective, safe, and affordable materials with enhanced properties in addition to good mechanical stability and long lifetime, and full accounting for end-of-life aspects (Nunberg 2016). However, packaging selection has traditionally followed empirical or intuitive criteria, leading in some cases to unnecessary risks to the artifacts (Fatuzzo et al. 2017). Common material classes include polyolefin, polyester, polyamide, polyacrylate, polyvinyl, and epoxy polymers, e.g. in foams, corrugated sheets of polymer blends, BEVA® and heat-seal adhesives, and multilayer or pressure-sensitive adhesive composites (Chércoles Asensio et al. 2009). Even if these materials include fillers and UV adsorbers to extend their useful lifetimes (Chércoles Asensio et al. 2009), new solutions with higher efficacy and improved sustainability are needed, relying on biopolymers and renewable sources rather than petroleum-based compounds. While this trend can be observed in several industrial fields (Moustafa et al. 2019), green packaging materials are still far from being applied to CH.

GREENART is developing different types of innovative materials. The first class comprises silica-nanocellulose-based foams, e.g. stable aerogels, with several key properties such as VOC absorption, mechanical stability, potential for upscaling and integration into existing or new storage materials, low environmental footprint, and sustainable end-of-life aspects such as reusability. In addition, phase changing materials (PCMs) are being integrated as thermal regulators in the foams. The second class consists of packaging foams from bio--based polyesters, adapting molecular weight and functionalities to meet preventive conservation needs. Nanocellulose and nanostructured inorganic fillers or PCMs will also be included to provide, respectively, enhanced thermomechanical properties (anti-shock, anti-vibration), high thermal-hygrometric insulation, and barrier properties. Reversible-by-design foams are being tackled by including suitable monomers in the foams that induce reversibility in response to external stimuli. In addition, ionic liquids will also be explored for imparting antifungal properties. The third class includes foams synergized with nanocellulose and graphene-based nanomaterials, or graphene biopolymer aerogels with bio-inspired polymers, which represent highly promising evolutions of multi-functional 2D hybrid aerogels demonstrated for gas absorption



Figure 3. Above: prototype of an archive box designed to be integrated with several sensors and absorbents. Below: a box filled with paper and equipped with PVA/GRM boards. Reproduced from Gorgolis et al. (2023). ©Authors 2023.

(Androulidakis et al. 2021). Finally, boxes and packaging made with fibers from plant waste and agricultural residues, or with recycled polymers, are being assessed. The project will evaluate the practical integration of these innovative solutions in archive boxes for long-term storage, with the final goal of replacing petroleum-based polymers and non-sustainable practices in preventive conservation.

Bio-based consolidants

Research in effective and sustainable bio-based consolidants partially overlaps with protective coatings, sharing similar goals and useful materials. Consolidation is carried out to re-introduce adhesion and cohesion of binders with pigments, of surface layers of murals and stone, or of fibers in paintings on canvas, textile, collagen-based (leather, parchment) and cellulose-based substrates (paper, canvas, wood). Conservators have traditionally employed both natural and synthetic materials. The latter comprise the polymers mentioned in the 'Protective coatings' section, with similar issues. New synthetic polymers are already being researched and assessed (Zhang et al. 2018). In the case of murals and stone, valid alternatives to synthetic polymers have been provided since the 1970s with the 'Ferroni method' discussed by Baglioni et al. (2013) and Chelazzi and Baglioni (2023), which uses a two-step process to extract sulfates and consolidate frescoes using barium hydroxide, and, since the late 1990s, with the use of alkaline earth hydroxide nanoparticles (Chelazzi and Baglioni 2023; Chelazzi et al. 2013). In addition, hybrid systems have recently been devised, where inorganic particles and biopolymers were mixed for the consolidation of earthen masonry (Camerini et al. 2019).

Regarding oil- or acrylic-bound painted layers, or cellulose- and collagen-based substrates, research is still progressing to find alternatives with greater sustainability than synthetic polymers, and comparable or higher consolidation power. The rationale is to optimize the use of natural compounds (Russo and Avino 2019; Schellmann 2007), reprocessing them within the framework of colloids and material science to impart enhanced properties (Casini et al. 2021; Cianci et al. 2022; Chelazzi, Badillo-Sanchez et al. 2020). In GREENART, the focus is on challenging surfaces for which few consolidation processes are available at present, such as vulnerable paint layers with underbound pigments found in modern/contemporary art, and on flexible supports such as historical/archaeological textiles. Starch is a promising renewable biopolymer that has been employed in paper conservation (Alexopoulou and Zervos 2016). However, rather than using solutions of bulk starch, GREENART takes advantage of bottom-up syntheses to formulate starch nanoparticles in aqueous or solvent dispersions. The potential of this methodology has been recently demonstrated on matte, fragile paint layers (Casini et al. 2021), and the GRENART project is now expanding the formulations using different synthetic routes and particles' functionalization, with the final goal to have affordable, sustainable bio-based consolidants for easel paintings.

Regarding textile consolidation, GREENART is addressing consolidants and adhesives for cellulosic and silk artifacts to overcome the limitations of traditional adhesives, such as those employed in lining (Ackroyd 2002; Chelazzi et al. 2014). Promising alternatives have recently been proposed, based on nanocellulose and the combination of polyelectrolyte-treated silica nanoparticles with cellulose nanofibrils (Kolman et al. 2018). Building on this expertise, GREENART aims to develop hierarchically structured composites on the surface of canvas, paper, or cardboard, using silica, cellulose derivatives, and chitin-based materials, along with calcium hydroxide or carbonate to neutralize acidity and stabilize cellulosic substrates (Baglioni et al. 2013; Chelazzi et al. 2006; Giorgi et al. 2009; Palladino et al. 2020; Xu et al. 2020; Ahn et al. 2013). Silk consolidants are being developed from self-regenerated silk fibroin (SRSF), based on known silk aging processes (Badillo-Sanchez et al. 2019) and on the preparation of colloidal SRSF from textile waste. The fibroin dispersions improve the mechanical properties of aged silk when SRSF films are deposited onto weak textile fibers (Chelazzi, Badillo-Sanchez et al. 2020). Further mechanical improvement is obtained when colloidal SRSF is combined with nanocellulose (Cianci et al. 2022; Poggi et al. 2022). The project is developing new chemical pathways to improve the stability and physico-chemical properties of SRSF-cellulose dispersions, while assessing their consolidation properties. The new consolidants are expected to provide valuable alternatives to replace synthetic polymers or traditional materials.

Gels and cleaning liquids

Cleaning is a delicate, recurrent operation in conservation treatment, consisting of the removal of unwanted layers such as soil, aged and/or non-original coatings, and overpaint from the surface of works of art. Cleaning methodologies must be selective, i.e. able to remove the unwanted layers without altering original components. Mechanical cleaning with blades, brushes, swabs, or cloth, is part of the process, but it must often be accompanied with wet cleaning, where fluids swell and soften the soil/coatings (Baij et al. 2020), to decrease the stress caused by mechanical removal. Traditionally employed materials comprise solvents, aqueous solutions, surfactants, and highly viscous polymer dispersions (HVPDs) used as thickeners (Chelazzi, Bordes et al. 2020; Wolbers et al.

2020; Baij et al. 2020). The selection of solvents is typically based on solubility tests and/or consideration of solubility parameters to target the swelling and solubilization of soil and coatings. Interactive programs and predictive computational methods have been developed to help end-users optimize the solvent selection (Fardi et al. 2014; Baij et al. 2020; Ormsby and Learner 2009), and the Modular Cleaning Program developed by Chris Stavroudis. Two major limitations involve lack of selectivity and the toxicity of many solvents. Solubility parameters are not exhaustive in predicting solvent–polymer interactions (Baij et al. 2020), and the risk of swelling or leaching binders or original polymer layers remains. Unless these liquids are effectively confined in retentive matrices, end-users need to adopt time-consuming procedures to check, at each step, that no damage occurs to objects (Mastrangelo et al. 2020). Regarding health and safety, an inclusive evaluation has been recently carried out of solvents used in cleaning paint surfaces, and for each solvent the green metric scores provided by industrial and academic institutions were averaged to yield a global score, as reported in Figure 4 (Casini et al. 2023). While most alcohols and several esters and ketones have good green metric scores, other typically used solvents pose health and/or environmental risks, e.g. most ethers, aromatic hydrocarbons (toluene, xylene), siloxanes and turpentine (Casini et al. 2023).

Surfactants were historically used serendipitously, since they are contained in natural materials that were traditionally used to clean works of art (Chelazzi, Bordes, et al. 2020). The inclusion of surfactants in solutions, regular emulsions (that are only kinetically stable), or thickener formulations, was systematically demonstrated by Wolbers in the 1980s to 1990s

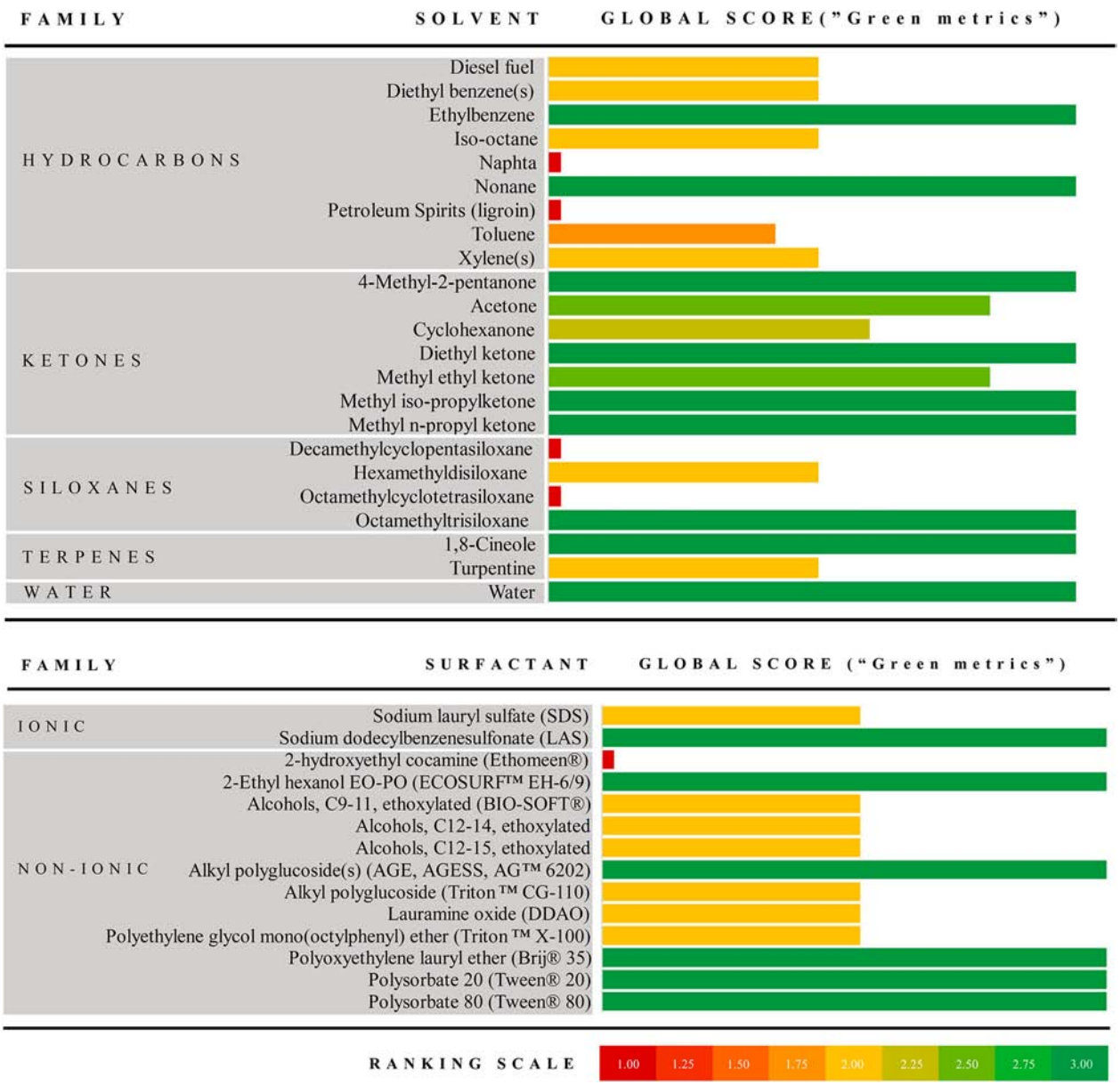


Figure 4. Global score that averages, for selected solvents (above) and surfactants (below), the green metric scores provided by industrial and academic institutions. Reproduced from Casini et al. (2023). Copyright © 2023, The Authors.

(Wolbers et al. 2020), as typified by 'solvent gels', which are HVPDs based on polyacrylic acid (PAA) and weakly basic non-ionic cocoamine surfactants (such as Ethomeen®). In addition to the very low green metric score of 2-hydroxyethyl cocoamine, the main limitation of the HVPDs lies in the need for clearing solvents to remove polymer and surfactant residues from the treated surfaces, which can lead to alterations of the original compounds (Casoli et al. 2014). The residue issue is also common to other HVPDs thickeners, such as cellulose ethers: there is a need for confining matrices with better mechanical properties, namely higher viscoelasticity (Mastrangelo et al. 2020).

To overcome these limitations, a significant amount of research has involved the development of soft matter and colloids systems such as nanostructured cleaning fluids (NSFs) and chemical or physical gels (Casini et al. 2023; Chelazzi and Baglioni 2023; Chelazzi et al. 2018; Baglioni et al. 2015). Oil-in-water (o/w) microemulsions are thermodynamically stable, optically clear water-based fluids where limited amounts of solvents are dispersed in water by inclusion in self-assembled surfactant nanostructures, like micelles, with a vast interfacial area. The water content ranges from c.70% to 99% w/w (Baglioni et al. 2013), which significantly reduces environmental impact.

The nanosized micelles have fast exchange dynamics of surfactants, co-surfactants, and solvent molecules with soil and coatings, boosting their removal from surfaces (Bonelli et al. 2019). NSFs have also been formulated using partially water-soluble solvents that are partitioned between the continuous water phase and the micelles, resulting in enhanced cleaning properties. In particular, the copresence of solvent and surfactants, dynamically exchanged with the target soil/coatings, allows for different removal mechanisms than classic solubilization, as for instance the dewetting or controlled swelling and detachment of unwanted polymer layers (Baglioni, Montis et al. 2018; Mirabile et al. 2020; Baglioni et al. 2022). These mechanisms offer highly effective and selective removal even of overpaints (Baglioni et al. 2021b) that have similar composition as the original paint layers, one of the most delicate types of interventions. While the efficacy of the NSFs has been widely demonstrated, GREENART is now focusing on the replacement of fossil-based surfactants (alcohol ethoxylates, and several non-ionics) and part of the solvents with more sustainable counterparts. Currently investigated chemicals include alcohols, esters/lactones and alkyl carbonates recommended by REACH and (IMI)-CHEM21 regulations (Casini et al. 2023), and bio-surfactants, such as sugar-based, bacterial, or bio-fatty acid esters and bio-ethylene oxide from natural feedstock. The task is to maintain the efficacy of state-of-the-art NSFs while gaining highly enhanced sustainability. In addition, there are cases where water-sensitive artistic surfaces must be cleaned, such as some acrylic or oil paintings. Water-in-oil (w/o) NSFs have been proposed (Keefe et al. 2011), to use a continuous inert hydrocarbon phase and confined water domains with safer cleaning action, even though in some cases this approach can involve high amounts of surfactants (from 5–10% to more than 25% or even 50% w/w). Alternatively, o/w NSFs can be confined in retentive physical or chemical gel matrices. Optimal results have been achieved in recent years using chemical networks of poly(2-hydroxyethyl methacrylate) semi-interpenetrated with polyvinylpyrrolidone (pHEMA/PVP semi-IPNs), or the recent PVA 'twin-chain' physical polymer networks (TC-PNs) (Baglioni et al. 2023; Baglioni, Domingues et al. 2018). The latter are formed by demixing and phase-separation in mixtures of PVA chains with different degree of hydrolysis and molecular weight, followed by freeze-thawing, to yield gel networks with sponge-like porosity and mechanical compliance that grant time-effective and safe cleaning even on the rough surfaces of several modern/contemporary canvas paintings (Mastrangelo et al. 2020). These hydrogels can be loaded with aqueous solutions or with o/w NSFs to produce highly advanced cleaning systems, and have been demonstrated in the cleaning of works by Pablo Picasso (Pensabene Buemi et al. 2020), Jackson Pollock (Mastrangelo et al. 2020), Roy Lichtenstein (Bartoletti, Barker, et al. 2020), and others (Bartoletti, Maor, et al. 2020). Currently, research in art cleaning is progressively focusing on the development of gels based on biopolymers and renewable sources, targeting both hydrogels and organogels (Rosciardi et al. 2022; Rosciardi and Baglioni 2023; Mazzuca et al. 2016; Yiming et al. 2019; Sansonetti et al. 2020). The latter, being able to upload organic solvents (Mirabile et al. 2020; Ferrari et al. 2018), represent a complementary class of cleaning tools for highly sensitive surfaces that do not tolerate even minimal contact with aqueous fluids. In GREENART, two crucial research lines include: expanding the sustainability of the TC-PNs by partial replacement, or the enrichment, of PVA with biopolymers or biomolecules; and the development of completely new organogels based on castor oil.

In the first case, it was recently proved that biopolymers, like starch components, can take part in the gelation process (Figure 5), yielding hybrid gel networks with improved sustainability (Rosciardi et al. 2022; Rosciardi and Baglioni 2023). Similar formulations have been further implemented in GREENART, also considering different biomolecules to enrich the PVA network and impart different hydrophilicity, structural and cleaning properties.

Concerning the organogels, castor oil is a vegetable oil from renewable sources that does not impact on the food chain and can be grown in marginal lands, representing a good candidate to formulate organogel polymer networks, which have already shown high

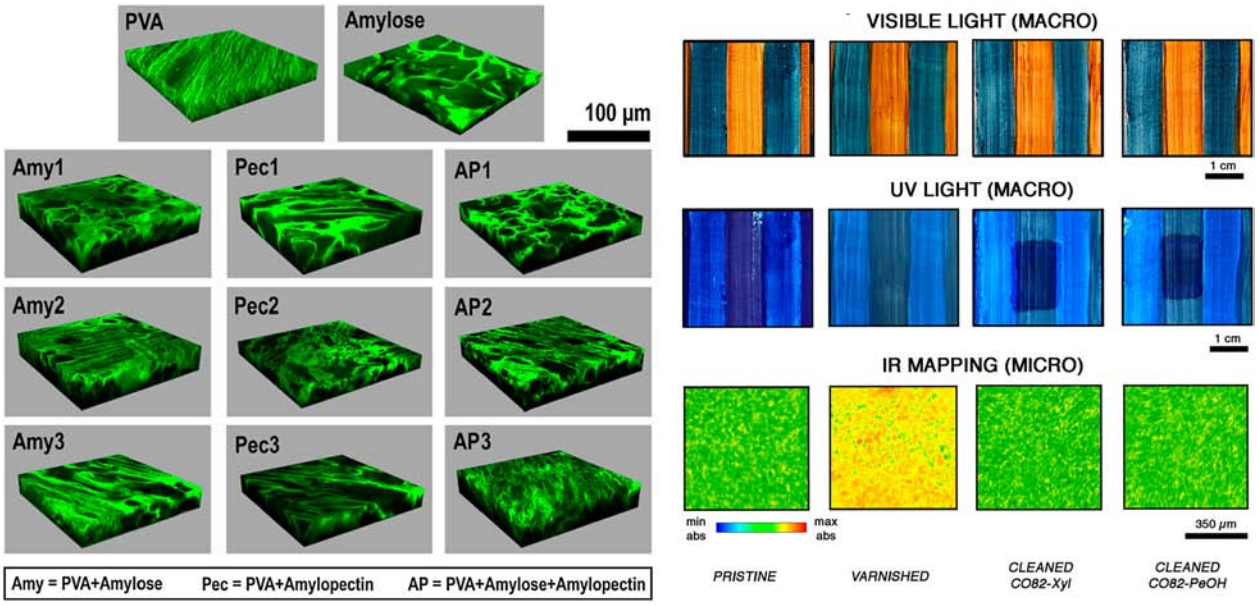


Figure 5. Left: Confocal laser scanning microscopy images of cryogels of PVA and starch polymers, swollen in a Rhodamine B solution. The gel network is shown in green, while voids are in black. Numbers (1,2,3) indicate a PVA content of 66, 50, and 33%, respectively. Different structures (and porosity) are obtained by changing the composition of the gels. Reprinted from Rosciardi and Baglioni (2023) with permission from Elsevier. Right. Rows 1 and 2: Pictures of mock-ups acquired under visible/UV light before (pristine) and after the application of an acrylic-ketonic varnish (varnished), and following treatment with castor oil-based polyurethane organogels (CO82-Xyl and CO82-PeOH) to remove the varnish. Row 3: 2D FTIR imaging of the same samples obtained by mapping the 1860–1685 cm^{-1} region, where the characteristic absorption of the acrylic-ketonic varnish falls. Green and orange-red pixels indicate, respectively, the absence or presence of the varnish absorption peak in the FTIR spectra of the mock-up surface. Reproduced from Poggi et al. (2023). © 2023 The Authors. Published by Elsevier Inc.

efficacy as VOCs absorbers for preventive conservation (Zuliani et al. 2022; Zuliani et al. 2023). Within GREENART, the use of a castor oil-based polyurethane organogel for varnish removal has been recently demonstrated for the first time, as shown in Figure 5 (Poggi et al. 2023). The amount of cross-linking and the type of solvents loaded can be controlled to tune the nanoscale mesh size of the gels, their viscoelasticity, and thus their cleaning capability. The new gels have been successfully used to remove aged varnishes from canvas paintings in a safe and highly time-effective way, in a new class of cleaning tools that will be further developed in the project.

Green tech solutions for monitoring

Monitoring environmental parameters and air pollutants has been a preventive conservation task for decades (Valentini et al. 2018; Adamopoulos and Rinaudo 2021). Early detection of risky conditions in enclosures or sites allows for mitigation. Solutions for indoor and outdoor CH currently include sensors to monitor relative humidity (RH) and temperature (Rittersma 2002), gas corrosivity (Prosek et al. 2013) and particulate matter (Proietti et al. 2014), and smart sensors to monitor biofilms (Albertano et al. 2005). Nanomaterials are being increasingly employed (Valentini et al. 2018) to devise miniaturized portable sensors with wireless transmission of analytical information (Gawade et al. 2021; Agbota et al. 2014), using information communication technology (ICT) and the Internet of Things (IoT) (Mitro et al. 2022) to handle data and suggest preventive measures or conservation interventions. These tools add to a wide range of early-warning systems: solid-phase microextractors combined with gas chromatography-mass spectrometry (Strlič et al. 2007), multi-platforms for remote sensing in archaeological sites (Luo et al. 2019), as well as passive and close-range sensors (Bacci et al. 2008; Adamopoulos and Rinaudo 2021). Recently, 'tattoo' devices are being proposed, i.e. non-invasive and non-destructive portable contact sensors directly applied to artworks (Torsi et al. 2013).

In sustainable CH preservation, novel sensors must be smart, portable, non-invasive, and low-energy consumption tools (Valentini et al. 2018; Gawade et al. 2021), to be feasibly adopted by end-users and logged into the data networks of museums, archives, etc. Coping with these requirements, GREENART is developing solutions for monitoring CH assets non-invasively against pollutants and changes of environmental conditions.

Building upon the background on sensing tools and techniques (Figure 6) acquired within its partnership (Agbota et al. 2014; Gawade et al. 2021; Strlič et al. 2007; Agbota et al. 2013; Olivieri et al. 2023b), the project focuses on eco-friendly, recycled, or waste materials for developing novel monitoring

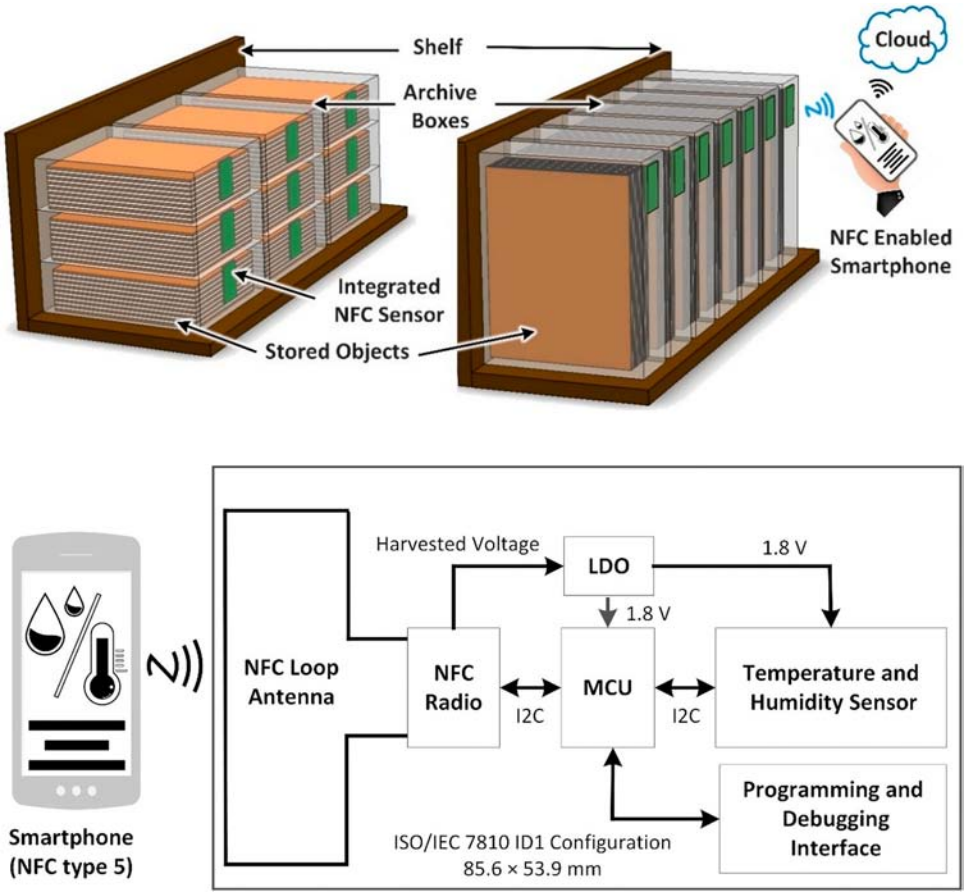


Figure 6. Top: a smart archive box for microclimate monitoring that uses a battery-less NFC sensor wirelessly powered by a standard smartphone. Bottom: block diagram of the NFC sensor. Reproduced from Gawade et al. (2021). ©Authors 2021.

devices. Sensing materials for temperature, RH and gas monitoring are being formulated with GRMs synthesized by environmentally friendly green methods. Low-cost solutions for producing graphene electrochemical sensors in GREENART are based on direct laser writing using laser-induced graphene (LIG) to prepare graphitic electrodes on substrates of natural polymer formulations. The use of 2D-nanomaterials, including GRMs, is being explored to produce miniaturized sensor devices with low power dissipation and advanced non-contact or remote monitoring, targeting high performance under noise for urban or rural sites. Low-cost graphene electrochemical sensors have been recently proposed by fabrication of graphitic carbon electrodes using LIG on chitosan (Larrigy et al. 2023), and this expertise will be used to explore different sustainable natural polymers. The project partnership includes museums where the novel sensors will be compared to currently used benchmarks. This research is expected to foster valuable alternatives for preventive conservation end-users.

Conclusions and future perspectives

Green chemistry and sustainability are progressively entering remedial and preventive conservation practices. The main trends include the use of green materials (water-based fluids, green organic solvents, bio- and natural polymers), smart sensors, and low-energy consumption processes. However, even though some progress has already been achieved, common practices still use petroleum-based or toxic materials, and procedures with low time- or energy-efficiency.

In this context, the GREENART project is developing solutions to target different remedial and preventive conservation tasks, employing green and natural compounds to replace traditional materials. SSbD criteria have been adopted to achieve solutions that are fully sustainable, in addition to their high effectiveness. The main solutions comprise protective coatings, foams and packaging materials, bio-based consolidants, hydro- and organogels, nanostructured cleaning fluids, and green tech sensors. A preliminary screening has selected the constituents of the new materials, using current regulations to indicate components with high green metrics. The development stage is progressing, and the first potential products, e.g. gels and cleaning fluids, have already entered the assessment phase, where museums and institutions in the project will help refine the best performing systems. Finally, LCA and LCC will be employed to estimate the environmental and economic impact of the most promising solutions across their full life

cycle, comparing them to currently existing solutions. The best products developed so far in the project are being extensively disseminated to external and GREENART end-users, an effort that will continue throughout the project and after its end.

GREENART is already improving state-of-the-art tools for conservators with improved green metric scores, proposing some completely new systems, and introducing new green and sustainable concepts into the preservation of CH. Published outputs from the project are listed in the Appendix.

Acknowledgments

This project has received funding from CSGI (Consorzio per lo Sviluppo dei Sistemi a Grande Interfase, Center for Colloid and Surface Science) and from the Horizon Europe Grant Agreement 101060941 for GREENART.

Disclaimer

Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

David Chelazzi http://orcid.org/0000-0001-9994-3356
Giovanna Poggi http://orcid.org/0000-0002-4158-0705
Piero Baglioni http://orcid.org/0000-0003-1312-8700

Appendix: GREENART publications

Bandelli, D., A. Casini, T. Guaragnone, M. Baglioni, R. Mastrangelo, L. Pensabene Buemi, D. Chelazzi, and P. Baglioni. 2024. "Tailoring the properties of poly(vinyl alcohol) "twin-chain" gels via sebacic acid decoration." *Journal of Colloid and Interface Science* 657: 178–92. https://doi.org/10.1016/j.jcis.2023.11.093.

Bandelli, D., R. Mastrangelo, G. Poggi, D. Chelazzi, and P. Baglioni. 2024. "New sustainable polymers and oligomers for Cultural Heritage conservation." *Chemical Science*. https://doi.org/10.1039/D3SC03909A.

Boccaccini, F., C. Ricucci, E. Messina, M. Pascucci, F. Bosi, D. Chelazzi, T. Guaragnone, P. Baglioni, G. M. Ingo, and G. Di Carlo. 2023. "Reproducing bronze archaeological patinas through intentional burial: a comparison between short- and long-term interactions with soil." *Heliyon* 9 (9): e19626. https://doi.org/10.1016/j.heliyon.2023.e19626.

Casini, A., D. Chelazzi, and P. Baglioni. 2022. "Advanced methodologies for the cleaning of works of art." *Science China Technological Sciences* 66: 2162–82. https://doi.org/10.1007/s11431-022-2348-7.

Chelazzi, D. and P. Baglioni. 2023. "From Nanoparticles to Gels: a Breakthrough in Art Conservation Science." *Langmuir* 39 (31): 10744-55. https://doi.org/10.1021/acs.langmuir.3c01324.

Elnaggar, A. 2024. "Nine principles of green heritage science: life cycle assessment as a tool enabling green transformation." *Heritage Science* 12: 7. https://doi.org/10.1186/s40494-023-01114-z.

Gorgolis, G., E. Messina, M. Kotsidi, M. P. Staccioli, E. L. Nhuch, G. Di Carlo, H. S. Schrekker, G. Paterakis, N. Koutroumanis, and C. Galiotis. 2022. "Antifungal Graphene-based Absorbers as Advanced Materials for Preventive Conservation of Cultural Objects." *ChemNanoMat* 8 (12): e202200265. https://doi.org/10.1002/cnma.202200265.

Gorgolis, G., S. Ziemann, M. Kotsidi, G. Paterakis, N. Koutroumanis, C. Tsakonas, M. Anders, and C. Galiotis. 2023. "Novel Graphene-Based Materials as a Tool for Improving Long-Term Storage of Cultural Heritage." *Materials* 16 (9): 3528. https://doi.org/10.3390/ma16093528.

Kotsidi, M., G. Gorgolis, M. G. Pastore Carbone, G. Paterakis, G. Anagnostopoulos, G. Trakakis, A. C. Manikas, C. Pavlou, N. Koutroumanis, and C. Galiotis. 2023. "Graphene nanoplatelets and other 2D-materials as protective means against the fading of coloured inks, dyes and paints." *Nanoscale* 15: 5414–28. https://doi.org/10.1039/D2NR05795F.

Mastrangelo, R., D. Chelazzi, and P. Baglioni. 2024. "New horizons on advanced nanoscale materials for Cultural Heritage conservation." *Nanoscale Horizons*. https://doi.org/10.1039/D3NH00383C.

Mastrangelo, R., C. Resta, E. Carretti, E. Fratini, and P. Baglioni. 2023. "Sponge-like Cryogels from Liquid–Liquid Phase Separation: Structure, Porosity, and Diffusional Gel Properties." *ACS Applied Materials and Interfaces* 15 (39): HYPERLINK "file:///C:\Users\giovannapoggi\Documents\RTD\2023\ICC%20LIMA%202024\Articolo\2nd%20revision\46428-39. https://doi.org/10.1021/acsami.3c03239.

Novak, M., and B. Ormsby. 2023. "Poly(vinyl acetate) Paints: a Literature Review of Material Properties, Ageing Characteristics, and Conservation Challenges". *Polymers* 15 (22): 4348. https://doi.org/10.3390/polym15224348.

Poggi, G., H. D. Santan, J. Smets, D. Chelazzi, D. Noferini, M. L. Petruzzellis, L. Pensabene Buemi, E. Fratini, and P. Baglioni. 2023. "Nanostructured bio-based castor oil organogels for the cleaning of artworks." *Journal of Colloid and Interface Science* 638: 363–74. https://doi.org/10.1016/j.jcis.2023.01.119.

Rosciardi, V., D. Bandelli, G. Bassu, I. Casu, and P. Baglioni. 2024. "Highly biocidal poly(vinyl alcohol)-hydantoin/starch hybrid gels: A "Trojan Horse" for *Bacillus subtilis*." *Journal of Colloid and Interface Science* 657: 788–98. https://doi.org/10.1016/j.jcis.2023.11.142.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S35–S43
https://doi.org/10.1080/00393630.2024.2375161

ORIGINAL RESEARCH OR TREATMENT PAPER

International Cooperation between Korea and Cambodia to Conserve and Manage Angkor Stone Heritage using Non-destructive Technology

Cooperación Internacional entre Corea y Camboya para Conservar y Gestionar el Patrimonio de Piedra de Angkor utilizando Tecnología no Destructiva

Myoungju Choie [1], Myeong Seong Lee [1], Sineth Oum[2] and Sovann In[2]

[1]Conservation Science Division, National Research Institute of Cultural Heritage, Daejeon, Republic of Korea; [2]Department of Safeguarding and Preservation of Monuments, Angkor Conservation Office, Siem Reap, Cambodia

ABSTRACT

The stone team of the National Research Institute of Cultural Heritage (NRICH) in Korea implemented a technology transfer project 2016 – 2020 to manage heritage monuments during the Angkor period in Cambodia. This saw staff from both countries' conservation organisations participating in training, education, and joint research, and making joint academic presentations on technology transfer. The research subjects included statues recovered from the Don Tei and Phnom Bei Temple located near Angkor Thom; the Nokorbachey Temple in Kampong Cham Province, the southern stronghold; and the Banteay Chhmar in Banteay Meanchey Province, a central transportation point in the northwest. Non-destructive technology from Korea was used to investigate the condition of the Angkor ruins, evaluating the suitability of the approach and modifying it as appropriate, and training was conducted to improve the participants' problem-solving and technology application abilities. This exchange project and the data it generated demonstrate the benefits of continuing this approach to develop the conservation skills and problem-solving abilities of managers of Angkor ruins, and ultimately contribute to the preservation of Asian cultural heritage.

El equipo de piedra del Instituto Nacional de Investigación del Patrimonio Cultural (NRICH) de Corea implementó un proyecto de transferencia de tecnología entre 2016 y 2020 para gestionar el patrimonio relacionado con la construcción de templos budistas durante el período Angkor en Camboya. En este evento, personal de organizaciones conservacionistas de ambos países participó en capacitación, educación e investigación conjunta y realizó presentaciones académicas conjuntas sobre transferencia de tecnología. Los temas de investigación incluyeron estatuas recuperadas de Don Tei y los templo Phnom Bei ubicados cerca de Angkor Thom; el Templo Nokorbachey en la provincia de Kampong Cham, el bastión del sur; y el Banteay Chhmar en la provincia de Banteay Meanchey, un punto central de transporte en el noroeste. Se utilizó tecnología no destructiva coreana para investigar el estado de las ruinas de Angkor, evaluar la idoneidad del enfoque y modificarlo según corresponda, y se llevó a cabo una capacitación para mejorar las habilidades de resolución de problemas y aplicación de tecnología de los participantes. Este proyecto de intercambio y los datos que generó demuestran los beneficios de continuar con este enfoque para desarrollar las habilidades de conservación y resolución de problemas de los administradores de las ruinas de Angkor y, en última instancia, contribuir a la preservación del patrimonio cultural asiático.

ARTICLE HISTORY
Received October 2023
Accepted June 2024

KEYWORDS
Angkor stone heritage; non-destructive technology; technology transfer
Patrimonio de piedra de Angkor; tecnología no destructiva; transferencia tecnológica

Introduction

Jayavarman VII expanded the Angkor Empire's territory throughout the Indochina Peninsula, bringing about its heyday in the twelfth and thirteenth centuries. He reigned from 1181 to 1219 and improved the empire by building nation-wide infrastructure with reservoirs, hospitals, roads, Angkor Thom, and the Bayon Temple. His outstanding achievements in many fields, including politics, economics, and culture, are confirmed by the remains of the Angkor period, which are found not only in Cambodia but also in China, Laos, Myanmar, Thailand, and Vietnam. Therefore, the ruins present throughout the Indochina Peninsula and dating to the reign of Jayavarman VII provide vital information to understand the Angkor Empire.

Since António da Madalena's visit in 1589 (Higham 2003), Angkor's ruins have received worldwide attention. Many archaeological studies have been conducted

CONTACT Myoungju Choie mjchoie@gmail.com; Myeong Seong Lee mslee75@korea.kr National Research Institute of Cultural Heritage, 132, Munji-ro, Yuseong-gu, Daejeon 34122, Republic of Korea

© The International Institute for Conservation of Historic and Artistic Works 2024

around the Angkor region in Siem Reap, the empire's capital, revealing much of its history. In recent times, condition issues such as damage caused by civil war and the natural weathering of numerous stone monuments have been recognised, and conservation projects, research and training have been initiated by international organisations and countries (ICOMOS 1993; Thomson 2007; ICC-ANGKOR 2013; UNESCO 2023). The international community's conservation activity around the Angkor ruins has reached a stage where it goes beyond an emergency response to a more comprehensive initiative, encompassing long-term preservation and the development of the local community (UNESCO 1991; 1993; 2003). As case studies, the cultural heritage sites in Angkor represent historical products of conservation, resulting from global preservation efforts.

Despite multifaceted efforts worldwide, preserving the Angkor heritage faces many barriers. While most conservation investments and efforts in Cambodia focus on ruins related to the capital of the Angkor Empire – whose condition has dramatically improved – many monuments outside this region have similar conservation issues and are still in a critical condition. Therefore, the overarching objective in conserving Angkor cultural heritage must expand from the 'restoration of representative ruins' to 'universal conservation'.

Conservation activities of the Angkor Conservation Office

In Cambodia, relics had been destroyed and looted across the country during the civil war in the 1970s and the ensuring social chaos in the 1990s. Following this, the importance of conserving the Angkor ruins was recognised, and the Royal Government of Cambodia decided to protect the Angkor region with the cooperation of international organisations, which designated Angkor as a UNESCO World Heritage Site in 1992. As a follow-up measure, the Authority for the Protection and Safeguarding of Angkor and the Region of Angkor (APSARA) was established in 1995 to protect and manage the Angkor area in Siem Reap province in northwestern Cambodia, the capital of the Khmer empire. APSARA's responsibilities are shared with the Angkor Conservancy, which has managed all of Cambodia's cultural heritage, including the Angkor period ruins, from 1908 onwards.

Between 1908 and 1973, under the supervision of the Ecole Française d'Extrême-Orient (EFEO), the Angkor Conservancy conducted conservation projects in Cambodia by collecting, documenting, and restoring artifacts, to prevent looting and to protect the Angkor ruins. The Angkor Conservancy was subsequently renamed the Angkor Conservation Office (ACO), and it has been under the supervision of the Department of Safeguarding and Preservation of Monuments, in the General Department of Heritage of the Ministry of Culture and Fine Arts, since 2007. The ACO perform tasks such as archaeological excavation, restoration of ruins, and collection of artifacts for an average of 3 – 5 monuments annually throughout Cambodia, except for Siem Reap (which is under APSARA), and the temples in Sambor Preikuk, Preah Vihear and Kohker.

If it is not feasible to have a continuous on-site presence at a cultural heritage site, an alternative is to study the site over a period of time and identify the main causes of deterioration and trends in how it progresses. Recognising the changes in deterioration patterns over time makes it possible to determine the optimum timing of preservation treatments and prepare for emergencies. Therefore, an effective preservation approach involves monitoring using non-destructive damage assessment. Accordingly, the Stone Conservation Team of the NRICH of the Republic of Korea has investigated ways of leading the organisation's heritage management work efficiently and strategically by transferring conservation science skills and to the people dedicated to preserving ACO's stone cultural heritage. The results of this research will be used to promote the development of conservation science methodologies for cultural heritage distributed throughout Cambodia, and to establish sustainable management strategies.

Construction of a progressive project

Asia Cooperation Programme on Conservation Science (ACPCS) training

The ACPCS is a 1:1 matching training programme in which conservators in the Asian region select appropriate research areas for fieldwork and acquire related skills to carry out their work. Human exchange for this project began with the ACO sending conservators to the NRICH Conservation Science Division in 2016 and 2017. The Stone Conservation Team of NRICH provided the ACO conservators with theory and laboratory practice on petrological material analysis and non-destructive condition diagnosis of stone cultural heritage from the Angkor period, through a three-month training course. An additional outcome of the training was that a Korean mentor became aware of the challenges faced by the mentees in preserving stone monuments in Cambodia. After the first ACPCS training programme for Cambodian conservators ended in 2016, the ACO and Conservation Science Division of the NRICH discussed joint research.

Joint research: survey and memorandum of understanding

A mentor and the mentees from the ACPCS training undertaken in 2016–2017 discussed how best to

enhance the heritage management skills of the ACO conservators. They decided to focus on knowledge transfer related to condition assessments, because this would be the most efficient approach given the small size of the ACO workforce, who undertake the management and restoration of large-scale stone cultural sites such as temples, bridges, roads, and moats throughout Cambodia. To this end, focusing on the stone monument conservation project's critical tasks in Cambodia, the NRICH stone team targeted stone objects and monuments where non-destructive technology must urgently be applied.

Support from the senior directors in NRICH and ACO was crucial in ensuring good collaboration between the two organisations. The practitioners within the two organisations were encouraged to develop the project by reflecting on the purpose and usefulness of the methods discussed in the design stage for joint research. Once a preliminary joint investigation had been conducted in 2016 and the effectiveness of the project had been demonstrated, the two organisations recommended signing a memorandum of understanding (MOU) so that the members of the collaborative project could solidify their relationship and further develop the project. The following year, the joint research team on stone cultural heritage signed an MOU (2017 – 2020) titled *Joint Research: Survey for Conservation and Maintenance of Stone Cultural Heritage in Cambodia* and proceeded with the project.

The initial collaborative workforce consisted of NRICH stone team personnel and ACO conservators, who developed technical knowledge and practical experience through ACPCS training, and the number of cooperative members gradually expanded. During five years of the exchange programme, 16 professional personnel were involved in conducting joint investigations and research on seven stone cultural heritage objects, aiming to improve the ACO conservator's abilities to apply Korean non-destructive technology to the field and interpret the data obtained. Furthermore, portable scientific equipment was provided in connection with the Official Development Assistance programme of the Korea Cultural Heritage Foundation within the Cultural Heritage Administration, to enhance the knowledge transfer.

Collaboration achievements

Case study 1: ACO collection

The ACO collection consists of stone statues and monuments from the Angkor period, many of which have been put into secure storage to protect them from theft. Most stone relics required restoration, because they were damaged by theft, war, or religious reasons (Figure 1a). In particular, two Bayon-style Avalokitesvara statues and one Gaja-singha statue collected from two sites near Angkor Thom, which had been kept in the deep storage canopy, had been damaged by physical and biological weathering over time. Additionally, previously restored materials were deteriorating. Therefore, these statues had to be assessed urgently to establish a restoration plan.

One of the Avalokitesvara statues was judged to be at high risk of icon loss due to noticeable damage caused by both flaking and cracking (Figure 1b). Deterioration mapping and ultrasonic measurement methods were applied to diagnose the statue's physical condition, and a treatment was proposed with appropriate, durable materials that are safe from secondary pollution, and at a lower risk of secondary damage.

Conservation of the statues was conducted following techniques possessed by ACO's and using materials proposed by NRICH. Surface cleaning and desalination were performed, and old restoration materials were removed. For conservation, ACO used sandstone powder with a colour and mineral composition similar to that of the statue, ethyl silicate, and stainless steel bars. Additionally, given that physical loss had been progressing rapidly in the statue, monitoring was conducted for two years (2017 – 2018) after treatment, referring back to the results of the ultrasonic property evaluation conducted before conservation treatment (2016) to confirm that the statue remained physically stable (Figure 2).

Case study 2: Nokorbachey Temple

The Nokorbachey Temple (or Vat Nokor) was built in Kampong Cham Province on the banks of the Mekong River, approximately 245 km southeast of Angkor Thom, in the final years of King Jayavarman VII's rule (early thirteenth century). This temple was constructed in the Bayon style by the King to devote himself to Mahayana Buddhism, but it later underwent many changes, including replacement of its icons and construction of a central stupa after succession to throne (Figure 3a).

In the early 1900s, the EFEO investigated the temple, studying its iconographic significance and preservation status, and revealed its geopolitical significance in connection to King Jayavarman VII's territorial expansion in the south-central Indochina Peninsula (Parmentier 1916; Hawixbrock 1998). The joint research objects were two doors made of medium-grained sandstone with bas-relief, decorated with fake windows and Hindu gods. They were located on the east and west sides of the third enclosure, among the four enclosures arranged in the east – west direction in the temple. The two stone gates had suffered from physical, chemical, and biological weathering, and structural problems such as sloping, separation, and deviation; therefore, a comprehensive condition assessment was required (Figure 3b).



Figure 1. Bayon style statues in Angkor Conservation Office collection, and physical deterioration. (a) Avalokitesvara statues in Bayon style, Angkorian period, thirteenth century. (b) Flaking and cracking on of the surface.



Figure 2. Discussion on the deterioration and treatment of an Avalokitesvara statue in Bayon style.

The sandstone monuments of the Angkor period are characterised by masonry of block-shaped stones with bas-relief. Stones of relatively uniform size were used originally, and when restoring a building, stone replacements are performed in block units. After completing the theoretical and laboratory training, ACO conservators were deployed in the field using appropriate analysis methods, and data were acquired to describe the location and condition of the stone. The physical, chemical, biological, and structural conditions of each stone was evaluated, and statistics were generated to show the frequency with which each grade of deterioration occurred, and to what extent. The following trials were undertaken to ensure that the non-destructive analysis methods used in Korea could be utilised in the local Cambodian context (Figure 4).

- Macroscopic examination of petrological features and magnetic susceptibility measurements, to assess the homogeneity of stones
- Ultrasonic measurements and correction in an environment where heavy rainfall frequently occurs as a physical condition monitoring method
- Scaling area detection method using sunlight and an infrared camera in an environment without an electricity supply
- Normalised Difference Vegetation Index (NDVI) calculation method using hyperspectral scanning, to detect algae and lichens living actively on monument surfaces
- Evaluation of the usefulness of creating a conservation management checklist to help participants to assess the condition of the stones.

Case study 3: Banteay Chhmar

Banteay Chhmar, nicknamed 'Little Bayon', is a temple in Banteay Meanchey Province, approximately 110 km northwest of Angkor, which was built by King Jayavarman VII to honour Prince Srindrakumara and his four generals. This temple has existed for a long time and it has suffered due to a lack of management, the impact of war, plundering, and changes in the hydraulic system of the moat.

In particularly, the bas-relief with the eight Avalokitesvaras in the western gallery, which was the subject of this joint investigation, had been damaged during a period of internal social turmoil after the mid-1900s, when looting occurred (Figure 5a). Following this some icons were repatriated, but they could not be completely restored (Boisselier 1965; Groslier 2004; Schäfer et al. 2012; Miura 2016) until 2022. Additionally, the Southern Causeway of Giants, which serves as a passageway to the temple, suffered a loss of iconography for religious reasons and ground subsidence due to water in the moat, and many stone statues decorating the railings have not survived (Long et al. 2013). The two study areas in Banteay Chhmar were made of various coloured sandstones, and have suffered differential erosion, granular decomposition, cracking, and significant losses, making condition assessment and monitoring essential (Figure 5b).

Sandstone shows anisotropic and has a bedding structure, resulting in differences in its physical properties, which affect its sensitivity to weathering such as grain sanding, cracking, and breaking out. Therefore, an experiment was conducted to obtain objective data using ultrasonic measurements, which provide information about the physical properties of stone non-destructively. For the experiment, the key to long-term monitoring of the physical properties of stone in high-temperature and high-humidity environments was to create consistent measurement conditions. Additionally, a conservation management checklist was applied to enable long-term monitoring of the condition of stones in which sedimentary structures are very well developed and the loss occurs (Figure 6), as follows:

- Correlation between various structures, textures, and weathering patterns occurring in clastic sedimentary rocks
- Ultrasonic measurements and monitoring in environments where heavy rainfall frequently occurs
- As before, the usefulness of the conservation management checklist was evaluated.

Dissemination

While conducting experiments on joint field surveys and monitoring methods over a four-year period, scientific and conservation data on Bayon-style stone monuments from the Angkor period in Cambodia were prepared. Nine oral presentations, poster presentations, and publications were delivered, sharing technical considerations on the preservation environment for each heritage site, the characteristic of the stone, and the methods of condition diagnosis used in the field (Choie et al. 2018; 2024). Additionally, in 2020, the Korea-Cambodia International Joint Research Report titled *Conservation and Restoration of Khmer Stone Cultural Heritage in Cambodia* was published (Choie et al. 2020). Topics that have yet to be announced will be published sequentially in conservation science-related journals in the future.

Discussion

As non-destructive analysis techniques for preservation must be applied flexibly depending on the environment and the damage pattern of the ruins



Figure 3. Nokorbachey Temple and biological deterioration. (a) Nokorbachey Temple, Angkorian period, thirteenth century, in Kampong Cham Province. (b) Sandstone colonized by algae and lichen.



Figure 4. Collaborative team for deterioration assessment of Nokorbachey Temple.

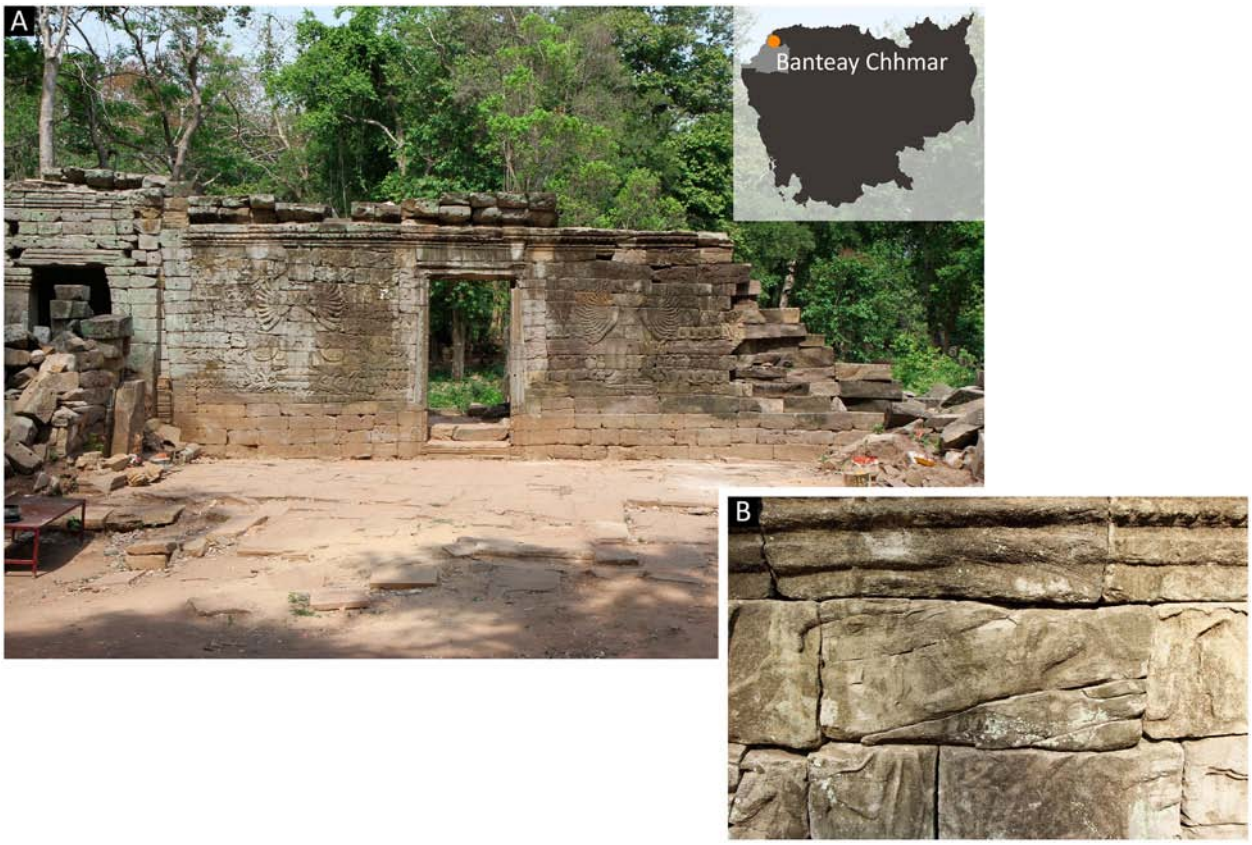


Figure 5. Banteay Chhmar and structural deterioration. (a) Two Avalokitesvaras bas-reliefs in the southwest gallery of Banteay Chhmar, Angkorian period, thirteenth century, in Banteay Meanchey Province. (b) Oblique fractures due to bedding structure.



Figure 6. Examining bas-reliefs in the southwest gallery of Banteay Chhmar.

being studied, the NRICH of the Republic of Korea possesses a range of scientific techniques. The acquisition and processing methods have been developed for the climate, materials, and conservation issues of South Korea. Applying these methods to the conservation issues of stone heritage sites in Cambodia must be approached with caution. Additionally, the methodology may need to be modified to suit the working practices of the conservators who work in the field in Cambodia.

In theory, learning the correct experimental methods is critical for applying non-destructive technologies to the conservation of cultural heritage. However, in practice, more meaningful ways of acquiring the skills required rely on: recognising the strengths and limitations of the practitioners and improving the methodologies to meet their needs; using the methods in the field over long periods of time; and repetitively learning the data analysis process. Furthermore, field training is an effective way to develop flexibility in operating equipment so that it can be applied to heritage sites with varying environments and damage types. Therefore, to increase the usability of non-destructive technology, rather than simply explain it, the stone team of NIRCH designed a step-by-step learning process to solve the problems faced by conservators and to generate data.

Eventually, ACO conservators must be able to respond appropriately to weathering resulting from the different environments and types of stone encountered throughout Cambodia; more follow-up work is needed to achieve this. Therefore, those who have been taught to use non-destructive technologies for condition assessments should further improve their expertise through continuous training and exposure to case studies, and further collaboration should be designed to meet these aims.

Conclusions

When teaching conservation science methodologies to a different organisation or country, the organization delivering the training needs to understand the situation in the field and the context in which the conservators being trained work. For this project, in order to collaborate effectively with ACO, the Korean conservators were first required to establish a shared understanding of the issues and goals involved in conserving Cambodia's cultural heritage. Additionally, setting common goals creates a sense of continuous solidarity that is not limited to the project period, encouraging ongoing support from stakeholders even after the project has ended.

To establish an effective preservation system with few human resources, conservators who manage sites distributed throughout Cambodia must be able to schedule restoration projects at appropriate times through continuous monitoring of damage to monuments. Therefore, technology transfer and training were developed to improve the ability of conservators to respond proactively to issues related with the deterioration of monuments in Cambodia. For this end, learning the methodology by conducting long-term case studies in at sites with a range of environments and damage patterns, and drawing conclusions from them together, was very effective.

Partial modification of methodologies for assessing and monitoring the condition of cultural monuments which are exposed to different climatic and conservation environments is essential for skills transfer. For example, the ultrasonic velocity measurement method utilises waves whose velocity varies depending on the density and elastic modulus of the media, and as pores develop inside the rock, the speed decreases. Therefore, this method is the most effective for the non-destructive monitoring of physical condition issues such as scaling, cracks, and differential erosion; and also for assessing the efficacy of preservation treatments. However, careful consideration regarding the application of ultrasonic measurement methods is necessary in environments where the moisture content of stones varies widely. Additionally, for large-scale masonry monuments, such as Cambodian temples, it was confirmed that calculating the weathering grade using the checklist method for biological weathering gives similar results to the NDVI, making it an appropriate monitoring method.

Acknowledgements

The authors would like to thank Jongduck Lim, Jiyoung Shin, KOU Vet, KIM Sothin, Yugun Chun, Jihyun Yoo, Yubin Ahn, Yuri Kim, the deceased Jinju Whang, Junga Kang, CHHAN Chamroeum, KHAN Lakhena, YOUNG Rotanak, Bonny Lee, and Taejung Choi for their cooperation.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the National Research Institute of Cultural Heritage of The Republic of Korea under the following grant: Cultural Heritage Research (R&D) project No. NRICH-2405-A70F-1.

ORCID

Myoungju Choie http://orcid.org/0000-0002-9647-5638
Myeong Seong Lee http://orcid.org/0000-0002-9707-5732

References

Boisselier, J. 1965. "Précisions sur quelques images khmères d'Avalokiteśvara. Les bas-reliefs de Bantãy Čhmàr." *Arts asiatiques* 11 (1): 73–89. https://doi.org/10.3406/arasi.1965.916.

Choie, M., M. S. Lee, S. In, S. Oum, Y. G. Chun, J. H. Yoo, and J. A. Kang. 2024. "Multidimensional Approach to Evaluation of Weathering Degree of Lower Plant on Stone Cultural Heritage in Cambodia." In *Conservation of Architectural Heritage (CAH),* Palermo, Italy, 25–27 May 2022, edited by M. L. Germanà, N. Akagawa, A. Versaci, and N. Cavalagli, 163–169. Cham: Springer. https://doi.org/10.1007/978-3-031-33222-7_14.

Choie, M., M. S. Lee, S. Oum, and S. In. 2020. *Conservation and Restoration of Khmer Stone Cultural Heritage in Cambodia, Korea·Cambodia International Joint Research Report*. Deajeon: National Research Institute of Cultural Heritage, The Cultural Heritage Administration of the Republic of Korea and Angkor Conservation Office of the Department of Safeguarding and Preservation of Monuments of Cambodia.

Choie, M., M. S. Lee, J. H. Yoo, Y. G. Chun, K. Sothin, S. In, and S. Oum. 2018. "Weathering Characteristics and Condition Assessment Conservation Treatment for Bayon Style Avalokitesvara, Cambodia." *Journal of Conservation Science* 34 (3): 167–177. https://doi.org/10.12654/JCS.2018.34.3.03.

Groslier, G. 2004. "Une merveilleuse cité khmère: 'Bantéai Chhmar' ville ancienne du Cambodge." *Aséanie, Sciences humaines en Asie du Sud-Est* 13 (1): 151–161. https://doi.org/10.3406/asean.2004.1816.

Hawixbrock, C. 1998. "Jayavarman VII ou le renouveau d'Angkor, entre tradition et modernité." *Bulletin de l'Ecole française d'Extrême-Orient* 85 (1): 63–85. https://doi.org/10.3406/befeo.1998.2544.

Higham, C. 2003. *The Civilization of Angkor*. London: Phoenix.

ICC-ANGKOR (International Co-ordinating Committee for the Safeguarding and Development of the historic site of Angkor). 2013. *20 Years of the ICC-ANGKOR*. Phnom Penh: UNESCO office in Phnom Penh.

ICOMOS. 1993. "Guidelines for Education and Training in the Conservation of Monuments, Ensembles and Sites." Presented at the ICOMOS General Conference, Colombo, Sri Lanka.

Long, N., S. Kim, S. Mao, and S. Warrack. 2013. *Conservation of the East Side of the South Causeway at Banteay Chhmar: SACRA Conservation Report*. Phnom Penh: Ministry of Culture and Fine Arts.

Miura, K. 2016. "Destruction and Plunder of Cambodian Cultural Heritage and Their Consequences." In *Cultural Property and Contested Ownership: The Trafficking of Artefacts and the Quest for Restitution*, edited by B. Hauser-Schäublin and L. V. Profitt, 23–44. Abingdon and New York: Routledge.

Parmentier, H. 1916. "Vat Nokor." *Bulletin de l'Ecole française d'Extrême-Orient* 16 (1): 1–38. https://doi.org/10.3406/befeo.1916.5282.

Schäfer, A., H. Mara, J. Freudenreich, B. Breuckmann, C. Düffort, and G. Bock. 2012. "Large Scale Angkor Style Reliefs: High Definition 3D Acquisition and Improved Visualization Using Local Feature Estimation." In *CAA2011 Revive the Past: Proceedings of the 39th Conference in Computer Applications and Quantitative Methods in Archaeology,* Beijing, China, 12–16 April 2011, edited by M. Zhou, I. Romanowska, Z. Wu, P. Xu, and P. Verhagen, 70–80. Amsterdam: Amsterdam University Press.

Thomson, R. G. 2007. "On-site Conservation Training in Cambodia: A Critical Survey of Activities at Angkor." *Built Environment* 33 (3): 371–391. https://doi.org/10.2148/benv.33.3.371.

UNESCO. 1991. "Records of the General Conference." In *26th UNESCO General Conference*, 60–61. Paris: UNESCO.

UNESCO. 1993. "Proceedings of the Intergovernmental Conference on the Safeguarding and Development of the Historical Area of Angkor." In *Intergovernmental Conference for the Safeguarding and Development of the Angkor Site*, 1–3. Tokyo: UNESCO.

UNESCO. 2003. "Paris Declaration Safeguarding and Development of Angkor." In *2nd Intergovernmental Conference for the Safeguarding and Sustainable Development of the Historic Site of Angkor*, 1–3. Tokyo: UNESCO.

UNESCO. 2023. "Angkor." https://whc.unesco.org/en/list/668/.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S44–S54
https://doi.org/10.1080/00393630.2024.2340894

ORIGINAL RESEARCH OR TREATMENT PAPER

Uplifting Community and Incorporating Reuse in Conservation Planning for the Noah Purifoy Outdoor Desert Art Museum of Assemblage Sculpture

Inspirando a la Comunidad e Incorporando la Reutilización en la Planificación de la Conservación del Museo de Arte de Escultura Ensamblaje al Aire Libre del Desierto Noah Purifoy

Anya Dani[1], Jennifer Kim[2], Joe Lewis[3], Robin Meyer-Lorey[4], Jill Moniz[5] and Laleña Vellanoweth[6]

[1]UCLA/Getty Interdepartmental Program in the Conservation of Cultural Heritage, Los Angeles, USA; [2]Your Neighborhood Museum, Los Angeles, USA; [3]Department of Art, UC Irvine, Irvine, USA; [4]UCLA Department of Anthropology, Los Angeles, USA; [5]Transformative Arts, Los Angeles, USA; [6]LA County Department of Art and Culture, Los Angeles, USA

ABSTRACT

In 2023 the Noah Purifoy Foundation received a Mellon Foundation Grant to develop, with conservators, an innovative and thoughtful conservation plan for the over 100 sculptures at the Noah Purifoy Outdoor Desert Art Museum of Assemblage Sculpture. Located in the high desert of Joshua Tree, California, USA, it encompasses four hectares of rural art space where Purifoy lived and worked from 1989 until his death in 2004. Although Purifoy was a trained artist, his works also draw from his time as a US Navy Seabee and the tradition of Black self-taught artists from the American South. His artworks were never complete, but alive, and in an ongoing conversation among him, nature, and material. Amidst the physical challenges of addressing found material assemblage in a challenging landscape, the project also requires bringing stakeholders and knowledge bearers into conversation to determine an appropriate 'patina' of weathering for the works. To achieve this, the project involves identifying Purifoy's definition of community, reuse, and interaction with the natural landscape into the conservation plan. The project also included drone mapping as a documentation tool alongside condition surveys and photographic documentation. Being led by a group of racially diverse conservators who are centering community involvement in the work helps the team mimic Purifoy's own commitment to community engagement. This project has the potential to act as a model for the development of conservation plans for other sites of contemporary sculpture, especially those in remote locations or those focused on African American artists.

En 2023, la Fundación Noah Purifoy recibió una subvención de la Fundación Mellon para desarrollar, junto con los conservadores, un plan de conservación innovador y reflexivo para las más de 100 esculturas del Museo de Esculturas de Ensamblaje de Arte al Aire Libre del Desierto Noah Purifoy. Ubicado en el alto desierto de Joshua Tree, California, EE. UU., el museo abarca cuatro hectáreas de espacio de arte rural donde Purifoy vivió y trabajó desde 1989 hasta su muerte en 2004. Aunque Purifoy era un artista calificado, sus obras también se basan en su época como miembro de la Marina de los EE. UU. y la tradición de los artistas autodidactas negros del sur de EE. UU. Sus obras de arte nunca estuvieron completas, sino vivas y están en una continua conversación entre él, la naturaleza y el material. En medio de los desafíos físicos de abordar el ensamblaje de materiales encontrados en un paisaje desafiante, el proyecto también requiere conversar con las partes interesadas y los expertos para determinar una 'pátina' adecuada para las obras. Para lograr esto, el proyecto implica identificar conceptos dictados por el artista, como son la definición de comunidad, la reutilización e interacción con el paisaje natural en el plan de conservación. El proyecto también incluyó el mapeo con drones como herramienta de documentación junto con estudios de estado y documentación fotográfica. Al ser dirigido por un grupo de conservadores racialmente diversos que centran la participación de la comunidad en el trabajo, ayuda al equipo a imitar el propio compromiso de Purifoy con la participación comunitaria. Este proyecto tiene el potencial de actuar como modelo para el desarrollo de planes de conservación para otros sitios de escultura contemporánea, especialmente aquellos en lugares remotos o aquellos centrados en artistas afroamericanos.

ARTICLE HISTORY
Received October 2023
Accepted March 2024

KEYWORDS
Outdoor sculpture; contemporary art; conservation ethics; drone mapping; Noah Purifoy

Escultura al aire libre; Arte contemporáneo; Ética de la conservación; Mapeo con drones; Noah Purifoy

CONTACT Anya Dani anyadani@ioa.ucla.edu A210 Fowler Building/Box 951510, 308 Charles E. Young Dr. North, University of California, Los Angeles, CA 90095, USA

© The International Institute for Conservation of Historic and Artistic Works 2024

Introduction

On the Mojave desert floor of Southern California, in the western region of the USA, where 50°C temperatures are increasingly common, and wildfires are becoming a greater threat, sits a four hectare outdoor museum with over 100 sculptures continuously evolving as they interact with visitors, creatures, and the elements. This constant exposure and change were intended when artist Noah Purifoy created, installed, and reworked the large scale and site-specific sculptures that became this Noah Purifoy Outdoor Desert Art Museum of Assemblage Sculpture. Despite this intentional mutability, the Outdoor Museum itself was meant to endure, as evidenced when Purifoy and his trusted colleagues created the Noah Purifoy Foundation (NPF) to maintain stewardship of the sculpture park and promote Purifoy's ideas about community-based art beyond his own lifetime (Smith 2016).

In 2023, the NPF received a three-year $500,000 grant from the Andrew W. Mellon Foundation, which will be transformational in efforts to preserve Purifoy's assemblage sculptures. Working with a team of California conservators in partnership with the UCLA/Getty Interdepartmental Program in the Conservation of Cultural Heritage (a graduate training program at the University of California, Los Angeles) and the nonprofit Your Neighborhood Museum (a new organization dedicated to sharing conservation and cultural heritage support with underserved communities), all of Purifoy's artworks at the Outdoor Museum are being assessed as part of this project. Condition reports and comprehensive action plans are being created for the museum as a whole. Along with the large scope of the site, the challenge is to incorporate Purifoy's philosophy around assemblage, reuse, community, and social justice into the conservation project. The overall project has been split into three phases. This publication is largely an account of Phase I activities as well as overarching ethical concerns.

Land acknowledgement

The Outdoor Museum is located on the traditional territories of the Yuhaviatam/Maarenga'yam (Serrano). The Yuhaviatam/Maarenga'yam are indigenous people that historically lived mainly in what is now called the San Bernardino Mountains, and in the Southern Mojave Desert in Southern California.[1] They were forcibly removed to the San Manuel Reservation in 1891 but continue to live in and care for their traditional places (San Manuel Band of Mission Indians 2023).

Noah Purifoy

Artist, theorist, and community activist, Purifoy (Figure 1) was a renegade and an innovator who understood that shared visual language builds strong communities. Born 1917 in Snow Hill, Alabama, in the Southern USA, Purifoy was a high school industrial arts teacher and social worker before becoming an artist. He earned a bachelor's degree from Alabama State Teachers College and a masters in social service administration from Clark Atlanta University. Following service as a US Navy Seabee (Naval Construction Battalions) during WWII, he moved to Los Angeles, California, and enrolled at Chouinard Art Institute (now CalArts), earning a bachelor of fine arts degree in 1956. Purifoy was the founder and first director of the Watts Towers Art Center in the 1960s, and in 1976 was appointed to the California Arts Council, where he served for 11 years. In 1989, Purifoy moved his practice from Los Angeles to Joshua Tree, in the Mojave Desert. From 1989 until his death in 2004, he transformed the 4 hectares of his high desert studio and environment with assemblage sculptures and installations, dedicating the space to his aesthetic pursuits of materiality, volume, and form. As Purifoy would muse, the installations are in the open and, 'collaborate with their environment' (Purifoy 1999). This otherworldly environment, constructed entirely from junk materials, is one of America's great art historical wonders.



Figure 1. Noah Purifoy. Image: Harry Drinkwater. Courtesy the estate of Harry Drinkwater.

Purifoy's earliest body of sculpture, constructed out of charred debris from the 1965 Watts Rebellion, a riot in the predominantly African American neighborhood of Watts and surrounding areas that was spurred by racial injustice, was the basis for *66 Signs of Neon*, a landmark 1966 group exhibition on the Watts uprising that traveled throughout the USA for three years. Purifoy knew the community intimately and his *66 Signs of Neon* presented visual narratives of the tensions, traditions, and survival of a people under an oppressive system. Following traditions of Black

Southern outsider artists, Purifoy led a re-defining movement of Black artistic consciousness through assemblage sculpture.

In line with the postwar period's fascination with urbanization, Purifoy's vision married outsider aesthetics with the canonical Duchampian *avant-garde* movement, Dada, that profoundly impacted David Hammons, John Outterbridge, and Senga Nengudi, among other artists coming of age during that time in Los Angeles. Today, contemporary artists including Todd Gray, LaToya Ruby Frazier, Hannah Collins, Cauleen Smith and others make pilgrimages to the Outdoor Museum in Joshua Tree to be inspired by Purifoy's work and use his visual language to signify the breadth and depth of Black American experiences. Purifoy's work was the subject of a Los Angeles County Museum of Art 2015 monographic exhibition, *Noah Purifoy: Junk Dada* (Sirmans and Lipschutz 2015). His art has been included in virtually every major exhibition focusing on Black or outsider art.[2] In 2015 a faithful replica of a catalogue Purifoy himself had fabricated with photographs and writings in 1997 was published by Steidl (Purifoy 2015). Today, it is the inspiration behind UCLA's Hammer Museum 2023 *Made in LA* biennial.[3]

Noah Purifoy foundation (NPF)

In 1998, Purifoy's representative and colleague of many years, Sue A. Welsh, suggested to Purifoy the importance of preserving his Outdoor Museum. The following year, the NPF was formally established as a 501(c)3 non-profit private foundation (Smith 2016).

NPF's mission is to preserve and maintain the site Purifoy developed in Joshua Tree, California as a permanent cultural center and sculpture park open to the public; to promote public recognition and appreciation for the values that Purifoy's work as an artist and educator has embodied; and to pursue these goals in a manner that protects his contribution as an artist and educator.

The primary activities of the NPF are to:

- Preserve and maintain Purifoy's existing works of art
- Maintain the Outdoor Museum for public engagement, tours, and educational programs
- Provide an arts educational experience to urban middle school Black and Latinx students in South Los Angeles through an Urban Arts Initiative (UAI) program[4]
- Provide curatorial assistance giving visitors a coherent explanation of the desert museum project, its development, its relationship to the USA during Purifoy's lifetime and the recognition of Purifoy as a world leader in the genre of assemblage art
- Organize Purifoy's papers and develop research opportunities for national and international artists and scholars to review his *oeuvre*

The outdoor museum

There are 163 distinctly catalogued artworks on the site, 115 of which are outdoor assemblage sculptures. A smaller subset of artworks is kept indoors. Each work is constructed of numerous parts and materials. Since Purifoy's passing, the NPF has approached conservation and preservation issues from a reactive position. This approach, though serious and thoughtful, is more along the lines of a Band-Aid®. If the site is to endure and be available for the public, schools, and researcher's enjoyment and scholarship, the NPF must think long-term.

The NPF conservation project

The lead conservators for the Mellon-funded project are Jennifer Kim (Your Neighborhood Museum) and Anya Dani (UCLA/Getty). The diverse Conservation Project team also includes UCLA anthropology graduate student, Robin Meyer-Lorey, as well as UCLA/Getty Conservation Program graduate students. Additional support was provided by the UCLA Cotsen Institute of Archaeology's Digital Archaeology Lab, UCLA Libraries, and the Los Angeles County Department of Arts and Culture. During this project, all of the artworks on site are being assessed. Condition assessments and comprehensive preservation plans are being created. Part of the grant will fund building a conservation and gallery facility at the Outdoor Museum site to house Purifoy's smaller sculptures while also providing a conservation workspace. NPF aims to create a conservation planning and implementation program that can serve as a model for other groups or institutions facing similar challenges. The conservation facility will also be available as a community resource for collaborative opportunities with students, local cultural organizations, and tribal communities. The conservation project will be executed in three phases. The authors completed Phase I in 2023 and are in the midst of Phase II.

Phase I

Assessment and survey execution

The conservation team performed an assessment of the Outdoor Museum. Both conservation leads were familiar with performing preservation assessments for traditional museums. However, the Outdoor Museum functions uniquely and is in large part self-sufficient. While the museum is technically open daily only during daylight hours, there are no fences or gates to prohibit the public from entering or interacting with the artworks. Staffing is intermittent and any admission fees collected are received digitally *via* a QR code. A visitor center across from the sculpture park is open part-time. The site itself is off a series of

unpaved roads. Several assessment models and questionnaires (Dardes, Avrami, and De la Torre 1999; FAIC 2023; Patkus 2003) were reviewed and considered during project planning. Ultimately, a fluid, customized protocol was deemed necessary for this unique context.

Work began with a first preliminary walkthrough in winter 2022 and conversations with NPF board members to begin planning for a longer work period on site for documentation and assessment. Major concerns noted in these early conversations included the lack of formal collections or conservation policies, sparse condition reporting or conservation documentation, and the lack of collections numbering systems or sculpture location mapping. Additionally, NPF institutional and Purifoy's personal archives exist but are not easily accessible. A great deal of knowledge of the artworks, their locations and movements, site history, and maintenance or restoration history exists, but mostly in the memories of individual board members, friends, and colleagues of Purifoy.

A Phase 1 itinerary was created for winter/spring 2023 that included document gathering, research, and on-site assessment of the Outdoor Museum, ending with all findings summarized in a preliminary report. Conservators gathered information on Purifoy and his artworks from the NPF board, the site, foundation and collections records, management practices, as well as conducted preliminary art historical research on his *oeuvre* and impact, and climate and site research for the region. Overall assessment of the site included walkthroughs of the location and artworks, a drone survey of the entire site, and a more detailed condition assessment of works displayed and stored indoors in a Quonset hut, workshop, and visitor center at the desert site. A more detailed conservation survey of these indoor works was performed both to aid the assessment and as a paid learning opportunity for UCLA/Getty conservation graduate students (Figure 2).

Due to the extreme weather worsening with climate change (Hopkins et al. 2018), very low rainfall with occasional flood risks, and the Southern California fire season, site work has significant seasonal limitations. Major limiting factors are the reasonable safety and comfort of the team working largely outdoors, and extreme weather or fire events that can cause road closures in an already remote area. To demonstrate the reality of these risks, two months after the site assessment, the region was struck by the massive York wildfire which ultimately scorched an estimated 40,000 hectares. The York Fire began on 28 July in the New York Mountain Range of the Mojave National Preserve located in eastern San Bernardino County (Inciweb 2023). This wildfire was ultimately contained on 19 August, when the area was doused by the first tropical storm to hit California for



Figure 2. Quonset Hut gallery indoor conditions. UCLA/Getty Conservation students participating in the site survey. Left to right: Kathryn Peneyra (MA), Moupi Mukhopadhyay (PhD), and Makayla Rawlins (MA).

decades. Heavy rainfall from this storm hit inland desert areas particularly hard, including Joshua Tree, causing significant destruction from flash flooding, mudslides, and debris flow, stranding many communities in the area (Fonseca and Li 2023; Solis and Toohey 2023). Although these events occurred in the same region as the Outdoor Museum, thankfully they did not cause significant direct damage to the site and artworks. However, the risk remains real.

A temporary object numbering system was introduced to track the artwork and assessment during the indoor work survey. A survey custom format created using the Airtable online hybrid database and spreadsheet platform was used by the survey team to enter all condition notes, treatment or other intervention suggestions, as well as photo-documentation. In addition, an overall five-step condition ranking system was created to tease out physical stabilities of artworks from highest to lowest risk of instability or catastrophic damage.[5]

Drone survey and mapping

The Phase I photogrammetric drone survey of the Outdoor Museum was carried out on 6 May 2023, to quickly and fully document the location and basic physical characteristics of all 115 outdoor assemblage sculptures.[6] The resulting map (Figure 3) will be used



Figure 3. Noah Purifoy Outdoor Desert Art Museum of Assemblage Sculpture. Copy of orthomosaic by Robin Meyer-Lorey, 2023.

to track changes (deterioration and movement due to wind/weather) and can be built upon with additional technology in the future. The survey team utilized a DJI Phantom 4 RTK Drone, DJI D-RTK 2 GNSS Mobile Base Station, and an iPhone 12 Pro WIFI Hotspot. Under sunny skies, no clouds, light to negligible wind, a temperature averaging 21°C, and low relative humidity, the survey conditions were ideal.

Post-flight, the collected images were processed in Agisoft Metashape Professional. This software facilitated the creation of a georeferenced orthomosaic of the entire site, at a resolution of 1 cm per pixel. Additionally, a georeferenced digital elevation model (DEM) was generated, providing a detailed representation of the terrain, vegetation, and sculptures, with a resolution of 2.7 cm per pixel. These outputs enable precise measurements of GPS locations, dimensions, and heights of sculptures, vegetation, and buildings within the museum grounds as of the survey date. GIS software was used to label the photogrammetric map and create a detailed list of all sculptures, with their GPS coordinates and dimensions.

Results

The key recommendations were:

Collections Management improvement Needs. The preservation and maintenance of Purifoy's existing works of art require the incorporation of more robust documentation and research, strengthening of broad stakeholder participation, and changes to intervention modalities to better meet current standards of best practice. In particular, preserving the primary evidence of Purifoy's hand in the physical construction of his artwork requires immediate attention.

Codifying Ethics and Values. A cohesive overarching preservation and collections management plan that aligns with and can be incorporated into the NPF Board's strategic plan and values is needed.

Education. Aspects of the preservation and maintenance practices of Purifoy's artworks are well suited for incorporation into an arts educational experience either with or adjacent to the NPF UAI program.

Archives. Purifoy's papers and archives should be assessed urgently as they provide critical contextual history to the site.

The scopes of the third and fourth points are straightforward and will be actualized in Phases 2 and 3 of the Conservation Project. However, the first two recommendations will require further investigation and deliberation.

Conservation and collections management improvement needs

During the assessment process it became clear that the Outdoor Museum could benefit from the introduction of collections management policies as part of an overall preservation plan. Therefore, it was recommended that the NPF create an object numbering system, and that they follow American Alliance of Museums standards (AAM 2023) by writing, formalizing, and implementing the following additional core documents: *Institutional Code of Ethics*, *Strategic Plan*, *Collections Management Policy*, *Disaster Preparedness*[7] and *Emergency Response Plan*. Formalizing policies would help give clear guidance and expectations to the site's caretakers, and may assist with future grant solicitation.

Codifying ethics and values

In order to incorporate Purifoy's values into an overall preservation plan and into interventive conservation treatments, it was important to delve into the artist's views on art and preservation. Purifoy felt that assemblage was the artform closest to human existence. In many ways the process of creating art was his true fascination and superseded the final outcome. At the same time, he did care about the longevity of his artworks and performed some repairs himself.[8] Purifoy himself said:[9] 'Art and the creative process are not one and the same thing. My idea is to interrelate them if I can, like I attempted to interrelate my mind with my body to make one whole person'. It soon also became part of the project's mission to integrate preservation of the artworks and the creative process into the developing conservation plan. We attempted to reconcile these seemingly contradictory values as we moved forward with the project.

Managed loss and patina

Deciding on appropriate patina for the artworks is critical before proceeding with conservation treatment. When Purifoy originally created the sculptures, he

meant for them to interact with the natural landscape and undergo natural wear (Figure 4). However, at the same time he did not mean for the sculptures to be temporary. One way this is evident is the fact that he approved and was involved in the creation of the NPF whose mission includes site preservation.[10] Given this, what level of wear is acceptable and when should either stabilization or restoration treatments take place? After research and interviews, the project conservators recommended that most surface weathering be allowed to continue naturally. This could take the form of weathering of wood surfaces, metallic surface corrosion, paint loss, etc. According to Purifoy's friend and colleague, Sue Welsh, Purifoy described some of his own repairs as 'stabilization'.[11] Given this, incorporating the value of

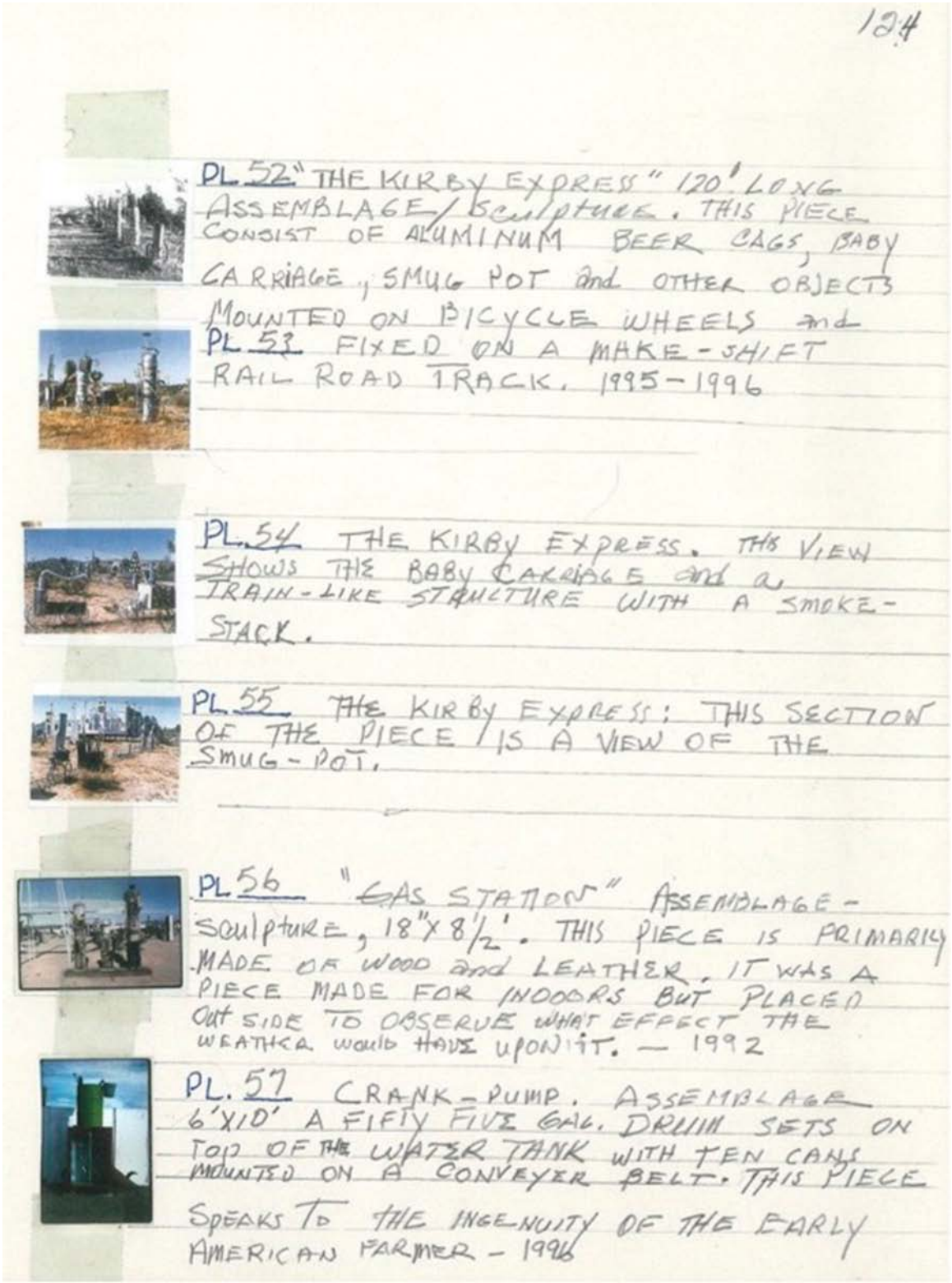


Figure 4. Regarding his work *Gas Station*, Purifoy wrote in 1992 (Purifoy 2015, 124): 'This piece is primarily made of wood and leather. It was a piece made for indoors but placed outside to observe what effect the weather would have upon it.'

stabilization to maintain structural integrity seems appropriate.

More comprehensive restoration treatments are deemed appropriate for the most vulnerable materials that disintegrate so quickly that their absence negatively affects visitors' interactions with the artworks (i.e. textiles, paper, and some plastics). The textiles in particular already have a history of being replaced by site caretakers as seen in the *Three Witches* sculpture (Figure 5). Therefore, a regular renewal schedule should be created for these sensitive materials where they can be replaced. This replacement process should be documented extensively and executed using historical evidence as an aesthetic guide. Recycled materials should be used as often as possible while adhering to Purifoy's aesthetic.

One could view a simple Google image search of images taken by visitors of the sculptures at the Outdoor Museum as an informal survey of what the community sees and values from their experience. These images generally always showcase two key themes: the landscape, and weathering of the material from that landscape. When the works are restored to 'new' the effect can be jarring. Furthermore, wholesale repainting is for all intents and purposes irreversible, obliterates any vestige of the artist's hand, and strays from Purifoy's vision of natural weathering.

Repainting of sculptures has been done in the past (Figure 6) but should now be given significant thought and only be done in extreme cases. Color choice, material choice, layering, the use of conservation barriers, surface preparation, and application should all be considered. The appearance of paint with natural weathering is acceptable and even welcomed, thereby making repainting an uncommon activity going forward.



Figure 6. Noah Purifoy, *The* White *House* 1990–93. Courtesy of Noah Purifoy Foundation ©2023. Top: Undated historical image in NPF records. Bottom: presumed to be after a November 2013 restoration campaign which 'Stabilized elements of interior, added four piers below floor. Repaint.'.



Figure 5. Noah Nurefoy, *Three Witches* 1994. Left: historic, undated image from NPF records. Courtesy of Noah Purifoy Foundation ©2023. Center: presumed to be after a November 2020 restoration which NPF records describe as 'Layer of burlap attached, new guy wires.' Right: in May 2023.

Reuse discussion

Purifoy believed deeply in assemblage, using found, discarded, and recycled materials in his work. As the creative process is at the crux of Purifoy's ethos, attempts should be made to integrate his beliefs into the conservation process as well. To accomplish this, the project conservators recommended that reused materials be incorporated into any future conservation treatment. This would include the incorporation of materials that are currently in the *palette* area of the site. This is a designated area at the Outdoor Museum where Purifoy himself kept found materials and allowed them to weather. If the purchase of new materials is unavoidable during conservation treatment, then those materials too can be left for a time in the *palette* area to facilitate aging. Calls for community donations to the *palette* should be encouraged and would be in line with Purifoy's own practices. With this model, materials similar to the original materials may need to be incorporated into the conservation process. Given this, it makes documentation and discrete labeling of any added materials that much more important in order to be able to distinguish between original *vs* added material in the future. The use of conservation 'barrier layers' can also facilitate differentiation. Although we do not suspect that Purifoy's assemblage philosophy was driven by environmentalism, the planned efforts to reuse found and donated materials has the added benefit of being environmentally friendly and limiting waste.

Natural landscape

Purifoy intentionally did not significantly manipulate the site while he lived in Joshua Tree, and must have appreciated the juxtaposition of his artworks with the surrounding landscape.[12] The desert views surrounding the artworks are certainly striking. A variety of desert plants can be seen at the site (shrubs, succulents, cacti, grasses, trees, and flowers). Although the vegetation is sparsely distributed, some of it is in close proximity or touching artworks. In order to continue this relationship between the landscape and the artworks, the conservators recommended continued minimal manipulation of the vegetation. The only exception would be to slightly trim branches directly touching artworks for fire safety and pest management reasons.

Council of Black artists

The context that informed Purifoy's practice and continues to inform his extant work is deeply intertwined with his commitment to Black and underserved communities. His philosophies were informed by his experiences as a Black man and by his social work background (Choi 2016). NPF has already been involved in community engagement through their UAI. In alignment with Purifoy's ethics and evolving contemporary conservation ethics, the conservators recommended that NPF convene an advisory council of Black artists whose art practices are influenced by Purifoy to help guide long-term preservation planning in conversation with conservators and the Board. This idea is still under consideration by NPF. Such a Council of Black artists would incorporate the public and community stakeholder voice in an informed and fruitful manner.

Conservation team

Aligning with Purifoy's ethics, the conservation/preservation team will strive to include representation from Black, Indigenous and People of Color (BIPOC) preservation professionals and community members to ensure perspectives that are rooted in the marginalized experience. The team will have strong representation from conservators whose lived experiences can help them to better understand Purifoy's experience. This is not an easy task given the lack of diversity in American cultural heritage conservation (AIC/FAIC 2022). Despite this reality, the team is committed to diversity and an expansive view of conservation at the Outdoor Museum that prioritizes the preservation of Purifoy's creative process and incorporates community engagement. This is innovative as it is uncommon to consider the lived experiences of the conservation professionals involved in a project and not just their skills as practitioners, scientists, or scholars.

Community engagement as an integral element of preservation

Future stages of the conservation project will build upon the NPF's existing community engagement framework to hand down knowledge to community members and emerging artists. In addition to Purifoy's commitment to Los Angeles artists and the predominantly BIPOC Watts community, he was also dedicated to his Joshua Tree community, making it reasonable to involve locals from both of these locations in the conservation or recyclable collection process. The team also plans to involve representatives from local Indigenous groups into the process, as they were Purifoy's neighbors, and the traditional caretakers of the surrounding landscape that continues to be so important to the life of the artworks.

Who ultimately decides the approach taken?

Ultimately, the preservation approach taken will be decided by the NPF Board members. One shift

currently underway from previous practice is that all future conservation treatments will be agreed upon by the Board before they commence. These decisions will be informed by predetermined criteria regarding patina, reuse, and landscape interaction.

Phases II and III planning

Phases II and II will invite community participation to further document the sculptures, begin structural assessments of the outdoor works, and to begin hands-on conservation treatment in a communal setting. Interviews with Purifoy's friends and colleagues are continuing in order to further uncover artist intent and to evolve the project's ethical framework.

Preliminary efforts to connect with local Indigenous tribes began during Phase 1 by leveraging a pre-existing relationship between Your Neighborhood Museum and the Malki Museum,[13] which serves the numerous local Southern California tribes, and operates the Malki Ballena Press, an academic outlet for publishing current Native American research. An outreach avenue was established to reach intertribal audiences for participants and partners through their museum network.

During subsequent phases we will continue building on information and assessments gathered in Phase 1. The conservation team, with a structural engineer and mount-fabricator, will review select outdoor sculptures that have pre-eminent structural stability and safety concerns. Conservators will perform an in-person assessment of the physical Noah Purifoy Archives. The preservation of the archives is critical not only to ensure Purifoy's legacy, but also because they are an original resource that can help us understand the artist's creative process and original constructions. Finally, there will be a condition survey of the 115 distinctly catalogued outdoor sculptures by conservators, and a team comprised of conservation students and community members. In addition to assessment work, five priority pieces determined by the assessment to have greatest structural instabilities and art historical importance will be treated by UCLA students under guidance of the lead conservators. This work can potentially begin at the new conservation facility being built on the Outdoor Museum site with Mellon funding. Ahead of site work, dataloggers will be purchased and introduced into all buildings on the site. Based on the results of Phase II, direct interventions that ensure the stability of the outdoor sculptures through mount fabrication and stabilization treatment are likely to be incorporated into Phase III. In the end, a tailored and clear conservation values document and overall preservation plan will be created.

Conclusions

In 2023, Phase 1 of the Noah Purifoy Conservation Project was completed by a racially diverse team of conservators and students working in collaboration with the NPF Board. An overall general assessment of the site has been completed along with more detailed examinations of the 41 indoor sculptures. Amidst the physical challenges of addressing found material assemblage in a challenging landscape, the project also required bringing stakeholders and knowledge bearers into conversation to determine an appropriate 'patina' of weathering for the works. Following Purifoy's lead, natural surface weathering of sculptures will be allowed to continue. Instances where stabilization treatments, repainting, or the replacement of materials will be utilized will be clearly defined. Adhering as close as possible to Purifoy's philosophy, materials will be reused and recycled. Community donations will be welcomed. This all has the added benefit of promoting environmental sustainability of conservation activities on site. These artworks are not meant to be static as change is just part of the ongoing conversation among Purifoy, nature, and material. However, instituting conservation documentation procedures will help the team track these natural changes and make informed preservation decisions. Most important to this project are the incorporation of Purifoy's ethics fused with evolving modern conservation ethics and social justice. Promoting diverse conservation teams and connections to Black stakeholders will ultimately help ensure that the Outdoor Museum remains relevant and promotes cultural sustainability.

Notes

1. The Outdoor Museum is located in the area of the San Manuel Band of Mission Indians. They use the name *Yuhaviatam*, or 'people of the pines'. In 1891 the USA established the San Manuel Reservation for the Serrano people, which took its name to honor Chief Santos Manuel.
2. *Outliers and American Vanguard Art*: National Gallery of Art, Washington, D.C. 2018, *Now Dig This!: Art and Black Los Angeles 1960–1980*: Hammer Museum, Los Angeles 2011–12; MOMA PS1, Long Island City 2012–13; Williams College Museum of Art, Williamstown 2013, *Soul of a Nation: Art in the Age of Black Power*: Tate Modern, London, UK 2017; Crystal Bridges Museum of American Art, Bentonville 2018; Brooklyn Museum, New York 2018–19; Broad Museum, Los Angeles 2019; Fine Arts Museums of San Francisco, de Young, San Francisco 2019–2020.
3. *Made in* LA 2023: *Acts of Living*, Hammer Museum, Los Angeles 2023.
4. This addresses the critical lack of arts curriculum centered on artists of color who use innovative practices to address issues faced in their communities. These students face not only housing and food insecurities, but during and post-pandemic, were and remain

bereft of arts education and engagement. Like Purifoy they continue to face racial and economic hardships. The UAI meets California's Department of Education, Visual and Performing Arts Standards and utilizes visual thinking strategies. The Foundation offers this curriculum free of charge to educators wishing to incorporate these ideas into their programs.

5. For the For 41 indoor artworks: 5 items scored 5 (major structural damage); 10 items scored 4 (minor structural damage); 9 items scored 3 (significant rehousing/storage improvement needed); 24 items scored 2 (aesthetic issues only); and 0 items scored 1 (no treatment or major rehousing necessary).
6. Photogrammetry is a process for creating 3D models and large 2D images by stitching together overlapping photographs. Accurate 3D models can be generated due to the parallax effect. Handheld cameras are often used to generate 3D photogrammetric models of small objects and sculptures, and drone photogrammetry is often used to generate topographic data and detailed maps over large areas. However, we used an innovative approach by using drone photogrammetry to 3D model many sculptures in a short period of time. This approach was made possible by the outdoor nature of the Noah Purifoy museum and its unique spatial characteristics as a cultural landscape.
7. The degree to which the site is susceptible to disasters was considered. There is seismic risk: the nearby San Andreas Fault is capable of a catastrophic earthquake. Wildfire danger is real and serious. Regional wildfires may also contribute to periods of poor air quality. Power cuts are possible due to fire damage to the power infrastructure, preemptive power cuts due to fire risk, or power cuts in an overtaxed power grid situation (extreme heat).
8. Sue Welsh, Interviewed by Anya Dani, 28 June 2023 at Welsh's home in Los Angeles, California. Uncatalogued, NPF.
9. *Noah Purifoy*, interview by Karen Anne Mason, transcript. African American Artists of Los Angeles, Oral History Program, University of California, Los Angeles, Charles E. Young Research Library, Department of Special Collections, UCLA.
10. See note 8.
11. See note 8.
12. See note 8.
13. Started in 1964, the Malki museum is an intertribal museum located on the Morongo Reservation. The Malki Museum was founded by Jane K. Penn (Wanikik Cahuilla), and Katherine Siva Saubel (Cahuilla), and a group of dedicated community members.

Acknowledgements

The authors would like to thank the Andrew W. Mellon Foundation for their generous support of this project. We would also like to thank the NPF Board of Trustees. Special thanks to John Baker and Chris Ogata for their participation in the conservation project and their dedication to the care of the Outdoor Museum. Thanks to Sue Welsh, former NPF Board trustee, for providing invaluable Purifoy information. Thanks to the UCLA/Getty conservation students involved in this project: Saiful Bakhri, Taylor Brehm, Chongwen Liu, Rachel Moore, Moupi Mukhopadhyay, Makayla Rawlins, and Kathryn Peneyra. Thanks to Deidre Brin (Digital Archaeology Lab at the Cotsen Institute of Archaeology) and to UCLA Library.

Disclosure statement

Joe Lewis and Jill Moniz are members of the Noah Purifoy Foundation Board of Trustees, and Joe Lewis is the Board President. Anya Dani, Robin Meyer-Lorey, and Jennifer Klm (*via* Your Neighborhood Museum) were contracted to participate in this project and received financial compensation for select activities using Mellon Foundation grant funds. A significant portion of Anya Dani's involvement in this project was funded through her position in the UCLA/Getty Interdepartmental Program in the Conservation of Cultural Heritage.

Funding

This work was supported by the Andrew W. Mellon Foundation under the Arts and Culture Grants Program.

Data availability statement

The UCLA Dataverse, maintained and managed by the Data Science Center in the UCLA Library, will serve as the long-term preservation repository for the data generated by this project. The data has not yet been formatted and uploaded to the Dataverse.

References

AAM. 2023. *Collections Management Policy*, American Alliance of Museums. Accessed July 10, 2023. https://www.aam-us.org/programs/ethics-standards-and-professional-practices/collections-management-policy/.

AIC/FAIC. 2022. *AIC/FAIC Conservation Compensation Research Overview Report*, April 2022. Accessed July 10, 2023. https://www.culturalheritage.org/docs/default-source/publications/reports/survey-reports/2022-faic-compensation-survey.pdf?sfvrsn = 75c01720_5.

Choi, C. H. 2016. *Noah Purifoy." Now Dig This! Art in Black Los Angeles, 1960–1980. Digital Archive*. Los Angeles: Hammer Museum. Accessed May 10, 2023. https://hammer.ucla.edu/now-dig-this/artists/noah-purifoy.

Dardes, K., E. C. Avrami, and M. De la Torre, eds. 1999. *The Conservation Assessment: A Proposed Model for Evaluating Museum Environmental Management Needs, version 9/99*. Los Angeles: Getty Conservation Institute.

FAIC. 2023. *Collections Assessment for Preservation: Assessor Handbook.* https://www.culturalheritage.org/docs/default-source/resources/cap/collections-assessment-program/accessors-handbook/cap-assessor-handbook-2022.pdf?sfvrsn = db945284_37.

Fonseca, R., and H. Li. 2023. "How Bad was Hilary? Mountain and Desert Communities Got the Worst of the Tropical Storm". *Los Angeles Times*, August 22, 2023. https://www.latimes.com/california/newsletter/2023-08-22/tropical-storm-hilary-aftermath-essential-california.

Hopkins, F. M., V. Carranza, H. Ajami, J. E. Allison, et al. 2018. *Inland Deserts Region Report*. California's Fourth Climate Change Assessment, California Energy Commission; State of California Governor's Office of Planning and Research; California Natural Resources Agency. Publication Report Number: SUM-CCCA4-2018-008.

InciWeb. 2023. *York Fire: Incident Overview*. Accessed December 14, 2023. https://inciweb.wildfire.gov/incident-information/camnp-2023-york-fire.

Patkus, B. 2003. *Assessing Preservation Needs: A Self-Survey Guide*. Andover, MA: Northeast Document Conservation Center.

Purifoy, N. 1999. *College Art Association Annual Conference Distinguished Artist Interview. Personal communication to Joe Lewis*. Los Angeles: College Art Association.

Purifoy, N. 2015. *Noah Purifoy: High Desert Assemblage Artist*. Göttingen, Germany: Steidl Publishers.

San Manuel Band of Mission Indians. 2023. *History*. Accessed December 15, 2023. https://sanmanuel-nsn.gov/culture/history.

Sirmans, F., and Y. Lipschutz. 2015. *Noah Purifoy: Junk Dada*. Los Angeles: Los Angeles County Museum of Art.

Smith, R. C. 2016. "Art is a Confrontation With a 'Me' That Needs Improving: The Beginnings of the Noah Purifoy Foundation". *VoCA Journal*, Fall 13, 2016, https://journal.voca.network/art-is-a-confrontation-with-a-me-that-needs-improving/.

Solis, N., and G. Toohey. 2023. "'I Think I'll be Able to Get Out Today': Residents Trapped by Tropical Storm Hilary Begin to Dig Out". *Los Angeles Times*, August 22, 2023. https://www.latimes.com/california/story/2023-08-22/flooding-woes-after-tropical-storm-hilary.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S55–S62
https://doi.org/10.1080/00393630.2024.2339714

ORIGINAL RESEARCH OR TREATMENT PAPER

OPEN ACCESS Check for updates

Materials Analysis of Two Nineteenth-century Brazilian Polychrome Sculptures to Reveal Their History and Significance

Análisis de Materiales de dos Esculturas Policromadas Brasileñas del Siglo XIX para Revelar su Historia y Significado

Dâmia Carina Dias Do Carmo [1], Marcus Vinicius de Oliveira Andrade[2], Marcelo Carvalho Lasmar[2], Caio Tadao Joko[3], Karen Santos Silva[3], Karla Balzuweit[4,5], Marcelo Azevedo Maffra[6], Alessandra Rosado[1] and Luiz Antonio Cruz Souza[1]

[1]Center for Conservation and Restoration of Cultural Heritage, School of Fine Arts, Federal University of Minas Gerais, Belo Horizonte, Brazil; [2]Brazilian Federal Police in Minas Gerais, Belo Horizonte, Brazil; [3]National Institute of Criminalistics, Brazilian Federal Police, Brasilia, Brazil; [4]Physics Department, ICEx, Federal University of Minas Gerais, Belo Horizonte, Brazil; [5]Microscopy Center, Federal University of Minas Gerais, Belo Horizonte, Brazil; [6]State of Minas Gerais Prosecutor's Office, Belo Horizonte, Brazil

ABSTRACT

A pilot project is presented, in which two metal sculptures involved in a real case managed by the Brazilian Federal Police underwent microscopical examination and analysis by forensic scientists, including Raman and XRF spectroscopies and SEM-EDX, made possibly by damage sustained when they were vandalized. The findings are interpreted from the points of view of both materials history and material culture. Both sculptures had previously been described as patinated bronze but were found to have been cast in zinc, a popular material for sculpture in the nineteenth century, with their original patination later removed. The investigation showed that the bronze-colored polychromy then applied consisted of materials used by Brazilian Concrete artists of the 1950s and 1960s, and could be related to the re-siting of the capital of Brazil from Rio de Janeiro to Brasilia in the same period.

Se presenta un proyecto piloto en el que dos esculturas de metal involucradas en un caso real gestionado por la Policía Federal de Brasil fueron sometidas a exámenes y análisis microscópicos por parte de científicos forenses, incluidas espectroscopias Raman, XRF y SEM-EDX, posiblemente debido a los daños sufridos durante un incidente de vandalismo. Los datos se interpretan desde el punto de vista tanto de la historia de los materiales como de la cultura material. Ambas esculturas habían sido descritas anteriormente como bronce patinado, pero se descubrió que habían sido fundidas en zinc, un material popular para la escultura en el siglo XIX. Su pátina original fue removida posteriormente. La investigación demostró que la policromía en color bronce aplicada entonces estaba compuesta de materiales utilizados por artistas brasileños de Arte Concreto de las décadas de 1950 y 1960, y podría estar relacionada con el traslado de la capital de Brasil de Río de Janeiro a Brasilia en el mismo período.

ARTICLE HISTORY
Received October 2023
Accepted March 2024

KEYWORDS
Zinc sculpture; concrete art; materials analysis; interpretation

Escultura de zinc; Arte Concreto; análisis de materiales; interpretación

Introduction and theoretical basis

Cultural heritage conservation is very complex and diverse, and is deeply rooted in an equally broad and intricate social environment (Avrami, Mason, and De la Torre 2000). The professionals involved essentially form a multidisciplinary group whose work should be complementary. They come from fields such as material sciences, humanities, social sciences, arts and many others that come together – or should – in a multidisciplinary undertaking that ought to form a harmonious and complete whole (Avrami, Mason, and De la Torre 2000).

Similarly, forensic scientists deploy their analytical skills to reveal the implications of the evidence remaining after a crime. When this concept is used in conservation science, there is an explosion of possibilities for broadening social and cultural knowledge of a particular object or collection through materials analysis. The more we know about our cultural legacy, the stronger our sense of belonging becomes and the more the community will be committed to protecting it (Arizpe 2000).

In many ways, forensic science and heritage science are very similar. They usually require the application of methods from different disciplines in order to carry out studies on history, provenance, authorship or authenticity (Galli and Bonizzoni 2014). The main challenges

CONTACT Dâmia Carina Dias Do Carmo damiacarinadc@gmail.com; damiacarina@hotmail.com Center for Conservation and Restoration of Cultural Heritage, School of Fine Arts, Federal University of Minas Gerais, Presidente Antônio Carlos Avenue, 6627 – Pampulha, Belo Horizonte, Minas Gerais 31270–901, Brazil

© 2024 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group
This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (http://creativecommons.org/licenses/by-nc-nd/4.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

of heritage conservation are the physical condition of the object itself; the records held by the relevant institution or group of institutions; and the cultural significance and social values embodied in the object. However, research efforts in this field are basically concentrated in the first area, generating a great deal of knowledge about materials, but without a connection to other aspects. In other words, often a lot is studied about the object, but almost nothing about its context (Avrami, Mason, and De la Torre 2000; Fredheim and Khalaf 2016; Lowenthal 2000; Michalski 2018).

Going far beyond the physical and chemical characteristics of the object, we should delve a little deeper to understand the object itself, and its value. In their research into the conservation of cultural heritage on paper, Almada and Zervos (2021) state that the methodological processes of conservation of cultural heritage necessarily cause changes in what they call the three layers of the object: the message carried by the support, whether textual or visual, inscribed or printed; the shape and material configuration of the object, defined by the chosen technologies and materials; and the physical and chemical structure of the object and its constituents. If we (deliberately) focus on the third layer, it is not uncommon for physical elements that have been added over time to be seen as interfering with or damaging the object. Dust, contaminants, dirt and handling marks are, in a straightforward way of thinking, components to be eliminated in a treatment process with the aim of recovering the original appearance. On the other hand, in the thinking of a forensic professional, these can become witnesses to the history of the object, its use, the conditions in which it was stored, whose hands it passed through, and which hands were responsible for its construction or alteration. All this information reveals how the object has been viewed over the years and, consequently, the value attributed to it in different historical periods (Ricca et al. 2021).

Conservation practice has become a field safeguarded by technically competent professionals who are so committed to their mission that it has distanced itself from the public and, of course, from the true meaning of the object. The community itself, whose social foundations are largely built on its cultural legacy, is hardly an active player in this process (Avrami, Mason, and De la Torre 2000; Lowenthal 2000).

If what is embodied in the object reflects its cultural value and how this has changed over the years, this tells us a lot about our own society and its transformations. The contribution of the forensic and materials sciences in elucidating this goes far beyond simply physically characterizing the object to support conservation processes. Their use, in all its technical potential and aggregation of disciplines, becomes crucial to uncovering processes of cultural transformation, values and principles. Hidden stories are unveiled if we are willing to view objects through the lens of wider knowledge which is readily accessible, albeit fragmented across various fields. However, when applied to cultural heritage, it becomes a pivotal axis for public appreciation and cultural understanding.

In the light of what is essential to heritage science, transdisciplinarity, this work aims to discuss the potential contribution of forensic science techniques to a better understanding of the physical–chemical nature and social context of cultural heritage, in close collaboration with conservation professionals, by means of a case study. Bypassing the traditional technical studies that are so widespread in conservation interventions to built heritage, it sets out to present reflections and questions from the viewpoint of materials history. The fundamental points for the authors are: how forensic disciplines can contribute to adding cultural value to a given object as part of the process of protecting cultural heritage; what kind of information can be revealed through the use of forensic science together with materials science and conservation; and how this conjunction could be facilitated so that the work of the professionals involved in the process is made easier, enhancing new discoveries and promoting physical, intellectual, and community access to cultural heritage.

The aim was to identify what makes the contributions of forensic science most relevant, and how to facilitate this process. To this end, in addition to the theoretical framework, this work makes use of a pilot project in which two metal sculptures were examined in a partnership between the UFMG Conservation and Restoration Center (CECOR) and the Brazilian Federal Police through its forensic corps. As the sculptures are still involved in an ongoing legal case, this paper will not reveal any details that would identify them. By using a real case, which is the result of initial collaborative work between the institutions involved and part of an even larger project in which the aim is to gain significant knowledge of Brazilian cultural heritage and increase the efficiency of its protection processes, this study highlights the complementarity of the fields of conservation science and forensic science.

Materials and methods

The analyses were carried out to verify the morphology and composition of two metal sculptures damaged as a result of crime perpetrated against public property. These pieces required additional investigation to determine their constituent material, and to provide data for valuation reports. A brief description of the sculptures is shown in Table 1.

Examination and analysis

In order to characterize the material and assess the damage caused by vandals, on-site examinations were

Table 1. Basic information for the sculptures S1 and S2.

Sculpture ID number	Description
S1	Vandalized polychrome metal sculpture, of known authorship, dated c.1880, 65 × 32 × 20 cm (H x W x D)
S2	Vandalized polychrome metal sculpture, no attribution, dated c.1904, 80 × 32 × 25 cm (H x W x D)

conducted, and microsamples were collected for solubility tests, microchemical tests, and instrumental analysis. Macroscopic and microscopic observation was then carried out under both natural and artificial illumination.

Microsamples were removed using a scalpel with the aim of sampling all layers of the polychromy from both sculptures (Figure 1). Cross-sections were prepared for observation under a optical microscope (Olympus BX50) using polarized light, scanning electron microscopy with energy-dispersive X-ray (SEM-EDX) analysis, and Raman spectroscopy. SEM-EDX was conducted using a Hitachi TM4000Plus tabletop SEM with an acceleration voltage of 10 kV, at low pressure in air, using a backscattered electron (BSE) detector and Oxford AZtecOne software. Raman spectroscopy coupled to an optical microscope was performed using a Horiba XPLORA equipped with a 785 nm laser, 10x and 100x objectives, and a spectral range of 100 cm^{-1} to 3500 cm^{-1}. XRF using a portable XRF Spectrometer (Thermo Scientific Niton XL3t 950 model, with Thermo Scientific NDT and Thermo Scientific NDTr software) was used the analyze the surface.

Solubility tests were carried out by placing microfragments of the ground layer in contact with deionized water, 1 M sodium hydroxide, xylene, ethanol, and acetone, observed under a stereoscopic microscope at 40× magnification.

Results and discussion

Part of sculpture S1 detached from the rest of the piece by the vandals is shown in Figure 2. The damage varied from small isolated dents to complete structural fragmentation**.** It can be seen with the naked eye that the main structural material of the work has different characteristics from that of the exterior. Table 2 shows the XRF results for S1 and their interpretation. XRF analysis showed a high zinc content (greater than 95%) in the alloy. Normally, zinc sculptures have a zinc content of 95–98%, while other elements such as lead or iron, naturally present in zinc ore, are minority elements (Grissom 1994).

Figure 3 shows damaged parts of the S2 sculpture and the results obtained from XRF analysis can be seen in Table 3. S1 and S2 are sculptures both made from metal composed mostly of zinc, known as spelter. Sculptures made from zinc became very popular, especially in the second half of the nineteenth century, and were commonly used to replace other materials such as bronze, largely due to their lower cost and greater ease of casting, despite zinc being

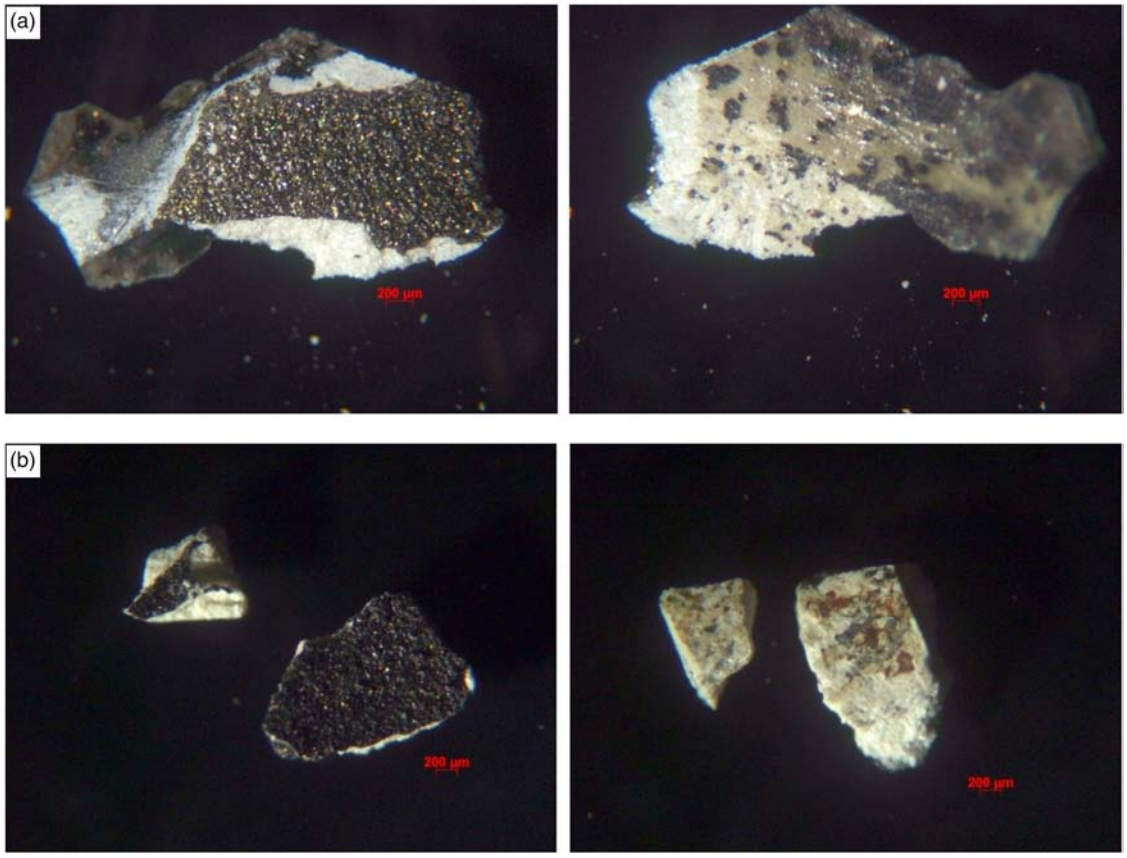


Figure 1. (a) Fragment of the polychromy on S1, front (left) and back (right) at 45x. (b) the same for S2, at 35x.



Figure 2. Detached piece of sculpture S1, with areas for XRF analysis.

Table 2. XRF results for S1, at the areas shown in Figure 2.

Region analyzed	Analysis	Material (apparent)	Alloy (indicative)
Single piece – broken foot (X1)	Internal alloy without coating	Gray metal without coating	Zinc alloy (spelter)
Single piece – broken foot (X2)	Unaltered surface with coating	Metal with dark coating	Zinc alloy (spelter) with copper-containing coating

comparatively more fragile and friable than bronze. Thus, this type of work, quite common between 1850 and the beginning of the twentieth century, is an important cultural marker of that period (Smithsonian Museum Conservation Institute 2023).

Sculptures made from zinc show fracturing characteristic of friable material, which differs from the typical cracks in bronze alloys, as shown in Figures 2 and 3. Corrosion products, if present, are whitish crystals, and the fracture acquires a shiny appearance with very noticeable granulation. Compared to bronze alloy sculptures, they are easier to break (Grissom 1994).

Sculptures S1 and S2 have a similar surface appearance. Neither has typical patina for the second half of the nineteenth century. The surface is multilayered, consisting of a transparent bottom layer, a white intermediate layer and a top layer the color of patinated bronze. The micrographs in Figure 4a,b show the coating. Layer 01 refers to the bronze-colored paint; layer 02, colored white, is the ground layer; and layer 03 (not in the image) is compatible to a primer, the contact layer with the metallic surface. The SEM images in Figure 4c,d show the granules and elongated structures that make up the white ground layer. Raman microspectroscopy carried out on the ground layer revealed titanium dioxide (rutile form) and carbonates. Polarized light (Figure 4a) indicated the presence of elongated structures in the same layer, and in Figure 4d obtained by SEM imaging, this has laminar morphology. These structures indicate the presence of silicates. Solubility tests on fragments of the ground layer suggested the presence of a nonpolar resin, due to its partial solubility in xylene and acetone and its insolubility in water. SEM-EDX on fragments from site X2 revealed that the ground layer is mostly made up of silicon, magnesium, and titanium (Figure 5). Further analysis revealed that for both sculptures the ground layers have microstructures (in the form of granules, microspheres and sheets, respectively) made up of



Figure 3. Detached parts of sculpture S2, with areas for XRF analysis.

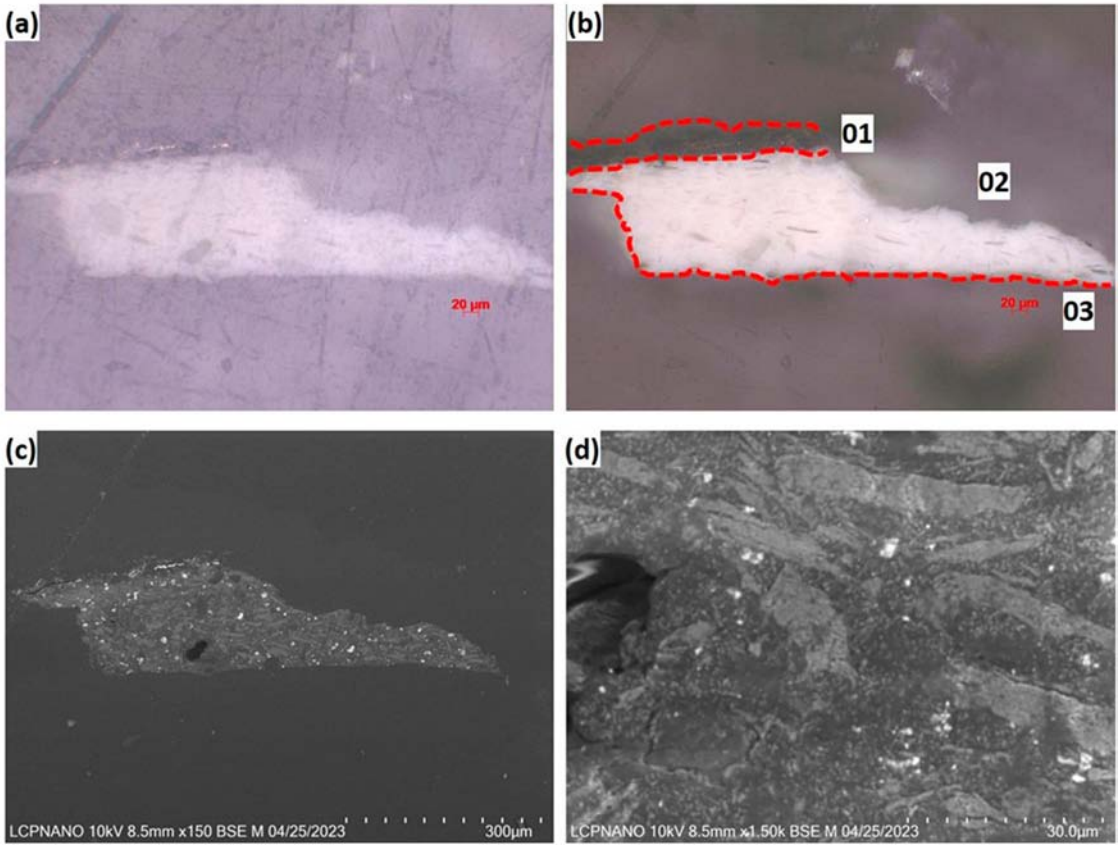


Figure 4. Cross-section from S1 revealing the multi-layered coating, in (a) polarized light, (b) brightfield, (c) SEM-BSE at 150x, (d) SEM-BSE at 1500x.

barium sulfate, titanium dioxide and magnesium silicate. In addition, the top layer consists of elongated structures made of copper (Figure 6).

Souza et al. (2021) have studied the materials of Brazilian Concrete Art from the 1950s and 1960s. One of the works analyzed is shown in Figure 7. There are

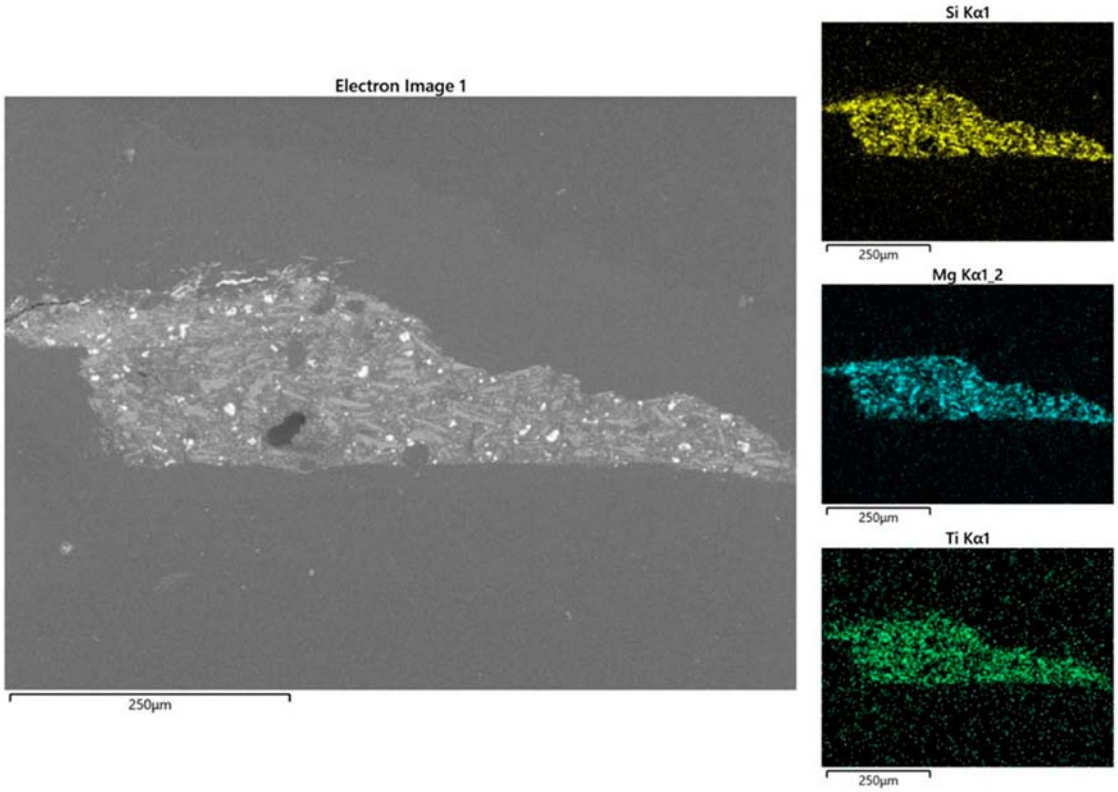


Figure 5. SEM-EDX mapping of the cross-section from S1, showing the distribution of silicon, magnesium and titanium.

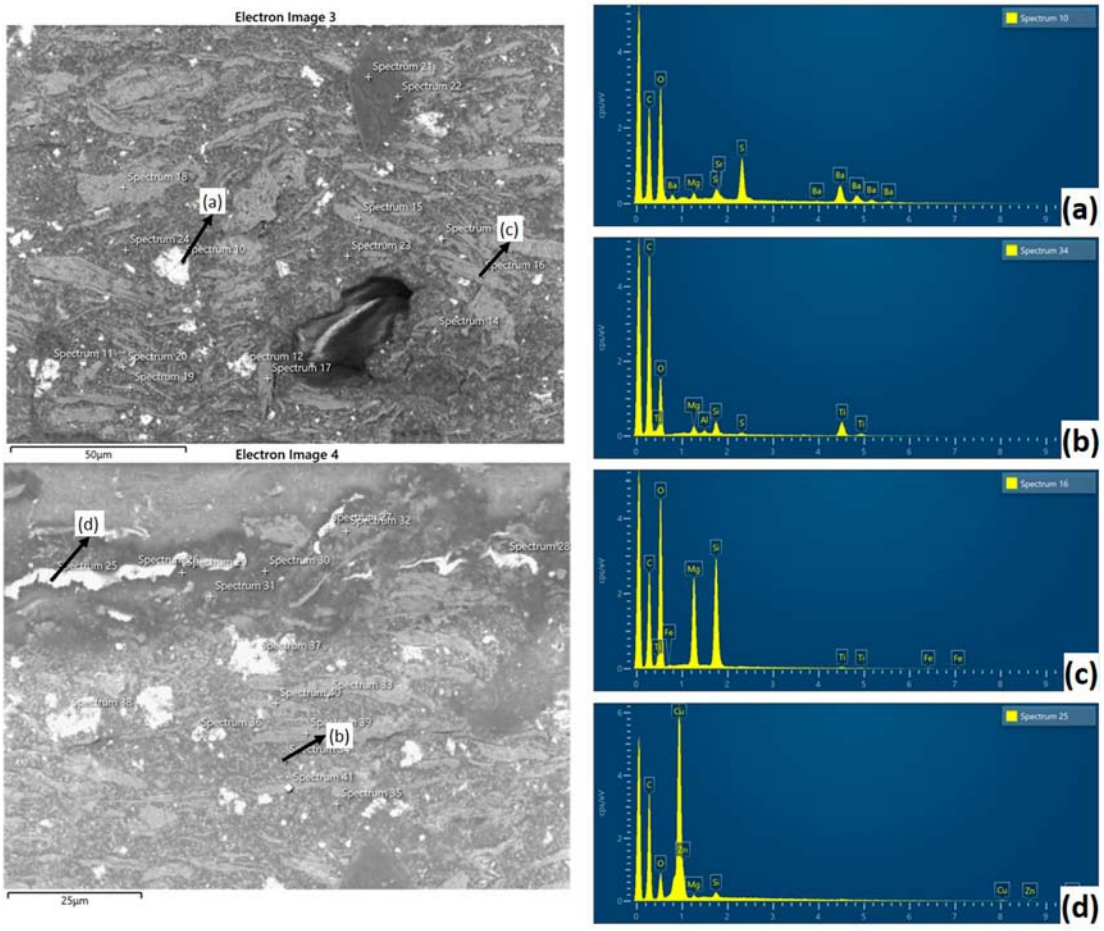


Figure 6. SEM-BSE detail of the ground layer of the cross-section from S1, with EDX spot analyses of (a) a granule, (b) a microsphere, (c) and (d) lamellae.

Table 3. XRF results for S2, at the areas shown in Figure 3.

Region analyzed	Analysis	Material (apparent)	Alloy (indicative)
Broken right arm – inside (X3)	Unaltered surface with coating	Dark coated metal	Zinc alloy (spelter)with coating
Broken right arm – internal part (X4)	Filling compound	Gray putty	Filling compound
Broken neck – part with internal metal (X5)	Unaltered internal alloy without coating	Uncoated silver metal	Zinc alloy (spelter)
Back of platform	Altered alloy without coating	Matte copper metal with alterations	Zinc alloy (spelter)with copper

similarities with the samples taken from the sculptures S1 and S2, such as the presence of magnesium silicate.

These results suggest that the two sculptures were repainted in the 1950s–1960s since the constituent elements of the ground layer are characteristic markers of this period. The original patina was removed in order to apply the current coating, bringing about a significant change in appearance. It was confirmed by the curator responsible for the sculpture collection that there was indeed an intervention carried out in the second half of the 1950s, for the transfer of the capital of the Brazilian Republic from Rio de Janeiro to Brasilia.

Conclusions

Sculptures S1 and S2, whose appearance imitated bronze, consist of an alloy predominantly composed of zinc, contrary to the records of the institution housing them, where they were described as patinated bronze. Polychromy was identified, contradicting expectations for works in zinc from the mid-nineteenth century, which are typically patinated. Microscopic investigation of the polychromy revealed the presence of a white ground consisting of particles with a lamellar structure. These particularly elongated particles are considered to be an important maker for Brazilian Concrete Art of the 1950s and 1960s. Solubility tests indicated the presence of a nonpolar resin which is also consistent with Brazilian industrial paint formulations in the 1960s, while Raman spectroscopy detected rutile titanium dioxide, used internationally at the same date, but not produced until the early twentieth century. SEM-EDX demonstrated that the ground layer is composed of barium sulfate granules, titanium

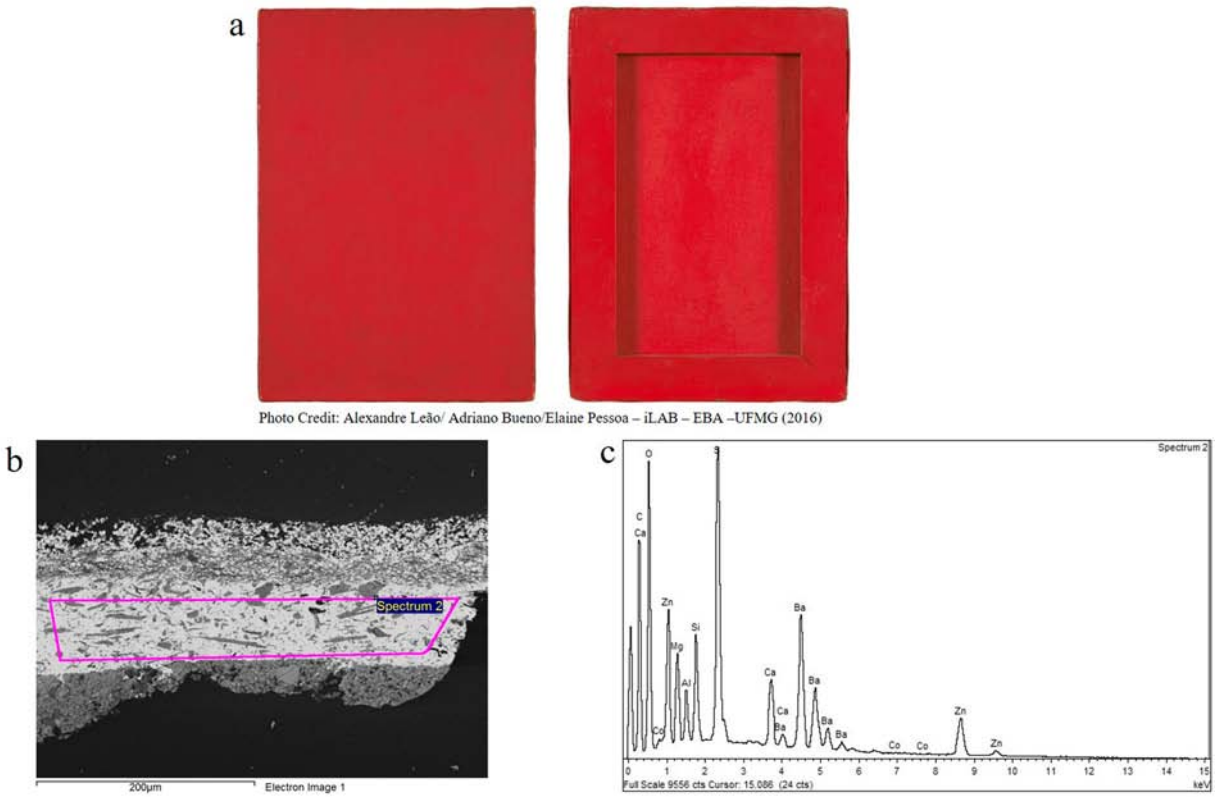


Figure 7. (a) Hélio Oiticica (Brazilian, 1937–1980), *Transdimensional* 1959, front (left) and reverse (right), polyvinyl acetate on canvas, 270 × 190 mm. Tuiuiu Collection. Rio de Janeiro. Image: Alexandre Leão/ Adriana Bueno/ Elaine Pessoa – iLAB – EBA – UFMG 2016. (b) SEM image of cross-section of its paint. (c) SEM-EDX spectrum of a lower layer of this paint.

dioxide microspheres, and magnesium silicate lamellae.

The polychromy of the sculptures is characteristic of materials and techniques employed in mid-twentieth century Brazil during the Concrete Art movement (Figure 7), suggesting a potential intervention in the late 1950s which was later confirmed from documentary evidence.

From a forensic point of view, the pieces have lost value both because they were cast in zinc rather than bronze, and because of the reworking of their surfaces, which has changed their original appearance. However, from the point of view of material culture, the reworking was due to a very significant moment in Brazilian history: the move of the national capital from Rio de Janeiro to Brasília at the end of the 1950s.

Forensic science has a lot to contribute to the study of cultural heritage, in investigating contexts and unraveling stories revealed by traces of material. The goal is state-of-the-art technology and resource sharing. The path of collaborative networks, integrated databases and common protocols seems obvious, especially in the context of global exchange. But it requires a change in the current way of working in Latin America, to preserve our cultural heritage.

Acknowledgements

Thanks for financial support from Minas Gerais Forensic Sciences Network, project number FAPEMIG RED-00042/16; Coordination for the Improvement of Higher Education Personnel of Brazilian Ministry of Education (CAPES-MEC); Brazilian National Council for Scientific and Technological Development (CNPQ); and IN2PAST.BR (Brazilian National Institute for Research in Natural History, Cultural Heritage, Arts, Sustainability and Territory) supported by CNPQ. The authors are also grateful to the Getty Foundation and the Getty Conservation Institute, for the funding and partnership within the context of the projects *Concrete Art in Argentina and Brazil* (2016–2018), and *Concrete Art and Modern Paints in Brazil* (2018–2022). The authors thank LCPNano at the Federal University of Minas Gerais for the use of SEM-EDX.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior.

ORCID

Dâmia Carina Dias Do Carmo http://orcid.org/0000-0001-8544-2315

References

Almada, M., and S. Zervos. 2021. "Value Supported Decision-Making in Paper Conservation." *PÓS: Revista Do Programa de Pós-Graduação Em Artes Da EBA/UFM* 11 (22): 143–156. https://doi.org/10.35699/2237-5864.2021.26504.

Arizpe, L. 2000. "Cultural Heritage and Globalization." In *Values and Heritage Conservation: Research Report*, edited by E. Avrami, R. Mason, and M. De La Torre, 32–37. Los Angeles: Getty Conservation Institute.

Avrami, E., R. Mason, and M. De la Torre. 2000. "Report on Research." In *Values and Heritage Conservation: Research Report*, edited by E. Avrami, R. Mason, and M. De La Torre, 3–11. Los Angeles: Getty Conservation Institute.

Fredheim, L. H., and M. Khalaf. 2016. "The Significance of Values: Heritage Value Typologies Re-examined." *International Journal of Heritage Studies* 22 (6): 466–481. https://doi.org/10.1080/13527258.2016.1171247.

Galli, A., and L. Bonizzoni. 2014. "True *Versus* Forged in Cultural Heritage Materials: The Role of PXRF Analysis." *X-Ray Spectrometry* 43 (1): 22–28. https://doi.org/10.1002/xrs.2461.

Grissom, C. A. 1994. "The Conservation of Outdoor Zinc Sculptures." In *Ancient and Historic Metals*, edited by D. A. Scott, J. Podany, and B. B. Considine, 279–304. Los Angeles: Getty Conservation Institute.

Lowenthal, D. 2000. "Stewarding the Past in a Perplexing Present." In *Values and Heritage Conservation: Research Report*, edited by E. Avrami, R. Mason, and M. De La Torre, 18–25. Los Angeles: Getty Conservation Institute.

Michalski, S. 2018. "Sharing Conservation Decisions: Tools, Tactics, and Ideas." In *Sharing Conservation Decision: Current Issues and Future Strategies*, edited by A. Heritage, and J. Copithorne, 183–204. Rome: ICCROM.

Ricca, M., M. F. Alberghina, L. Randazzo, S. Schiavone, A. Donato, M. P. Albanese, and M. F. La Russa. 2021. "A Combined Non–Destructive and Micro–Destructive Approach to Solving the Forensic Problems in the Field of Cultural Heritage: Two Case Studiess." *Applied Sciences* 11 (15): 6951, 14. https://doi.org/10.3390/app11156951.

Smithsonian Museum Conservation Institute. 2023. *Zinc Sculpture*. https://mci.si.edu/zinc-sculpture. Accessed October 2023.

Souza, L. A. C. S., A. Rosado, Y.-A. Froner, R. L. Rodrigues, M. A. S. Castello Branco, G. Giovani, and V. P. Amaral. 2021. "Experimentation and Materiality: Constructing the Brazilian Artwork, 1950-60s." In *Purity is a Myth: The Materiality of Concrete Art from Argentina, Brazil, and Uruguay*, edited by Z. Gilbert, P. Gottschaller, T. Learner, and A. Perchuk, 1: 221–235. Los Angeles: Getty Research Institute.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S63–S71
https://doi.org/10.1080/00393630.2024.2339728

ORIGINAL RESEARCH OR TREATMENT PAPER

OPEN ACCESS Check for updates

Learning from the Past: Rediscovering Traditional Medieval Wood Tar Adhesives for Sustainable Stone Conservation and Built Heritage

Aprendiendo del Pasado: Redescubriendo los Adhesivos de Alquitrán de Madera Medievales Tradicionales para la Conservación Sostenible de la Piedra y el Patrimonio Construido

Bettina Ebert

Museum of Archaeology, University of Stavanger, Stavanger, Norway

ABSTRACT

This paper outlines a research project on the use of wood tar as adhesive for architectural stone repairs. Tar was identified as having been used in medieval repair techniques on Stavanger cathedral in Norway, as well as on several other medieval cathedrals in England and Germany. The hypothesis is that a complex adhesive mixture based on wood tar was manufactured and strategically employed by medieval artisans in northern Europe as stone repair material. Given that such repairs have withstood centuries of wear, there must have been extensive material knowledge and awareness of the complex requirements of structural adhesives. These historic tar repairs created the impetus for a research project, the aim of which is to rediscover the lost medieval art of traditional stone repair using wood tar adhesives, recreate the historic adhesive and repurpose it for modern conservation practice. By reintroducing traditional wood tar adhesives based on natural renewable source materials, we could potentially reduce dependence on synthetically manufactured adhesives. Thus, newly-discovered medieval techniques which have successfully lasted centuries will be drawn on to help solve the limited selection of suitable adhesives for stone conservation, contributing to future preservation of stone architecture and the built heritage environment.

Este artículo describe un proyecto de investigación sobre el uso de alquitrán de madera como adhesivo para reparaciones de piedra en patrimonio construido. Se identificó que el alquitrán se había utilizado en técnicas de reparación medievales en la catedral de Stavanger en Noruega, así como en varias otras catedrales medievales en Inglaterra y Alemania. La hipótesis es que los artesanos medievales del norte de Europa fabricaron y emplearon estratégicamente una mezcla adhesiva compleja a base de alquitrán de madera como material de reparación de piedra. Dado que tales reparaciones han resistido siglos de desgaste, debe haber habido un amplio conocimiento de los materiales y conciencia sobre los complejos requisitos de los adhesivos estructurales para este tipo de adhesivos. Estas reparaciones históricas de alquitrán crearon el impulso para un proyecto de investigación, cuyo objetivo es redescubrir el arte medieval perdido de la reparación tradicional de piedra utilizando adhesivos de alquitrán para madera, recrear el adhesivo histórico y reutilizarlo para la práctica de conservación moderna. Al reintroducir los adhesivos tradicionales de alquitrán de madera basados en materiales naturales renovables, podríamos reducir potencialmente la dependencia de los adhesivos fabricados sintéticamente. Por lo tanto, se aprovecharán las técnicas medievales recién re-descubiertas que han durado siglos con éxito para ayudar a resolver la limitada selección de adhesivos adecuados para la conservación de piedra, contribuyendo así a la preservación de la arquitectura de piedra y del patrimonio construido.

ARTICLE HISTORY
Received October 2023
Accepted March 2024

KEYWORDS
wood tar; medieval; stone; repair; adhesive; built heritage; caft skills; tacit knowledge; sustainability

alquitrán de madera; medieval; piedra; reparación; adhesivo; patrimonio construido; habilidades artesanales; conocimiento tácito; sostenibilidad

A medieval stone adhesive case study with broad implications

Wood tars and tar-based adhesives have a very long history of use, and as the current publication demonstrates, novel uses of wood tar are still being identified. Simultaneously, even though adhesive research has been undertaken in various conservation disciplines, the use of adhesives in stone construction and architectural repair has received only limited attention. Within the course of a recent pilot study undertaken on Stavanger cathedral in Norway, extensive evidence of tar-based medieval repair adhesives was discovered (Ebert and Bjelland 2023). In this paper, the pilot study will be summarized, and latest results of the ongoing research presented, prior to addressing the repercussions and potential provided by this discovery.

CONTACT Bettina Ebert bettina.ebert@uis.no Museum of Archaeology, University of Stavanger, Postbox 8600, 4036 Stavanger, Norway

© 2024 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group
This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

Stavanger cathedral is a medieval stone cathedral located in south-western Norway. The cathedral remains in active religious use and has only been subjected to a limited degree of change since the Middle Ages. Consequently, Stavanger cathedral is Norway's most authentic medieval stone cathedral and is automatically protected under the Norwegian Cultural Heritage Act. The cathedral was constructed in the first quarter of the twelfth century using rubblestone masonry, with local soapstone employed for ashlar and decorative stone carvings. The original Romanesque nave remains from this early construction period. Around 1300, a Gothic construction period led to the cathedral's original choir being replaced, and two towers raised at either end of the new east façade (Figure 1). In preparation for the cathedral's and city's 900-year anniversary in 2025, a large ten-year restoration and conservation project is currently underway. Within the scope of this cathedral restoration project, the Museum of Archaeology at the University of Stavanger is responsible for conservation and documentation of the cathedral's soapstone exterior and interior, as well as the Renaissance inventory.

Pilot study and preliminary results

While undertaking condition assessment and documentation of Stavanger cathedral for the ongoing conservation project, the conservators discovered an unusual adhesive-like substance underneath some stone repairs (Figure 2). The adhesive was brownish black in appearance and had numerous inorganic inclusions, as observed using light microscopy. After initial examination, the nature and context of the find led to the hypothesis that the adhesive may be from historic tar repairs. Given the novelty of this discovery, a pilot study was undertaken to explore this initial hypothesis, and to determine the age of the repairs.



Figure 1. Stavanger cathedral, with Gothic east façade and towers prior to conservation. Image: Museum of Archaeology, University of Stavanger.

Samples of the adhesive were taken from a wide range of locations on the cathedral for further investigations. Four samples were selected for radiocarbon dating and material identification, these samples derived from both the interior and exterior of the cathedral to provide a broad cross-section of sites (see Table 1 for details). Gas chromatography – mass spectrometry (GC – MS) was employed for identification of the organic components in the adhesive. Radiocarbon dating is considered a suitable technique to date the wood tar repairs on Stavanger cathedral and link them to the respective building construction phases. The first set of radiocarbon dates obtained for tar repairs on Stavanger cathedral is reported in Table 1. This will be followed by radiocarbon dating additional tar repair samples from other locations on the cathedral, as well as other sites in Norway and from churches in other countries, as identified during the field surveys.

Material characterization studies undertaken on four of the samples from Stavanger cathedral during the pilot study identified pine resin, beeswax and inorganic fillers, in addition to pine tar (Table 1). The inorganic additives will be subjected to further study in order to determine whether they derive from stone debris or from other sources, and whether it is possible to determine the proportion of inorganic content. The radiocarbon dates of the four samples are in agreement, providing a *terminus post quem* for when the pine tar could have been manufactured and applied. These results clearly link the tar repairs to the Gothic construction period of Stavanger cathedral.

Results of the pilot study are revolutionary: an adhesive mixture based on pine wood tar with further additives was used as an adhesive for hundreds of large and small stone repairs dated to the cathedral's Gothic reconstruction period (see Ebert and Bjelland 2023 for further details). Surprisingly, the use of wood tar as a historic repair material on stone buildings is currently undocumented. This technique of stone repair has the potential for providing alternative



Figure 2. Stone repair with tar adhesive. Image: Museum of Archaeology, University of Stavanger.

Table 1. Four adhesive samples investigated using GC – MS and radiocarbon dating. All radiocarbon dates are reported to 95% probability (2σ, IntCal20).

Sample number and location on Stavanger cathedral	GC-MS results	Age range (cal AD)
#65 Choir interior, north wall (repair)	Pine tar, pine resin, beeswax	1027–1156
#121 Choir interior, ribbed vault	Pine tar, pine resin, beeswax	1035–1157
#139 Choir exterior, south facade window (repair)	Pine tar, pine resin, beeswax	1044–1213
#141 North tower (repair)	Pine tar, pine resin, beeswax	1052–1217

sustainable methods and materials for conservation based on traditional historic techniques.

The research project

The novel findings uncovered as part of the pilot study provided the impetus for the development of a larger research project, the aim of which is to investigate the historic and potential future use of wood tar adhesives in conservation. The project is called *Sticking Stones: rediscovering medieval wood tar adhesives for stone conservation*, and is funded by the Research Council of Norway, with co-funding and in-kind contributions by the project owners and respective partner institutions, contributing to a total budget of NOK 16 million (EUR 1.4 million). The project is scheduled to run for four years from 2024 to 2028 and consists of five work packages designed to address the research aims and project objectives. The interdisciplinary project is led and coordinated by the Museum of Archaeology at the University of Stavanger in Norway. Partner institutions in Norway include the Norwegian Institute for Cultural Heritage Research and the University of Bergen, while international collaborators are located at Delft University of Technology in the Netherlands and the Getty Conservation Institute in the USA. The project team consists of specialists from conservation, archaeology, art history, materials science, geology, and biology. A PhD candidate based at the Museum of Archaeology will join this interdisciplinary group. The project is supported by an advisory panel consisting of stakeholder representatives and experts from stone conservation, traditional masonry practitioners, materials characterization, and cultural heritage management. In addition, an innovation panel advises the principal investigator on intellectual property (IP) rights, IP management, market research, and product development.

The project team is undertaking pioneering research into the historic use of tar as stone adhesive, subsequently testing its potential application in architectural conservation. The project focuses on one case study, Stavanger cathedral, while also considering tar and other adhesive repairs in northern European countries including the United Kingdom and Germany. What follows is a brief review of the research history of wood tar and stone adhesives to demonstrate current knowledge gaps that are being addressed by this research.

Wood tar

Throughout history, wood tars have been prepared and employed by humankind as adhesives, sealants, and coatings. Wood tars are produced from the destructive distillation of biomass. Wood tar is a complex mixture of hundreds of hydrocarbon compounds, mainly a range of resin acids and phenols. In many parts of Scandinavia, the traditional funnel kiln distillation process involves kilns with a controlled burning system that creates a low-oxygen environment (Egenberg 2003; Hennius 2018). To produce pine wood tar, old pine stumps are used since these contain the highest amount of pine resin. The wood is chopped and dried, and once the kiln is constructed, a circular wood stack is made, which is then covered in turf and ignited, allowing it to smoulder over the course of many hours. The tar then runs off via the funnel into collecting containers.

There is significant archaeological evidence of Neanderthal production of birch bark tar in the Palaeolithic (Kozowyk, Baron, and Langejans 2023a; Kozowyk, Fajardo, and Langejans 2023b). Residue analysis has led to the identification of birch bark tar on flint tools as well as a decorative or waterproof coating and repair adhesive on ceramics (Junkmanns 2001; Morandi, Porta, and Ribechini 2018; Niekus et al. 2019). In Norway, birch bark tar is known to have been used as caulking resin or sealant for lath-walled wooden vessels during the Early Iron Age (Nordby 2009). Birch bark tar production in Scandinavia remained on a small scale, while pine tar production developed into larger-scale production processes during the Late Iron Age, particularly the Viking period (Hennius 2018; Hjulström, Isaksson, and Hennius 2006). Hennius concludes that Viking shipbuilding provided the impetus for pine tar production on an expanded scale (Hennius 2018). Pine tar was used as caulking material in shipbuilding (Figure 3), also in postmedieval and pre-industrial times (Loewen 2005). In this context, fibrous material was soaked in pine tar and wedged between planks to create a watertight seal.

Another important use for pine tar is as a surface coating for wood. Pine tar was, and still is, used extensively as a protective and sacrificial coating on wooden stave churches (Egenberg 2003), and on vernacular historic wooden buildings and shingle roofs throughout Scandinavia (Källbom 2015; Lindblad, Fredriksson, and Källbom 2021). In fact, pine tar was a significant Scandinavian export commodity in the early modern period. Despite this ubiquitous use in earlier centuries,



Figure 3. Medieval ceramic vessel containing wood tar, likely used in caulking. Marine archaeological discovery from the Karmsund strait in Rogaland county, south-western Norway. Image: Museum of Archaeology, University of Stavanger.

wood tar is not currently documented to have been employed for stone repair beyond the recent discovery on Stavanger cathedral. Nevertheless, initial research by the author has revealed archival evidence which could indicate that pine tar adhesives were regularly used for stone repair and construction in medieval times in northern Europe. This will be explored in greater detail as research progresses, as it is a topic that has hitherto not been studied.

Stone adhesives

Craft skills play a crucial role in stone conservation, and collaboration between conservators, stone carvers and masons is necessary for successful remedial stone conservation. Techniques employed in architectural stone conservation have changed minimally over the centuries, being based on traditional stonemasonry skills. Architectural stone is usually repaired through full or partial replacement of deteriorated stone, ensuring that the building maintains its structural integrity. A range of mortars and cements is used, occasionally in conjunction with adhesives and metal pins, to hold indents in place. The use of wood tar in stone repair is currently undocumented, while mortar and synthetic resins are commonly used in this context nowadays (Daniels 2015; English Heritage 2012). Adhesives that are employed in stone conservation are more commonly used on sculptures or monuments, particularly indoors, rather than in the built environment. Weather exposure is an extreme environmental stress for adhesives, limiting their successful outdoor use in the built heritage sector to only a few adhesives, with the most common being polyester or epoxy resins (English Heritage 2012). Historically, a range of adhesives has been employed for repair and gluing of stone, though there is as yet very limited research on the topic (Alsalim 1981; Griswold and Uricheck 1998; Jorjani et al. 2009). Documented historic adhesives used in stone conservation include, for example, shellac, wax, animal glue, and bitumen, as well as various mortars and cements.

Stone adhesives mentioned in medieval written sources include animal glues (Smith and Hawthorne 1974), while a medieval Italian recipe for a mixture of mastic and wax has been described (Thompson 1954). However, use of wood tar as a stone adhesive has so far only been tentatively identified in a few medieval English purchase records linked to cathedral construction. In these contexts, a repair adhesive consisting of wax, tar, rosin and/or pitch is mentioned, occasionally with the addition of stone or tile dust (Raines 1859; Salzman 1952). Thus, archival evidence appears to indicate that wood tar was used for stone repair in medieval England. It is possible that documented evidence of medieval adhesive repairs identified around fifty years ago provides the missing link here. During conservation work on several English cathedrals in the 1970s and 1980s, numerous medieval adhesive findings were registered, with evidence on Wells and Salisbury cathedrals, amongst other places (Ayers and Sampson 2000; Harris 1982; Sampson 1998). The description of these adhesive repairs is remarkably similar to the newly-discovered tar findings in Stavanger, though the composition of the English samples has not been confirmed by materials analysis and will have to be analysed and compared to the Norwegian material. Despite these adhesive findings having been documented many decades ago, knowledge of medieval adhesive repairs in northern European contexts has not progressed significantly in stone conservation or building archaeology since then.

Knowledge needs and research objectives

This brief overview of wood tars and stone adhesives highlights the fact that there are significant knowledge gaps in building archaeology, stone conservation and adhesives research. There is currently no in-depth study of traditional medieval adhesives used in stone repair. Knowledge of wood tar production and use is more comprehensive, though there are no studies of wood tar usage in the context of architectural stone. The discovery of hundreds of tar repairs on Stavanger cathedral, in combination with archival sources and other medieval adhesive repairs tentatively identified elsewhere in northern Europe, has the combined potential to shed light on an understudied historic craft. This unique discovery highlights a knowledge gap on historic approaches to conservation and practices of repair. Such underexplored findings may indicate widespread northern European use of tarry adhesives in medieval stone construction and repair, shedding light on a neglected resource with significant potential for contemporary applications.

As a result of these pressing knowledge needs, it was decided to develop the *Sticking Stones* project, the aim of which is to rediscover the lost medieval art of traditional stone repair using wood tar adhesives. This will involve recreating the historic adhesive mixture and repurposing it for modern conservation practice and the built environment. It is exemplary that historic tar repairs on Stavanger cathedral have withstood many centuries of adverse coastal Scandinavian climate extremes without adhesive failure. Such longevity gives wood tar as a stone adhesive the potential to be used in conservation as a replacement for synthetic resins. This presents a novel solution for conservation in the form of alternative adhesives based on forgotten historic techniques.

The primary objective of the research is the systematic survey of historic architectural stone adhesives, highlighting the medieval artisan's complex toolkit, craft skills and early awareness of conservation ethics. This feeds directly into the secondary objective of material characterization for the development of a new sustainable adhesive for stone conservation based on historic materials and techniques. As identified in the pilot study, the main hypothesis is that a complex adhesive mixture consisting of tar and other organic and inorganic additives was manufactured and strategically employed by medieval artisans as a stone conservation and repair material in northern Europe. Given that large stone blocks were successfully attached and have withstood centuries of wear (Figure 4), there must have been extensive material knowledge and awareness of the complex requirements of such adhesive mixtures. The project team will uncover the lost medieval tradition of tar repairs and use this new-gained knowledge of traditional materials and techniques in contributing to method development for modern stone conservation.



Figure 4. Medieval tar repair on Stavanger cathedral. Image: Museum of Archaeology, University of Stavanger.

Project methodology

Numerous complementary methods are being employed to achieve the project aims, covering archival research into historic adhesives, explorations of tacit knowledge and the intangible heritage of craft skills, material characterization, adhesive re-engineering, and performance testing. Historical instruction manuals and primary sources are being studied to examine historic adhesive technology. Site surveys of selected medieval churches and lapidaries in northern Europe are currently being undertaken, mapping the incidence of medieval tar repairs in the built environment by looking for physical evidence of wood tar. At present, Heilig-Kreuz-Münster in Schwäbisch Gmünd, Germany, as well as the lapidary of Trondheim Cathedral Restoration Workshop in Norway are being evaluated, with further site surveys planned. In addition, a community science project is being set up to engage local communities in participatory heritage research, allowing participants to document potential adhesive repairs on medieval architectural heritage. This contributes to a broader scope than possible purely through selected site surveys.

The detailed composition of historic tar repairs is currently unknown, yet successful survival for centuries is testament to complex adhesive formulation. This crucial knowledge gap required for subsequent adhesive replication is currently being addressed through comprehensive material characterization of the organic and inorganic components of historic samples (Figure 5). Successful adhesive formulations often consist of mixtures, using additives to modify their working properties.



Figure 5. One of the tar adhesive samples investigated during the project. Image: Museum of Archaeology, University of Stavanger.

Additional samples from Stavanger cathedral and other churches elsewhere are being subjected to detailed material characterization to obtain as complete a picture as possible, given the possibility of variability in application and composition. Results will be compared to reference samples and mixtures of reference samples of known proportions, to determine accurate ratios of components. Organic characterization is being undertaken through Fourier transform infrared spectroscopy and GC-MS. Sample cross-sections and thin sections (petrography for inorganic inclusions) are being examined with light microscopy and scanning electron microscopy for insight into additives in the adhesive mixture. Identification of the inorganic components involves scanning electron microscopy with energy-dispersive spectroscopy and Raman spectroscopy.

Compositional data derived from material characterization will be compared to historic archival recipes to replicate adhesive mixtures. The project researchers will subsequently evaluate adhesive performance and test its application for stone conservation. The astounding performance of 700-year-old tar repairs is testament to their potential, and while tar may not outperform modern synthetic resins in all capacities, it has the ability to be a suitable natural alternative, given the correct blend with additives.

Standardized industrial adhesive material tests will be used to quantify properties of the re-invented adhesive. This allows comparison with modern synthetic resin adhesives. Stone adhesives need to withstand a range of environmental conditions for successful indoor and outdoor use. Therefore, replicated adhesives will undergo accelerated hygrothermal ageing at elevated temperatures and cyclic relative humidity. Samples taken at three different ageing durations will be subject to tensile lap shear tests and rheological analysis and will be compared to modern synthetic resin adhesives. Lap shear tests will be conducted to measure the quasi-static shear strength of each adhesive on different stone adherends, including soapstone due to its ubiquitous use on Stavanger cathedral. Rheology testing will measure creep, viscosity, and dynamic moduli at a range of temperatures. Given the importance of moisture passage in stone buildings, moisture uptake and its effects on material properties will be tested by water immersion and measuring changes in weight and rheological properties. Following lab testing, the adhesive will be subjected to real-life performance and application testing by relevant stakeholder groups to explore practical tar adhesive usage.

Tacit knowledge and craft skills

An exploration of the fundamental interplay of craft skills and tacit knowledge in relation to architectural conservation has received limited academic attention so far. Project researchers are exploring how tacit knowledge and the intangible heritage of craft skills used in medieval tar repair can inform current conservation practice. Polanyi's theory of tacit knowledge acts as guiding principle in this approach. Tacit knowledge is embodied in the idea that 'we can know more than we can tell', implying that knowledge has informal dimensions based on intuition, experience, and skill (Polanyi 1966, 4). For conservators working on Stavanger cathedral, tacit knowledge was embodied in the intuitive connection between the untapped potential of newly discovered historic tar repairs in addressing a pressing problem faced in contemporary stone conservation, namely the absence of suitable adhesives for the conservation of soapstone beyond synthetic glues. This demonstrates that the pursuit of scientific discovery also relies on tacit knowledge, while simultaneously exploring the embodied knowledge of a lost medieval craft.

Historical adhesives and medieval tar repairs are being examined through the lens of tacit knowledge and the intangible cultural heritage of craft skills. Traditional craftsmanship is protected under the UNESCO Convention for the Safeguarding of Intangible Cultural Heritage, yet academic research on craft in cultural heritage is still somewhat limited (though see, for example, Almevik 2016; Westerlund, Groth, and Almevik 2022). The project explores how the development of a novel conservation adhesive is informed through the study and understanding of a historic craft. This guarantees continuity and relevance of traditional skills into the future through analytical discovery and reengineering for modern conservation. Craft as a complex interplay of tacit knowledge, experiential learning, intuition, experimentation and awareness of material technology and its implications is being investigated in the process. In this manner, lost historic craft knowledge can be re-learnt and brought to life for future traditions of practice.

Close reading of physical evidence provides insight into the mind of medieval artisans, demonstrating extensive material awareness and ethical consideration with parallels in modern conservation practice (Figure 6). The project outputs will expand the corpus of research into concepts of authenticity by demonstrating the role of processual authenticity in the built environment. By framing this study within perspectives of tacit knowledge, craft skills and processual authenticity, the research demonstrates how tangible and intangible heritages are intimately combined within conservation. The discipline of conservation, while often seen to focus on material traces of the past by preserving material culture, is inherently dualistic. Craft skills and tacit knowledge that are required in successful conservation practice (see, for example, Muñoz Viñas 2022) allow the discipline to synthesize



Figure 6. Ethical considerations and craft skills evident in the use of tar to repair a crack in the scalp of a carved head. Image: Museum of Archaeology, University of Stavanger.

the tangible and the intangible simultaneously. Thus, traditions of practice contribute to processual authenticity in conservation, wherein tangible and intangible heritages are inextricably intertwined when tacit knowledge, traditional methods, materials and skills are successfully employed in modern conservation (Hassard 2008).

Stavanger cathedral's conservation history is also being examined through the lens of the biographical approach (Ebert 2019; Gosden and Marshall 1999; Kopytoff 1986), allowing comprehensive description of the cathedral's trajectory throughout history. The phases of conservation can be mapped, and their implications described in the light of contemporary approaches to repair and maintenance. In this manner, the biographical framework allows lines of comparison to be drawn between choices (material, practical, and theoretical) made by craftspeople in the past with present choices. By comparing medieval approaches to modern conservation, one can draw parallels between craft perspectives of artisans involved in cathedral construction and those charged with contemporary maintenance. When combined with comprehensive material characterization of historic tar samples, this allows mapping and explanation of the material choices made by medieval craftspeople, thus demonstrating their continued relevance for modern stone conservation. By developing a new adhesive formula based on rediscovered medieval knowledge, the project demonstrates the continued relevance of medieval craft skills in the present and future.

Sustainable adhesive technology

By focusing on traditional methods for conservation, the project outputs will contribute to the UN sustainable development goal (SDG) 11, sustainable cities and communities, target 11.4 of strengthening efforts to protect and safeguard the world's cultural and natural heritage. Medieval stone churches are more at risk with climate change, as wetter weather is linked to increased risk of damage (Hauglid et al. 2022). Now more than ever, it is therefore crucial to investigate adhesives which have withstood centuries, and to incorporate these into modern conservation practice. This novel discovery allows the reintroduction of lost medieval knowledge in the form of an 'extinct' traditional adhesive to the toolkit of the modern stone conservator, whose options are currently limited to materials not in keeping with principles of technological and processual authenticity.

The project aims to have a green impact on conservation practice by reducing dependence on synthetically-manufactured adhesives such as epoxy resins, instead exploring traditional natural renewable materials successfully employed in historic times. Once a modern tar adhesive mixture has been produced, lifecycle assessments can be run to compare the environmental sustainability of these in comparison with synthetic resins. Given that pine tar is traditionally obtained from old pine stumps, it is of course clear that the cutting down of old pine trees is not desirable in the context of finite natural resources. Nevertheless, there may be potential for using stumps from sustainably managed forestry or waste from timber industries in future tar production. This contributes to UN SDG 12, sustainable consumption and production patterns. By undertaking research that is related to sustainable development and our society's green transition, the project aims to contribute to minimizing the field's environmental impact and making modern conservation practice more sustainable by reducing reliance on synthetic adhesives.

Conclusion

The discovery of hundreds of medieval tar-based repairs on Stavanger cathedral, together with archival evidence pointing to the use of tarry adhesives during the Middle Ages, prompted the development of a research project on the topic of wood tars for adhesion and repair of stone. The *Sticking Stones* project investigates the historic use of tar adhesives in architectural stone repair, with the aim of developing a conservation adhesive based on wood tar. The

goal is to uncover the lost medieval tradition of tar repairs and use this new-gained knowledge of traditional materials and techniques in contributing to alternative adhesive use in modern stone conservation. In this manner, lost craft knowledge will be rediscovered and re-engineered for future traditions of practice, making conservation more sustainable by potentially reducing reliance on synthetic adhesives.

Historic methods and materials have significant potential in contributing to a more sustainable conservation practice, and it is hoped that this project will act as an impetus for similar approaches to materials and method development in conservation, using the past for inspiration. In developing alternative solutions for conservation, historic materials, methods, and techniques may offer more sustainable approaches than those currently in use.

Acknowledgements

I would like to thank the project participants and partners for contributing their invaluable expertise to this exciting project. I am indebted to the research cluster BEAM (Casting light on cultural heritage through interdisciplinary research) at the Museum of Archaeology, University of Stavanger for providing funding for the pilot study, thus allowing the project to develop at a crucial early stage. I sincerely thank Dr Gwen Wathne at the Research Department and Åse Ormøy at the Finance Department of the University of Stavanger for exceptional support and advice provided during the grant writing and application process. I am grateful to the Research Council of Norway for funding the research project. I thank the Museum of Archaeology, the Norwegian Institute for Cultural Heritage Research, the University of Bergen, Delft University of Technology, and the Getty Conservation Institute for their co-funding and in-kind contributions to the research project.

Disclosure statement

No potential conflict of interest was reported by the author.

Funding

Analytical work and radiocarbon dating for the pilot study was partially funded by the strategic research cluster BEAM at the Museum of Archaeology, University of Stavanger. The *Sticking Stones* research project (project number 344868) is funded with NOK 8 million by the Research Council of Norway for the period 2024–2028. The project is funded with an additional NOK 8 million in co-funding and in-kind contributions by the project owners and respective partner institutions.

ORCID

Bettina Ebert http://orcid.org/0000-0002-4940-823X

References

Almevik, G. 2016. "From Archive to Living Heritage: Participatory Documentation Methods in Crafts." In *Crafting Cultural Heritage*, edited by A. Palmsköld, J. Rosenqvist, and G. Almevik, 77–99. Gothenburg: University of Gothenburg.

Alsalim, H. S. 1981. "Construction Adhesives Used in the Buildings of Babylon." In *Adhesion 5, Proceedings of the 18th Annual Conference on Adhesion and Adhesives*, edited by K. W. Allen, 151–156. London: Applied Science Publishers.

Ayers, T., and J. Sampson. 2000. "The Middle Ages." In *Salisbury Cathedral: The West Front: A History and Study in Conservation*, edited by T. Ayers, 9–82. Chichester: Phillimore.

Daniels, C. 2015. *The Stone Restoration Handbook*. Ramsbury: Crowood Press Ltd.

Ebert, B. 2019. "Biographies Carved in Wood: Turning Points in the Lives of two Medieval Virgin Sculptures." *Journal of Material Culture* 24 (2): 144–175. https://doi.org/10.1177/1359183518811355.

Ebert, B., and T. Bjelland. 2023. "Stuck Like Glue: Wood tar as a Medieval Stone Adhesive." In *Working Towards a Sustainable Past*. ICOM-CC 20th Triennial Conference Preprints, Valencia, edited by J. Bridgland, 1–9. Paris: ICOM-CC. https://www.icom-cc-publications-online.org/search/ebert?wg = 0&vy = 2023+Valencia&t = 0&page = 1.

Egenberg, I. M. 2003. Tarring Maintenance of Norwegian Medieval Stave Churches." PhD Thesis, University of Gothenburg. https://gupea.ub.gu.se/bitstream/handle/2077/16060/gupea_2077_16060_1.pdf.

Gosden, C., and Y. Marshall. 1999. "The Cultural Biography of Objects." *World Archaeology* 31 (2): 169–178. https://doi.org/10.1080/00438243.1999.9980439.

Griswold, J., and S. Uricheck. 1998. "Loss Compensation Methods for Stone." *Journal of the American Institute for Conservation* 37 (1): 89–110. https://doi.org/10.1179/019713698806082912.

Harris, R. 1982. "A Survey of Medieval Repairs to the Fabric of the West Front, Wells Cathedral." *Transactions of the Association for Studies in the Conservation of Historic Buildings* 7: 7–8.

Hassard, F. 2008. "Intangible Heritage in the United Kingdom: The Dark Side of Enlightenment." In *Intangible Heritage*, edited by L. Smith, and N. Akagawa, 270–288. London: Routledge.

Hauglid, K., K. W. Lunke, K. Kambestad, and H. M. Kempton. 2022. *Norske Steinkirker fra Middelalderen: Nøkkeltallsrapport 2021*. Oslo: KA Arbeidsgiverorganisasjon for kirkelige virksomheter.

Hennius, A. 2018. "Viking Age tar Production and Outland Exploitation." *Antiquity* 92 (365): 1349–1361. https://doi.org/10.15184/aqy.2018.22.

Heritage, English. 2012. *Practical Building Conservation: Stone*. Farnham: Ashgate.

Hjulström, B., S. Isaksson, and A. Hennius. 2006. "Organic Geochemical Evidence for Pine Tar Production in Middle Eastern Sweden During the Roman Iron Age." *Journal of Archaeological Science* 33 (2): 283–294. https://doi.org/10.1016/j.jas.2005.06.017.

Jorjani, M., G. Wheeler, C. Riccardelli, W. Soboyejo, and N. Rahbar. 2009. "An Evaluation of Potential Adhesives for Marble Repair." In *Holding it all Together: Ancient and Modern Approaches to Joining, Repair and Consolidation*, edited by J. Ambers, C. Higgitt, L. Harrison, and D. Saunders, 143–149. London: Archetype Publications.

Junkmanns, J. 2001. "Vom "Urnenharz" zum Birkenteer: Der Prähistorische Klebstoff Birkenpech." *Tugium* 17: 83–90.

Källbom, A. 2015. *Tjära på Trätak*. Mariestad: Hantverkslaboratoriet.

Kopytoff, I. 1986. "The Cultural Biography of Things: Commoditization as Process." In *The Social Life of Things: Commodities in Cultural Perspective*, edited by A. Appadurai, 64–91. Cambridge: Cambridge University Press.

Kozowyk, P. R. B., L. I. Baron, and G. H. J. Langejans. 2023a. "Identifying Palaeolithic Birch tar Production Techniques: Challenges from an Experimental Biomolecular Approach." *Scientific Reports* 13 (1): 14727. https://doi.org/10.1038/s41598-023-41898-5.

Kozowyk, P. R. B., S. Fajardo, and G. H. J. Langejans. 2023b. "Scaling Palaeolithic tar Production Processes Exponentially Increases Behavioural Complexity." *Scientific Reports* 13 (1): 14709. https://doi.org/10.1038/s41598-023-41963-z.

Lindblad, L., N. Fredriksson, and A. Källbom. 2021. "Challenges in Pine Tar Production and Practices for Sustainable Preservation of Swedish Wooden Heritage." In *Earthen and Wood Vernacular Heritage and Climate Change*, edited by M. Dabaieh, 128–133. Lund: ICOMOS.

Loewen, B. 2005. "Resinous Paying Materials in the French Atlantic, AD 1500–1800. History, Technology, Substances." *International Journal of Nautical Archaeology* 34 (2): 238–252. https://doi.org/10.1111/j.1095-9270.2005.00057.x.

Morandi, L. F., S. N. Porta, and E. Ribechini. 2018. "Evidence for Birch Bark Tar Use as an Adhesive and Decorative Element in Early Iron Age Central Italy: Technological and Socio-Economic Implications." *Archaeometry* 60 (5): 1077–1087. https://doi.org/10.1111/arcm.12362.

Muñoz Viñas, S. 2022. "Conservation Science, Conservation Practice and the Conservator's Knowledge: A Naïve Exploration." *Journal of the Institute of Conservation* 45 (3): 173–189. https://doi.org/10.1080/19455224.2022.2112407.

Niekus, M., P. Kozowyk, G. Langejans, and G. Dusseldorp. 2019. "Middle Paleolithic Complex Technology and a Neandertal tar-Backed Tool from the Dutch North Sea." *Proceedings of the National Academy of Sciences* 116 (44): 22081–22087. https://doi.org/10.1073/pnas.1907828116.

Nordby, C. 2009. "Continuity or Change? The use and Function of Birch Bark tar in Norwegian Early Iron Age Grave Contexts." In *Holding it all Together: Ancient and Modern Approaches to Joining, Repair and Consolidation*, edited by J. Ambers, C. Higgitt, L. Harrison, and D. Saunders, 54–60. London: Archetype Publications.

Polanyi, M. 1966. *The Tacit Dimension*. Chicago: University of Chicago Press.

Raines, J. 1859. *The Fabric Rolls of York Minster*. Durham: Surtees Society.

Salzman, L. F. 1952. *Building in England Down to 1540*. Oxford: Oxford University Press.

Sampson, J. 1998. *Wells Cathedral West Front*. Stroud: Sutton Publishing.

Smith, C. S., and J. G. Hawthorne. 1974. "*Mappae Clavicula*: A Little key to the World of Medieval Techniques." *Transactions of the American Philosophical Society* 64 (4): 1–128. https://doi.org/10.2307/1006317.

Thompson, D. V. 1954. *Cennino Cennini's The Craftman's Handbook (Il Libro Dell' Arte)*. New York: Dover Publications.

Westerlund, T., C. Groth and G. Almevik (eds). 2022. *Craft Sciences*. Gothenburg: University of Gothenburg.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S72–S80
https://doi.org/10.1080/00393630.2024.2339727

ORIGINAL RESEARCH OR TREATMENT PAPER

Sustainable and Beneficial: Pollutant Absorption and Relative Humidity Control in Display Cases by Saturated Salt Solutions

Sostenible y Beneficioso: Absorción de Contaminantes y Control de la Humedad Relativa en Vitrinas Mediante Soluciones de Sales Saturadas

Gerhard Eggert [1], Oliver Brieger [2], My Sa Marschibois[2], Daniel Becker [2], Christian Bur [2], Katja Franziska Siebel[2,3] and Heiner Grieb[3]

[1]Institute of Conservation Sciences, State Academy of Art and Design, Stuttgart, Germany; [2]Laboratory for Measurement Technology, Saarland University, Saarbrücken, Germany; [3]Objects Conservation, Veste Coburg Art Collections, Coburg, Germany

ABSTRACT

In the light of sustainability, the nearly forgotten control of relative humidity (RH) in display cases with saturated salt solutions is re-evaluated. Spilling and creeping of salts can be avoided. By choosing magnesium nitrate or potassium carbonate, the temperature dependence of the RH and the emission of harmful gases are negligible. Measurements with metal oxide semiconductor (MOS) gas sensors showed such solutions to be excellent absorbers for corrosive pollutants such as acids and aldehydes, especially the alkaline potassium carbonate (hitherto not used in museums). The practical application of such solutions in display cases is currently being tested in a community science project in a number of museums. This will result in improved guidelines for conservators and it is hoped, in a revival of this passive, failsafe, low-carbon footprint technique.

Desde el punto de vista de la sostenibilidad, se reevalúa el casi olvidado control de la humedad relativa (HR) en las vitrinas con soluciones salinas saturadas. Derrames y filtraciones de sales pueden ser evitados. Al elegir nitrato de magnesio o carbonato de potasio, la dependencia de la temperatura relativa de la HR y la emisión de gases nocivos son insignificantes. Las mediciones con sensores de gas semiconductores de óxido metálico (MOS) mostraron que estas soluciones son excelentes absorbentes de contaminantes corrosivos como ácidos y aldehídos, especialmente el carbonato de potasio alcalino (hasta ahora no utilizado en museos). La aplicación práctica de estas soluciones en vitrinas se está probando actualmente en un proyecto científico comunitario en varios museos. Esto dará como resultado pautas mejoradas para los conservadores y se espera que resucite esta técnica pasiva, que es a prueba de fallas y de baja huella de carbono.

ARTICLE HISTORY
Received October 2023
Accepted March 2024

KEYWORDS
Climate control; display cases; MOS gas sensors; pollutant absorption; saturated salt solutions

Control de clima; vitrinas; sensores de gas MOS; absorción de contaminantes; soluciones salinas saturadas

Introduction

A sustainable solution to maintain a constant, unchanging relative humidity (RH) in display cases is desirable nowadays. It should not consume energy permanently nor need an electricity supply or expensive equipment. Textbooks on museum technology of the 1980s (Thomson 1986; Stolow 1987; Hilbert 1987) reported saturated salt solutions which meet these criteria.

According to Raoult's law, water molecules in the gas phase and in the solution maintain an equilibrium. The amount of water in the gas phase, measured as water vapour pressure, is proportional to the amount of water in the solution, measured as water activity. When a salt is dissolved in water, the water activity is reduced depending on the molar fraction of the salt in the solution. The RH is reduced accordingly from 100% (plain water) to lower values. Saturated solutions are preferred because the salt concentration and the water activity do not change as long as water and undissolved salts are present. The RH over such a solution is specific for a given salt depending on its solubility. It stays constant and does not shift. This is frequently used to calibrate RH sensors or to achieve constant RH in experiments in closed containers (Lide 2005). However, the current application of this method in display cases is rare. We could verify only a few examples:

- Veste Coburg Art Collections has used magnesium chloride ($MgCl_2$, RH = 33%) for their sensitive 'sick' glasses (Figure 1) for more than 30 years with good results. Although the display case is not fully airtight, the RH was successfully stabilised during a whole year (Figure 2).
- For two decades, magnesium nitrate ($Mg(NO_3)_2$, RH = 54%) has been used for the air conditioning of organic finds at the Fiske Center Boston, USA (Piechota and Piechota 2024) and in small museums in Denmark (Hovmand 2023), and for two *intarsia*

CONTACT Gerhard Eggert gerhard.eggert@abk-stuttgart.de Institute of Conservation Sciences, State Academy of Art and Design, Stuttgart, Germany

© The International Institute for Conservation of Historic and Artistic Works 2024



Figure 1. Display case 26 for 'sick' glasses at Veste Coburg using magnesium chloride solution in plastic containers in the lower part, during maintenance.

portraits in the Germanisches Nationalmuseum, Nürnberg (Dix 2023): no problems occurred.

- Titian's panel painting *The Tribute Money* has been had the climate within its frame controlled with sodium chloride (NaCl, RH = 76%) in the Old Master Painting Gallery, Dresden for over 50 years (Schölzel 2006). Sublimation of thymol was added for 'disinfection of the atmosphere' to prevent mould (Weber 1967). Damage caused by RH fluctuations no longer occurred.

What are the reasons why such solutions are now widely replaced by silica gel products, although their water absorption capacity is lower and their equilibrium RH shifts with the water content, thus more frequent maintenance is required? Why are almost no relevant articles published after 1992? Is it just an unfounded hesitation to introduce chemicals and liquids into display cases, or are there more profound reasons? To answer these questions the earlier literature was surveyed for any problems mentioned, which is reported in Eggert (2022a).

Concerns noted for RH control with salt solutions

Spilling

The use of liquids implies the risk of spilling. Solutions should therefore be placed at the bottom of display cases using small but sufficiently high containers, and should only be handled by trained staff. Creahan (1991) recommended coverage with a semipermeable membrane, although this will slow down the exchange

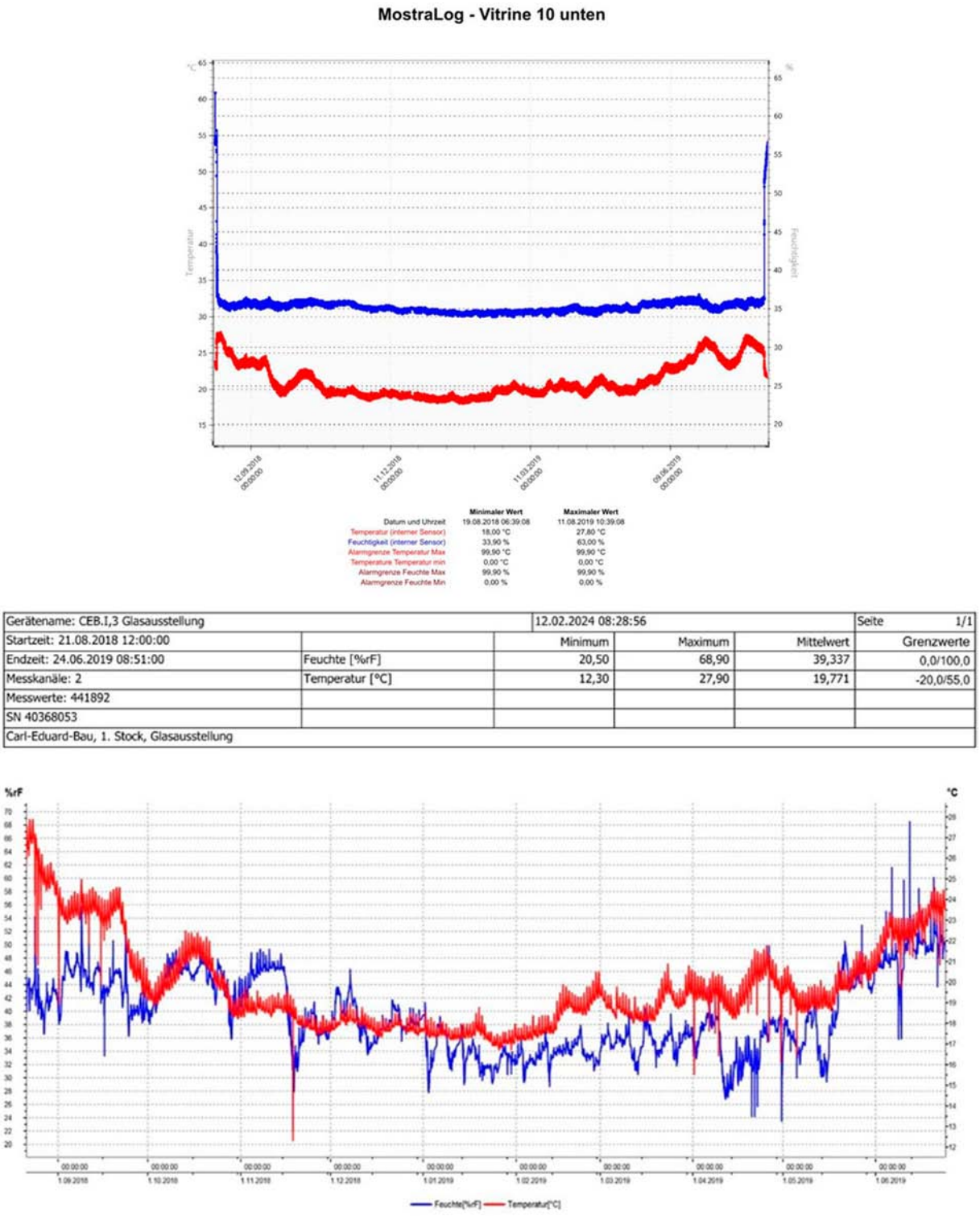


Figure 2. a–b. Effect of magnesium chloride during a full annual cycle: temperature (red) and RH (blue) inside display case 10 (a, above) and the exhibition room in the historic Veste Coburg (b, below). Broad lines due to daily variation.

of water molecules between air and solution. Other options in need of practical testing could be the use of thickeners or gelling materials.

Creeping

In earlier applications of glass and steel containers, creeping of salts over the rim was observed. When water evaporates, crystal crusts will precipitate at the walls. These act as a wick, drawing solution by capillary action to their surface where more crystals will deposit. By choosing hydrophobic container materials such as polyethylene or polypropylene, such creeping can be avoided.

Temperature dependence of RH

The solubility of any salt varies with temperature. This will change the water activity in the solution and the

RH in the air that is in equilibrium with it. A careful choice of less temperature-dependent salts can circumvent this problem. While the RH of calcium nitrate decreases 3% when the temperature increases by 5 °C, for magnesium nitrate, it is only 1.5%, which is acceptable in practical use. The RH of potassium carbonate, however, remains constant at 43.2% at a temperature interval of 15 to 30 °C (Eggert 2022a). This makes it a promising candidate for museum use when a lower RH is needed.

Emission of pollutants

Although no damage to objects was ever reported, the literature before 1992 mentioned the possibility that harmful pollutants may be emitted from solutions, but never discussed it properly (see Eggert 2022a for references.). Anions of strong acids such as chloride or nitrate mainly remain dissociated in solution. Only a small fraction will combine with H^+ from water and form an undissociated neutral acid molecule. Only traces of this acid evaporate into the air. Thermodynamic models for the activity coefficients of ions in such solutions allow one to calculate the equilibrium concentration of the corresponding acids in the gas phase (Harvie, Møller, and Weare 1984). The free online calculator ACCENT (2023) yields c. 0.2ppb of nitric acid over a magnesium nitrate solution, much less than the background concentration of NO_2 in clean, smoke-free rooms (which is > 5 ppb). The HCl concentration over magnesium chloride (11 ppb) is approximately two orders of magnitude higher than the background. However, 20 ppb HCl was found to cause visible corrosion on Cu-coated wafers within days even in very dry air (< 1% RH) (Tran et al. 2019). Therefore, magnesium chloride should not be used for metals or other materials sensitive to acid traces. The equilibrium concentration of CO_2 over potassium carbonate is c. 3 ppb. As the atmosphere currently contains 421 ppm (= 421,000 ppb), carbon dioxide will be absorbed by and not desorbed from a potash solution.

Anything that is placed in display cases should be Oddy tested for corrosivity. Tests of salt solutions cannot achieve the usual 100% RH but only the lower deliquescence RH of the salt at 60 °C. In accordance with the calculations, potassium carbonate and magnesium nitrate passed the test of 5 g salt + 0.5 ml H_2O (no corrosion detected after 28 days on any metal), while magnesium chloride failed. Despite the lower RH, a change of colour on the copper coupon occurred (Raman: cuprite, no basic Cu(II) chlorides).

Absorption of pollutants

Today, the degradation of exhibits by pollutants in sealed display cases is still a major problem. Examples are the action of acetic acid on calcareous materials (Eggert, Bette, and Dinnebier 2021), formaldehyde on metals in contact with unstable glass (Eggert and Fischer 2022), and sulfurous gases on silver and copper alloys (Kuhn-Wawrzinek, Eggert, and Schleid 2022). Schieweck (2020) warns that 'the assumption that silica gels, which are installed in display cases to buffer relative humidity, might also act as pollutant adsorbers, cannot be confirmed'. On the other hand, recent research (Sharma et al. 2022) found evidence for the emission of corrosive organic pollutants, from a fresh, preconditioned silica gel product. However, what about salt solutions?

If a liquid is introduced in a closed space, all compounds in the gas phase will maintain equilibrium with the solution. A fraction of the pollutant molecules in the atmosphere will enter the aqueous phase, the gas is washed and the pollutant concentration is lowered. Most corrosive pollutants are polar compounds that can form hydrogen bonds in solution and will readily dissolve in the aqueous phase.

All in all, no valid argument against the use of saturated salt solutions in display cases could be found. The expected but hitherto neglected absorptivity of salt solutions for all relevant pollutants needs to be tested experimentally.

Methods and materials

Sensors

To test the absorptivity of salt solutions, a method to follow trace concentrations of all relevant pollutants was needed: metal oxide semiconductor (MOS) gas sensors. Compared to standard reference analytical techniques like gas chromatography-mass spectrometry (GC-MS) in this field, MOS gas sensors allow real time monitoring of a large variety of different gases (Madou and Morrison 1989; Barsan and Weimar 2001). In principle, MOS gas sensors consist of a doped nano-porous material (e.g. tin dioxide) between two electrodes. This nano-porous material is heated on a micro hotplate, leading to reactions between gas and the ionically adsorbed oxygen on the sensor surface. This dramatically changes the conductivity of the material, which can be measured. To achieve an even higher sensitivity and selectivity, the sensor is used in a temperature cycled operation (TCO) (Baur, Schütze, and Sauerwald 2015; Leidinger et al. 2014). In brief, rapid temperature variations allow the simulation of a sensor array, where each moment within the cyclic temperature operation represents an individual sensor, hence it is sometimes called a virtual multi-sensor. In contrast to constantly heated sensor arrays, dynamically operated sensors allow for the evaluation of transient behaviour. It was found that the relaxation processes after a rapid temperature change provide significant information

regarding the gas mixture. This results in a complex pattern which is typically evaluated by means of machine learning, or lately, also by artificial intelligence, i.e. deep convolutional neural networks (Robin et al. 2021; Robin et al. 2022). Besides the identification of gases, selective quantification is also achievable through this approach (Baur et al. 2021). However, an enhancement of sensitivity can also be observed. The TCO conditions the sensor so that a fast change from high to low temperature leaves the sensor in a transient state with an excess of ionically adsorbed oxygen. This makes the sensor surface very reactive to gases (enhanced sensitivity) and the change of conductance is even higher (Schütze and Sauerwald 2020).

In the set-up shown in Figure 3, a MOS sensor in TCO is used to monitor the absorption of gases by the solutions. This sensor has four different integrated sensing layers, which enables the measurement of a wide variety of gases. The chosen TCO allows a measurement every 30 s. The setup shows a 2 L Duran glass bottle with 200 ml salt solution. Five similar bottles were prepared to compare the absorption of substances in potassium carbonate, magnesium nitrate, magnesium chloride, and pure water. One additional bottle is used as a reference without any liquid. This was used to dismiss the chances of adsorption effects on the glass, leakages, or reaction with materials in the glass. The sensors (all from Sensirion, Stäfa, Switzerland) used were a MOS gas sensor (SGP40) for pollutants, a temperature and humidity sensor (SHT35), a selective formaldehyde detector (SFA30), and a selective CO_2 sensor (SCD41).

Solutions

All salts for tests with gas sensors were supplied by Fa. Grüssing, Filsum, Germany. Additional to magnesium nitrate (analytical grade, no. 120911000) and magnesium chloride (purissimum, no. 12088100) already in use in museums, potassium carbonate (analytical grade, no. 12005100) was tested. Its saturated solution is strongly alkaline (pH > 13) and reacts with aldehydes via the Cannizzaro reaction to form carboxylate anions. Acid gases (including H_2S) will be neutralised to the corresponding non-volatile anions. This is an advantage over neutral magnesium salts, where only physical dissolution occurs, but no reaction. First orienting test measurements at the Fraunhofer Institute, Braunschweig, Germany, with formaldehyde in an emission chamber in still air showed that the formaldehyde gas concentration declined faster over potassium carbonate than magnesium nitrate, but both absorbed excellently (Eggert 2022a).

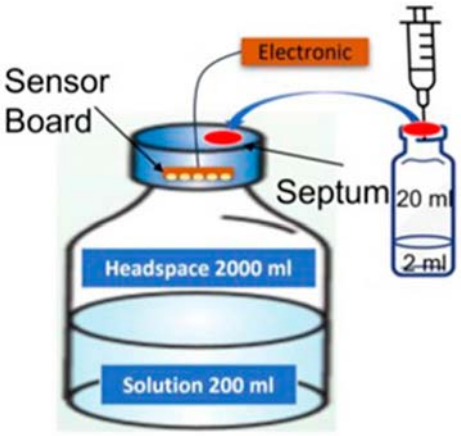


Figure 3. Set-up for fast evaluation of absorption behaviour of different salt solutions after injection of gases in the headspace.

Results and discussion

Measurements in the headspace over solutions

For the set-up in Figure 3, Figure 4 shows the absorption behaviour of different salt solutions for 5 ppm of acetic acid, formic acid, and hydrochloric acid measured by the SGP40 MOS sensor. The release and absorption of acids in the bottle can be followed by the sensor response. The reference bottle with air shows a comparably slow decline in the sensor response, while the bottles with any liquid show a much faster decline. After less than an hour, the sensor response levels off before the release of acids, indicating the strong absorption of the saturated salt solutions. Potassium carbonate shows the fastest absorption throughout the measurements.

Measurements in display cases

For measurements closer to the application in museums, four identical display cases (80×80 cm^2 floor area and a height of 200 cm) were set up in an air-conditioned room. They were further sealed with tape to reduce leakage. With a CO_2 sensor, the overall tightness of these display cases can be tested. After taping the display cases and releasing 5,000 ppm of CO_2, it can be observed that it takes more than 16 h to lose 50% of the released CO_2 through leakages, for each display case.

For the following measurements, a temperature and humidity sensor, a selective formaldehyde detector, a selective CO_2 sensor, and two MOS gas sensors at two different heights (bottom and middle) were placed in the showcases (Figure 5). Each showcase contains three containers with saturated salt solutions on the floor with a total surface area of 1,530 cm^2 (three times 30×17 cm^2). The different display cases contain the previously tested salt solutions. Additionally, there is one display case without any salt solutions (just with empty containers) as a control. The

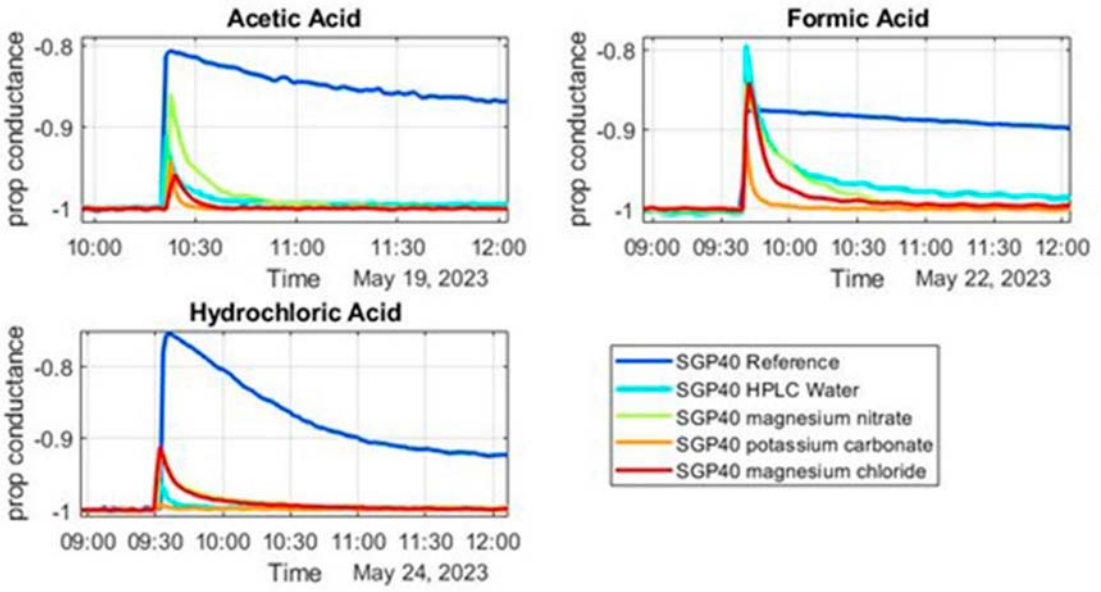


Figure 4. Sensor response (proportional to the conductance) to the release of acetic acid, formic acid and hydrochloric acid (5 ppm each).

experiment starts as soon as the display case has reached the deliquescence RH of the salt solution. Reaching this steady state condition takes approximately 36 h. The RH is continuously monitored by a SHT35 temperature and humidity sensor. To inject air pollutants in a controlled way, a 5 L stainless steel tank is used which can be precisely filled with any volatile pollutant at an over-pressure of 4,000 hPa. Through a small hole in the top, the volume of the tank can be vented into the display case. In the first experiment, the tank was filled with 20% CO_2 as well as 30 ppm of formaldehyde. Since the display cases do not show the same leakage, a release of a pollutant will always be accompanied by a release of CO_2. In this way, the difference in leakage between measurements and salt solutions can be monitored and, if necessary, calculated. The release leads to a mean concentration of approximately 3,200 ppm CO_2 as well as 480 ppb formaldehyde in the display cases.

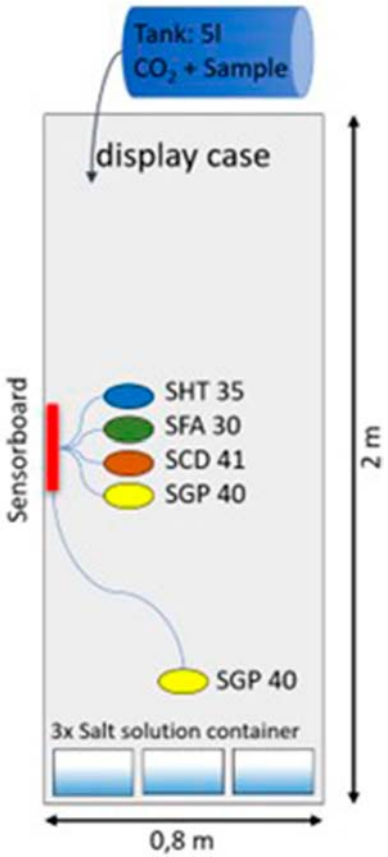


Figure 5. Schematic depiction of the set-up utilised for conducting field tests on the display cases.

Figure 6 shows the release of formaldehyde in such a display case without saturated salt solutions (green), with magnesium nitrate (light blue), and with magnesium chloride (dark blue). The CO_2 graphs are similar for all display cases, with the control display case being the least tight. At the same time, the formaldehyde concentration of the reference display case decreases the slowest, but still faster than that of CO_2. Formaldehyde seems either to have a much higher diffusion coefficient than CO_2 or to interact with materials in the display case through adsorption on surfaces or chemical reactions. It can still be concluded that magnesium nitrate and magnesium chloride absorb some of the formaldehyde released. Compared to the control (> 6 h), the salt solutions reached 200 ppb 2 h 41 min after release.

In these measurements, the concentrations tested are significantly higher than those typically encountered in display case applications. However, the distribution between the gas and liquid phase can reasonably be extrapolated to lower concentrations. While selective gas sensors such as the SFA30

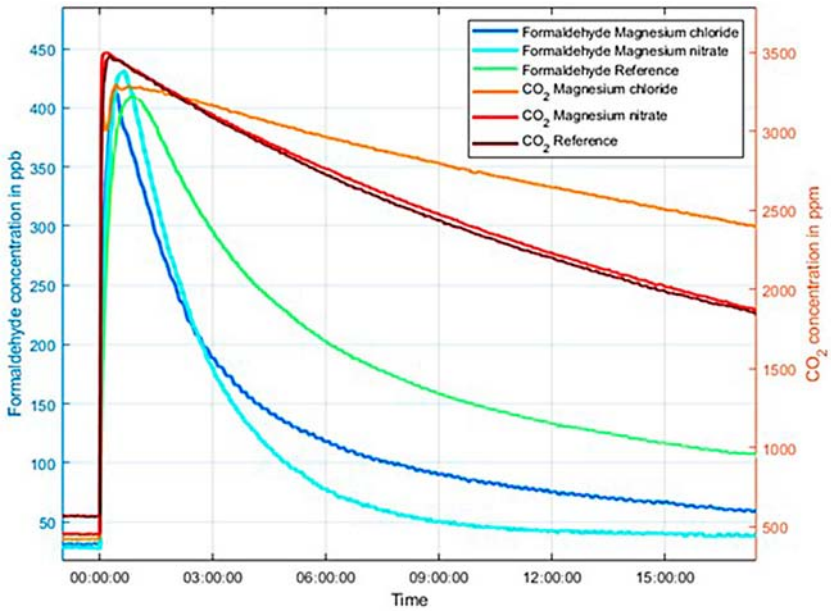


Figure 6. Release of formaldehyde in a display case at 00:00:00. The formaldehyde concentration is monitored by an SFA30 and CO_2 level by an SCD41.

provide valuable information about a single substance, they were found to exhibit cross sensitivities to hydrogen sulfide, and the response time from the release to the maximum measured concentration exceeded 25 min. In contrast, measurements with MOS gas sensors exhibit response times of less than one minute, enabling real-time, on-site qualitative monitoring of events within display cases. However, quantifiable measurements with MOS gas sensors demand extensive training with knowledge about the background gas mixture.

Measurements for other pollutants (e.g. SO_2, NO_2, acetaldehyde, H_2S) are currently in progress. Future measurements will also involve the collection of gas samples using thermal desorption tubes, which will be analysed by thermal desorption-GC-MS to affirm the findings of the MOS gas sensor measurements. Additional information about gas composition within display cases utilising saturated salt solutions is essential to further establish confidence in saturated salt solutions as climate control solution in art exhibitions. Theoretical considerations and measurements to date allow the prediction that saturated salt solutions have the additional advantage of being excellent absorbers for pollutants.

Conclusion

Silica gel products (e.g. ProSorb) and saturated salt solutions are both passive methods to achieve constant RH. No expensive air conditioning equipment and no electricity are needed. Therefore, they are inherently fail-safe, a significant attribute in risk assessment, and their carbon footprint is lower. However, except for the easier handling of silica gel products, saturated solutions of magnesium nitrate and potassium carbonate have several important advantages:

- Their higher water capacity enables longer maintenance intervals.
- The RH is fixed as long as undissolved salt and a liquid phase are present and does not shift slowly.
- Pollutant emissions from these solutions are negligible.
- Pollutants are strongly absorbed and the air in the cases is cleaned.
- Some fine dust might even stick to the liquid phase which otherwise would be swirled up again from solid surfaces.

Outlook

Experience with this application has now been widely lost in the field, and potassium carbonate has not been used before in museums. Implementation in museums might detect problems that were never considered in theoretical reflections. Therefore, a community science project was started in the summer of 2023 to collect as much knowhow on practical use as possible, and a *Guide for Participants* was widely distributed (Eggert 2022b). The aim is to gather as much diverse experience as possible regarding different climatic zones, museum types and buildings and their climate control, as well as many different display cases. The Veste Coburg Art Collections and 61 other institutions (as of October 2023) will monitor the RH in and outside display cases climatised with potassium carbonate or magnesium nitrate solutions using dataloggers during a full annual cycle. The following questions will be addressed:

- Is maintenance (adding salt or water) needed at all during the first year?
- How quickly and evenly is the desired RH achieved after closing the display case?
- Does the solution stay in equilibrium (no diluted upper layers causing higher RH on longer periods of dehumidification, no inhibiting crust layers during humidification)?
- Do the solutions appear darker after one year, do they act as sink for dust?
- Any accidents or special observations?
- At the Veste Coburg, the thickening of salt solutions with different thickening or gelling agents will also be evaluated – an approach that would be relevant for areas with seismic activity or for movable display cases.

The results will, of course, depend considerably on the geometry of the display cases and their construction materials, their airtightness, the difference from the outside RH, the amount of solution used, and their surface area. However, the project aims to create general guidelines for museums using the aggregated data of all participants. Likewise, if the project proves successful, participants might share their own experience with colleagues and act as disseminators: a crucial factor for a revival of the method, which is indeed a sustainable solution for conservation.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work is funded by the German Federal Foundation for the Environment (DBU) under grant Az. 38338/01. An IIC (International Institute for Conservation) seed money grant supported initial formaldehyde measurements in Braunschweig.

ORCID

Gerhard Eggert http://orcid.org/0000-0003-2443-1094
Oliver Brieger http://orcid.org/0009-0004-2686-2706
Daniel Becker http://orcid.org/0009-0008-8315-3729
Christian Bur http://orcid.org/0000-0003-2177-3646

References

ACCENT. 2023. The System H^+ – NH_4^+ – Na^+ – K^+ – Ca^{2+} – Mg^{2+} – $SO4^{2-}$ – NO_3^- – Cl^- – CO_3^{2-} – OH^- – H_2O, at 298.15 K. Accessed 30 September 2023. http://www.aim.env.uea.ac.uk/aim/accent4/model.php.

Barsan, N., and U. Weimar. 2001. "Conduction Model of Metal Oxide Gas Sensors." *Journal of Electroceramics* 7 (3): 143–167. https://doi.org/10.1023/A:1014405811371

Baur, T., J. Amann, C. Schultealbert, and A. Schütze. 2021. "Field Study of Metal Oxide Semiconductor Gas Sensors in Temperature Cycled Operation for Selective VOC Monitoring in Indoor Air." *Atmosphere* 12 (5): 647. https://doi.org/10.3390/atmos12050647.

Baur, T., A. Schütze, and T. Sauerwald. 2015. "Optimierung des temperaturzyklischen Betriebs von Halbleitergassensoren." *Technisches Messen* 82 (4): 187–195. https://doi.org/10.1515/teme-2014-0007.

Creahan, J. 1991. "Controlling Relative Humidity with Saturated Calcium Nitrate Solutions." *WAAC Newsletter* 13 (1): 17–18. https://cool.culturalheritage.org/waac/wn/wn13/wn13-1/wn13-106.html.

Dix, A. 2023. E-mail to G.E. on 16 March 2023.

Eggert, G. 2022a. "Saturated Salt Solutions in Showcases: Humidity Control and Pollutant Absorption." *Heritage Science* 10: 54. https://doi.org/10.1186/s40494-022-00689-3.

Eggert, G. 2022b. "Two at a Time: Climatisation and Pollutant Absorption." *News in Conservation* 93: 12–15. https://www.iiconservation.org/news-conservation-issue-93-december-january-2023.

Eggert, G., S. Bette, and R. E. Dinnebier. 2021. "Curious Compounds – Investigating the Variety and Structure of Calcium Acetate Efflorescence on Calcareous Objects by XRPD." In *ICOM-CC 19th Triennial Conference Preprints Beijing*, edited by J. Bridgland, 1–10. Paris: ICOM. https://www.icom-cc-publications-online.org/4463.

Eggert, G., and A. Fischer. 2022. "Curious Corrosion Compounds Caused by Contact: A Review of Glass-Induced Metal Corrosion on Museum Exhibits (GIMME)." *Corrosion and Materials Degradation* 3 (3): 553–565. https://doi.org/10.3390/cmd3030030.

Harvie, C. E., N. Møller, and J. H. Weare. 1984. "The Prediction of Mineral Solubilities in Natural Waters: The Na-K-Mg-Ca-H-Cl-SO_4-OH-HCO_3-CO_3-CO_2-H_2O System to High Ionic Strengths at 25°C." *Geochimica et Cosmochimica Acta* 48 (4): 723–751. https://doi.org/10.1016/0016-7037(84)90098-X.

Hilbert, G. S. 1987. *Sammlungsgut in Sicherheit, Teil 2. Lichtschutz, Klimatisierung*, 181. Berlin: Gebr. Mann.

Hovmand, I. 2023. Oral Communication to G.E. on 22 September 2023.

Kuhn-Wawrzinek, C. F., G. Eggert, and T. Schleid. 2022. "Sulfur, the 'Enemy of Copper': Replication of Sulfurous Efflorescence on Copper-Based Heritage Materials with Elemental Sulfur." *Proceedings of the Interim Meeting of the ICOM-CC Metals Working Group Helsinki*, 194–201, Paris: ICOM.

Leidinger, M., T. Sauerwald, W. Reimringer, G. Ventura, and A. Schütze. 2014. "Selective Detection of Hazardous VOCs for Indoor Air Quality Applications Using a Virtual Gas Sensor Array." *Journal of Sensors and Sensor Systems* 3 (2): 253–263. https://doi.org/10.5194/jsss-3-253-2014.

Lide, D. R., ed. 2005. *CRC Handbook of Chemistry and Physics, Internet Version*, 15: 25–26. Boca Raton: CRC Press.

Madou, M. J., and S. R. Morrison. 1989. *Chemical Sensing with Solid State Devices*. San Diego: Academic Press.

Piechota, D., and J. D. Piechota 2024. "Thirty Years of Sustainable Control of Relative Humidity." *WAAC Newsletter* 46 (1): 9–19.

Robin, Y., J. Amann, T. Baur, P. Goodarzi, C. Schultealbert, T. Schneider, and A. Schütze. 2021. "High-Performance VOC Quantification for IAQ Monitoring Using Advanced Sensor Systems and Deep Learning." *Atmosphere* 12 (11): 1487. https://doi.org/10.3390/atmos12111487.

Robin, Y., J. Amann, P. Goodarzi, T. Schneider, A. Schütze, and C. Bur. 2022. "Deep Learning Based Calibration Time Reduction for MOS Gas Sensors with Transfer Learning." *Atmosphere* 13 (10): 1614. https://doi.org/10.3390/atmos13101614.

Schieweck, A. 2020. "Adsorbent Media for the Sustainable Removal of Organic Air Pollutants From Museum Display Cases." *Heritage Science* 8: 12. https://doi.org/10.1186/s40494-020-0357-8.

Schölzel, C. 2006. "*Der Zinsgroschen* von Tizian: ein Kapitel Restaurierungsgeschichte in Dresden." *VDR Beiträge zur Erhaltung von Kunst- und Kulturgut* 2: 77–88.

Schütze, A., and T. Sauerwald. 2020. "Chapter Twelve – Dynamic Operation of Semiconductor Sensors." In *Semiconductor Gas Sensors*, 2nd edn, edited by R. Jaaniso and O. K. Tan, 385–412. Duxford: Woodhead Publishing.

Sharma, D., K. Schmidt-Ott, U. Rothenhäusler, E. Hildebrand, S. George, E. Joseph, and T. Lombardo. 2022. "Multi-Modal Analysis of Transparent Glass to Detect Early Signs of Volatile Organic Compounds-Induced Corrosion Due to Contaminated Silica Gel." In *Recent Advances in Glass and Ceramics Conservation*, edited by R. Gridley and V. Schussler, 195–204. Paris: ICOM.

Stolow, N. 1987. *Conservation and Exhibitions: Packing, Transport, Storage, and Environmental Considerations*, 168–170. London: Butterworths.

Thomson, G. 1986. *The Museum Environment*. 2nd edn, 113f. London: Butterworth-Heinemann.

Tran, M.-P., P. Gonzalez-Aguirre, C. Beitia, J. Lundgren, S.-I. Moon, and H. Fontaine. 2019. "Deposition of Hydrogen Chloride Gas on Copper Wafer Depending on Humidity and HCl Concentration." *Microelectronic Engineering* 207: 1–6. https://doi.org/10.1016/j.mee.2019.01.001.

Weber, K. 1967. "Der Zinsgroschen von Tizian wieder ausgestellt." *Maltechnik* 73 (4): 100–106.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S81–S90
https://doi.org/10.1080/00393630.2024.2336774

ORIGINAL RESEARCH OR TREATMENT PAPER

UK Museums and Heritage Sustainable Packing Group: Exploring Sustainable Strategies for Soft Wrapping Paintings

Grupo de Embalaje Sostenible de Museos y Patrimonio del Reino Unido: Exploración de Estrategias Sostenibles para Pinturas de Embalaje Suave

Rebecca Ellison[1], Rebecca Hellen[1], Alice Tate-Harte[2], Alexandra Gent [3], Kim Kraczon[4,5], Victoria Ward[6] and Clare Richardson[6]

[1]Royal Oak Foundation Conservation Studio, National Trust, Kent, UK; [2]English Heritage Trust, Swindon, UK; [3]National Portrait Gallery, London, UK; [4]Ki Culture, Amsterdam, The Netherlands; [5]Gallery Climate Coalition, London, UK; [6]Courtauld Institute of Art, London, UK

ABSTRACT

This paper explores methods to improve the sustainability of packing artworks, focusing on soft wrapping of framed paintings. In 2022, the UK Museums and Heritage Sustainable Packing Group was formed. The research described in this paper focuses on one aspect of the group's activity: seeking to find materials and methods which reduce environmental burdens and comply with conservation standards for soft wrapping two-dimensional artworks for short journeys between display, storage locations and conservators' studios. The project investigated the physical qualities of recycled content polyethylene (PE), bioplastics and paper-based alternatives, along with common barrier materials such as virgin PE sheet and Bubble Wrap®, to form comparative datasets. Each material's environmental impact, potential for reuse, interaction with artworks and ability to maintain adequate buffering against environmental changes during transport was researched. Alternative methods were also explored to reduce the quantity of sealing tape and promote its reversibility and reuse. The environmental impacts of the materials were assessed by sustainability specialists at the University of Manchester's Sustainable Materials Innovation Hub. Reusable and recycled content films offered the most promising alternatives to the PE wrapping most used at present. The use of a tying method, eliminating the need for adhesive tape, also showed potential for further investigation. The low-cost testing methodology should be refined to better control the variables and allow for more repeatable testing, but these preliminary results will help to refine future research directions.

Este artículo explora métodos para mejorar la sostenibilidad del embalaje de obras de arte, centrándose en el embalaje suave de pinturas enmarcadas. En 2022 se formó el UK Museums y Heritage Sustainable Packing Group. La investigación descrita en este artículo se centra en un aspecto de la actividad del grupo: buscar materiales y métodos que reduzcan las cargas ambientales y cumplan con los estándares de conservación para envolver obras de arte bidimensionales en viajes cortos entre exhibición, lugares de almacenamiento y estudios de conservadores. El proyecto investigó las cualidades físicas del polietileno (PE) con contenido reciclado, los bioplásticos y las alternativas a base de papel, junto con materiales de barrera comunes como láminas de PE virgen y Bubble Wrap®, para formar conjuntos de datos comparativos. Se investigó el impacto ambiental de cada material, su potencial de reutilización, su interacción con las obras de arte y su capacidad para mantener una protección adecuada contra los cambios ambientales durante el transporte. También se exploraron métodos alternativos para reducir la cantidad de cinta selladora y promover su reversibilidad y reutilización. Los impactos ambientales de los materiales fueron evaluados por especialistas en sostenibilidad del Centro de Innovación de Materiales Sostenibles de la Universidad de Manchester. Las películas reutilizables y con contenido reciclado ofrecían las alternativas más prometedoras al envoltorio de PE más utilizado en la actualidad. El uso de un método de atado, que elimina la necesidad de cinta adhesiva, también mostró potencial para una mayor investigación. La metodología de prueba de bajo costo debe perfeccionarse para controlar mejor las variables y permitir pruebas más repetibles, pero estos resultados preliminares ayudarán a perfeccionar las direcciones de investigación futuras.

ARTICLE HISTORY
Received October 2023
Accepted March 2024

KEYWORDS
Sustainability; transport; packing; soft wrapping

Sostenibilidad; transporte; embalaje; embalaje blando

Introduction

The UK Museums and Heritage Sustainable Packing Group was formed in 2022. The group's mission is to investigate more sustainable approaches to packing artworks that comply with conservation standards. The current membership of 37 conservators, conservation scientists, art handlers and registrars is drawn from 11 national museums and heritage organisations

CONTACT Rebecca Ellison rebecca.ellison@nationaltrust.org.uk Royal Oak Conservation Studio, Knole, Sevenoaks, Kent TN15 0RP, UK
© The International Institute for Conservation of Historic and Artistic Works 2024

across the UK. It is a collaborative and efficient network, pooling internal resources and expertise, working with external partners, for example Ki Culture; Gallery Climate Coalition (GCC); and the University of Manchester's Sustainable Materials Innovation (SMI) Hub, Henry Royce Institute.

This paper will focus on the group's work to investigate sustainable strategies for soft wrapping. In the UK, the style of soft wrapping commonly used for packing historic framed paintings involves creating inner and outer cushioning layers with acid-free tissue and PE Bubble Wrap® or closed cell PE Jiffy® foam corners and wrapping with a medium-thick PE barrier film. The barrier film is normally sealed with brown polyvinyl chloride (PVC) packing tape (Figure 1). The packing materials are usually discarded after one use because of damage to the materials from tape removal, and concerns about soiling and storage. The wrapping is not usually recycled so constitutes single-use plastic.

Conservators rely on soft wrapping two-dimensional artworks for short journeys between display, storage locations and conservators' studios. The key advantage of the inert, durable plastic barrier films is their ability to buffer against fluctuating relative humidity (RH) while protecting vulnerable surfaces from dust, insects and liquids. However, the environmental burden and social injustices associated with plastics necessitate an urgent re-evaluation of their use.

The group instigated a project to examine viable alternatives to the materials currently used for soft wrapping in the UK museum and heritage sector. The aim was to identify materials and methods of wrapping with comparable performance to traditional PE films sealed with pressure-sensitive tape, which could be then recommended for use with two-dimensional artworks that are highly susceptible to rapid fluctuations in temperature (T) and hence RH. Alternative materials and methods for soft wrapping that did not perform as well as their traditional counterparts could still find potential application in the transport of artworks that are not highly susceptible to RH and T fluctuation.



Figure 1. Pietro Longhi, *The Letter*, NT 774245, wrapped with virgin PE, Jiffy® corners, cotton tape and acid-free tissue. Image: Rebecca Ellison.

Background

Plastics are derived from a finite supply of natural resources with 10% of all available fossil fuels associated with plastics production (Davis 2022). Carbon dioxide is emitted in every phase of plastic production, contributing to 4.5% of global greenhouse gases as of 2015 (Choi-Schagrin and Tabuchi 2022). However, the energy and resources required for manufacturing plastic products vary drastically, resulting in a wide range of carbon footprints for commercially available plastic products. For example, Tyvek®, a high-density PE (HDPE) film, has a relatively small carbon footprint in comparison to other polymers such as low-density PE (LDPE) (Figure 2) indicating that the carbon footprint of plastics must be individually assessed. Another approach to reducing environmental impact is reduction of the weight and/or volume used: if any product can be used in smaller quantities this will enhance its environmental sustainability credentials.

Assessing the environmental burden of materials requires a comprehensive approach that includes, and extends beyond, the carbon footprint of manufacture. In determining which materials are least detrimental to the environment, as well as to human beings, additional impact categories found in life cycle assessments (LCAs), should be considered such as air, soil and water pollution. In the case of plastics, their disposal options raise particular concerns. The same properties we value in plastic films for the protection of tangible cultural heritage in transit – moisture repellence, durability, resistance to degradation – are undesired properties for their end-of-life scenario. Plastics can take thousands of years to degrade, often ending up as pollutants in our ecosystems.

It is important to engage with local waste management providers, as their capabilities can alter the end-of-life fate of materials. Where recycling is possible, there can be other drawbacks: we are only beginning to understand the repercussions of microplastics and nanoplastics released by the process entering our bodies and ecosystems (McVeigh 2023). Similarly, while tissue paper is compostable, it poses a littering

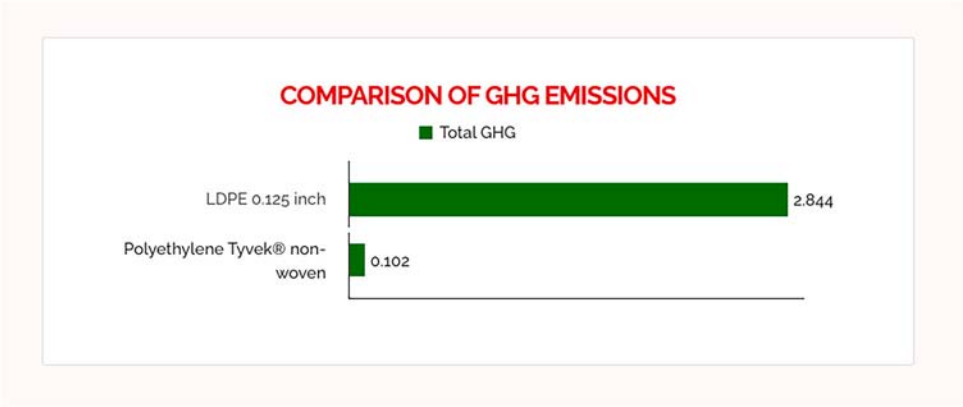


Figure 2. Comparison of the GHG emissions for LDPE and PE Tyvek®. Source: https://stich.cuturalheritage.org.

challenge for composting facilities and is therefore undesirable.

Selection of sustainable alternatives

The materials selected were evaluated in stages, and unsuitable materials were eliminated in the process, starting with: evaluation of working properties; sustainability testing at SMI hub; shelf life and cost; and testing the efficacy of barrier films shortlisted from the earlier stages.

The Gallery Climate Coalition's *Plastic Alternative Packaging Materials Research* (Kraczon 2021) provided an initial list, from which the group selected potential substitutes. In addition, the group was keen to include thinner plastic films, although a barrier film containing recycled material was preferred over lightweight virgin LDPE counterparts. Eco-Friendly Bubble Wrap®, a product marketed as 'biodegradable' was examined but discarded, since it contains additives that promote film fragmentation into microplastics. This highlighted the importance of examining the transparency of sustainability claims. Traditional materials were also included as a benchmark and products were selected from Westmount Packaging, a main supplier of materials to UK art transport companies (Table 1).

The physical characteristics of barrier film materials were evaluated during two workshops held at the National Gallery, London, and The National Trust, UK, in 2022. Seventy-six participants took part including conservators, art handlers and registrars who were asked to record their assessment of the materials through a Microsoft Forms questionnaire designed by the group. Evaluation categories included: foldability; propensity to mould to object; transparency; cushioning; strength/tear resistance; softness; water resistance; resistance to mould and insects; reusability; ease of storage; potential to create a good seal; reversibility and compatibility with different pressure-sensitive tapes.

The high-rated materials were taken forward to sustainability testing at SMI Hub. In their assessment, the technical specifications of alternative materials were qualitatively analysed, considering four key aspects as environmental performance indicators: recycled content; amount of material to fulfil the function of the product; compatibility with main waste streams and prospective end-of-life fate (Table 1). Shelf life and cost efficiency were also considered when selecting materials to take forward. Off-gassing was not considered as part of this study because the intended short-term purpose of the wrapping meant that volatile organic compounds (VOCs) were not a risk to the artworks.

During this initial phase of research, the group's increasing knowledge refined and expanded materials selected for testing. Between workshops, PE film with a higher-grade post-consumer waste (PCW) recycled content was identified (1000 mm 45µm thick 30% Yorkshire Packaging Systems (YPS)), which was less granular and more transparent, replacing previously assessed PCWFlex30 (Polystar Plastics).

The next stage of the project was to test the efficacy of selected alternative and benchmark films (Table 1) as a buffer against changes in RH. This was facilitated by Research Seed Funding awarded to The National Trust. Testing was designed and completed over the summer of 2023 by author Ward. The suitability of more sustainable sealing methods (Gill-Brown 2021) was evaluated and one method of using cotton ties (Green 2022) was selected for further testing with the range of barrier films.

Testing of buffering properties of barrier film

The testing aimed to recreate typical scenarios encountered at The National Trust and English Heritage where most paintings remain unglazed, many without backing. It remains a strategic decision to keep paintings unglazed due to the historic settings,

Table 1. List of soft wrapping materials (traditional and alternative) considered by the UK Museums and Heritage Alternative Packing Group (Kraczon 2021). Green indicates good, amber moderate and red poor.

Material	Supplier	Composition	Tested in workshop?	Tested at SMI Hub	Barrier film testing	Potential for recycling (UK only)	Potential for reuse
Barrier films							
Medium Duty 120 µm thick PE (not crease free) 1.8 m/3.6 m	Polythene Sheeting – Westmount Packaging	100% virgin LDPE	Y	Y	Y		
1000 mm 45 µm thick 30% recycled content PE	Polythene Transit Shrink Film | Yorkshire Packaging Systems (yps.co.uk)	LDPE/linear LLDPE, 30% recycled content	N	Y – this product replaced Tristar and PCWflex 30 PCW sourced from UK waste streams	Y		
Clear 160 g Pallet Top Sheets (Centre-folded on roll)	Pallet Covers - Westmount Packaging	LDPE 100% recycled content	N	N	Y		
534–0050 silicone-coated polyester film 50 µm thick 1030 mm wide × 25 m	Silicone-Coated Film - Preservation Equipment Ltd	Polyester: polyethylene Terephthalate (PET)	N	N	Y – replaced standard polyester film as non-stick if in contact with painted/ gilded surfaces		
CompostaFilm® Industrial	CompostaFilm compostable packaging | BioViron International	PLA – compostable by industrial composting process	Y	Y	Y		
CompostaFilm Home	CompostaFilm compostable packaging | BioViron International	PLA – home compostable	Y	N	N		
212–1422 Tyvek 1442R 1524 mm wide x 25 m	Tyvek roll 1442r (formally 1443r) - Preservation Equipment Ltd	Spunbound 100% HDPE	Y	N	Y		
Premium White Glassine Paper Rolls 900 mm wide × 500 m, 40 gsm	Glassine Paper Rolls - Westmount Packaging	cellulose	Y	N	Y		
Tristar 35 µm thick PE	Tristar™ Polythene Plastic Packaging | Polystar Plastics ✓	Coextruded LDPE	Y	N – replaced by YPS 30% recycled content PE	N		
PCWflex30	PCWflex Plastic Packaging | Polystar Plastics ✓	LDPE 30% PCW content	Y	N – replaced by YPS 30% recycled content PE	N		
NatureFlex™ 19NK/ 23NK/30NK/45NK	NatureFlex™ Cellulose Film Packaging Solutions	Modified cellulose from wood pulp	Y	N	N		
211–2230 Peltek 30 gsm 1200 mm wide × 100m	PELtek wrapping and covering material - Preservation Equipment Ltd	Spunbond 100% polypropylene (PP)	Y	N	N		
PYSPOA3143 Melinex® polyester pockets 310 mm × 430mm	Polyester Pockets | CXD International	PET	Y	N	N – replaced with silicone-coated polyester film for testing		
450 mm wide × 10 m Strong Brown Premium Kraft Wrapping Paper Roll	Buy 450 mm x 10M Strong Brown Premium Kraft Wrapping Paper Roll (globepackaging.co.uk)	Cellulose	Y	N	N		

(*Continued*)

Table 1. Continued.

Material	Supplier	Composition	Tested in workshop?	Tested at SMI Hub	Barrier film testing	Potential for recycling (UK only)	Potential for reuse
External cushioning layers							
Small Bubble Wrap® 1200 mm wide x 100m	Small Bubble Wrap® - Westmount Packaging	LDPE c.30% PCW content	Y	Y	N/A		
500 mm × 75 m roll Green Biodegradable Eco-Friendly Bubble Wrap®	Buy 500 mm x 2 × 75M Rolls of Green Biodegradable Eco-Friendly Bubble Wrap® (globepackaging.co.uk)	LDPE + oxo degradable additives	Y	Y	N/A		
Paper Bubble Wrap® 500 mm × 10m	Buy 500 mm x 10M Roll of Eco-Friendly Paper Bubble Wrap® (globepackaging.co.uk)	cellulose	Y	N	N/A		
CompostaFoam® 25 mm	CompostaFoam compostable packaging | BioViron International	PLA	Y	N	N/A		
CompostaBlock®	CompostaBlock compostable packaging | BioViron International	PLA	Y	N	N/A		
Woolcool®	The Packaging Company | Woolcool® Insulated Packaging	100% wool, LDPE and MDPE protective outer layer	Y	N	N/A		
Internal cushioning layers							
Acid-Free Tissue Paper Rolls 900 mm wide × 500 m, 225 gsm	Acid-Free Tissue Paper Rolls – Westmount Packaging	Cellulose	Y	Y	N/A		
Eco-friendly Recycled Plain White Acid-Free Tissue Paper/ 900 mm × 700 mm, 19 gsm, 480 sheets/ pack	Acid-Free White Recycled Tissue Paper,19gsm 500 × 750 mm, Jewellers Tissue Paper, Tissue Paper Suppliers (transpack.co.uk)	Cellulose	Y	Y	N/A		
Tapes							
Prima Brown Vinyl Tape 48 mm wide × 66m	PRIMA® Vinyl Tape - Westmount Packaging	PVC tape with solvent-based adhesives	Y	Y	Y		
25 × 50 m self-adhesive paper tape, 57 gsm	25 mm x 50 m Self-Adhesive Paper Tape - 6 Rolls | Priory Direct	Cellulose with solvent-based adhesives	Y	Y	N		
Velcro® straps	VELCRO® Brand Straps - VELCRO® Brand	Nylon polyamide (PA) and PET			N		
White cotton herringbone tying tape 50 mm wide × 20m	Herringbone Webbing / Tying Tape - Westmount Packaging	cotton	N	N	Y		
Combined barrier film/cushioning systems							
JFSFT Jiffy Furnisoft roll 1200 mm wide × 100 m	Jiffy Furnisoft Rolls | Furniguard Rolls - Packaging Express	Bubble LDPE core laminated to printed LDPE film on one side and simulated LDPE paper on the other side	Y	N	N/A		
Quilted Moving Blankets 1820 mm × 2235 mm	Removal blankets | Webbing Straps | Ratchet Straps - Buy At Phoenix Supplies (phoenixsuppliesonline.co.uk)	Outer and filler both PET	Y	N	N/A		
Artpaxx®SmatArt bag for artowk storage and protection 90 × 90 cm DBSB92S Available in a range of sizes	Artpakk: Smart Bag Artwork Storage And Protection: 92 × 92 cm | Jackson's Art Supplies (jacksonsart.com)	LDPE and PP	Y	N	N/A		

Table 2. Materials used for testing.

Name	Supplier	Website
Protimeter Timbermaster BLD5609 Wood Moisture Meter	Test-Meter.co.uk	https://www.test-meter.co.uk/protimeter-timbermaster-bld5609-wood-moisture-meter?gclid=EAIaIQobChMI_-2y1pKTgQMVn4lQBh2n0gqeEAAYASAAEgLDS_D_BwE
iButton DS1923T/RH data loggers	Measurement Systems	iButton® DS1923 Hygrochron Temperature/Humidity Data Logger (measurementsystems.co.uk)
RS PRO Metallic Tape	RS online	RS PRO Metallic Tape, 50 mm × 50 m | RS (rs-online.com)
35L Really Useful Boxes	Preservation Equipment	The 35 L Really Useful Box is ideal for a number of storage purposes such as; storage and transport of files, hanging files and folders, Carrying cleaning kit and disaster recovery items and much more. - Preservation Equipment Ltd.
Self-adhesive Velcro® Spots	Amazon.co.uk	Hook and Loop Dots 10 mm Self Adhesive,NOCHME 1008pcs/ 504 Pairs Waterproof Double Sided Strong Sticky Back Coins Dots for DIY Crafts,Hook and Loop Tapes for Floor,Glasses, Metals,Paper, Leather, White: Amazon.co.uk: DIY & Tools
A4 size Daler Rowney Simply Canvas Panel	Jackson Art Supplies	Daler Rowney: Simply: Canvas Panel: A4 | Jackson's Art Supplies (jacksonsart.com)
Oak picture frame	Amazon.co.uk	Wall Space 7 × 5 Oak Frame | Light Oak 7 × 5 Photo Frames | SOLID OAK Picture Frames 5 × 7 | 7 × 5 Inch Oak Photo Frame | Wooden 7 × 5 Photo Frames with REAL GLASS | 7 × 5 Wooden Frame | 7 × 5 Frame | 5 × 7 Frame: Amazon.co.uk: Home & Kitchen
Saturated salt solutions	Sigma Aldrich	Merck | United Kingdom | Life Science Products & Service Solutions (sigmaaldrich.com)

lighting and fixtures and fittings. Backing is considered desirable but often with the aim of physical and environmental protection.

Table 2 details the materials used for testing. An unglazed, un-backed, framed artist's canvas board was used as a mock-up, and wrapped in each of the selected barrier films. The package was then placed in a series of microenvironments to experience a sudden change in RH conditions mid-way through a 24-hour test cycle. The microenvironments were inexpensively created using three identical polypropylene crates set at different RH conditions. These were modified to improve the seal of the crate lids using strips of inert PE foam.

Saturated salt solutions, contained in metal trays, were placed on the base of each crate with a solution depth of 2–5 mm, to achieve consistent results (OIML 1996). The crates were placed out of direct sunlight, away from external walls, to reduce significant temperature variation. After 12 h, Crate 1 and Crate 2 were able to reach the desired RH conditions of 50–57% and 70–77% using saturated salt solutions of magnesium nitrate ($Mg(NO_3)_2.6H_2O$) and sodium chloride (NaCl) respectively. Crate 3 was unable to reach the desired RH of 33%, using magnesium chloride (MgCl), but on average the RH readings ranged from 37% to 48% RH.

Throughout the experiment, T and RH inside the crates and films were measured using calibrated iButton® DS1923T/RH data loggers, with a logging interval of 1 min. An activated logger was attached to the top right corner of the front of the framed canvas using self-adhesive Velcro® spots. A second activated logger was similarly attached to the outside of the wrapped mock-up.

First, the barrier films along with the mock-up artwork (unwrapped) were acclimatised for a 24-h period in Crate 1 (54% RH). The contents were removed, and the mock-up promptly wrapped and placed in Crate 2 (75% RH). After 12 h, the package was then moved to Crate 3 (33% RH) for a further 12 h. Ten types of barrier film, either taped or tied, were tested (Figures 3–5).



Figure 3. Tied method using white cotton herringbone tape, supplied 50 mm wide in 20 m lengths and Tyvek® acid-free tissue. Image: Victoria Ward.

Results

Whilst the methodology created broadly repeatable RH conditions in the crates for the variety of barrier films, the conditions were not perfectly consistent across the testing, as can be observed in Figure 6(a–d). As a result, the performance of each film should be carefully compared with the conditions that were experienced in each individual test.

To broadly categorise the performance of the barrier film materials, the range of conditions measured inside the barrier films was compared to the range of



Figure 4. Taped method using PVC tape (CompostaFilm®). Image: Victoria Ward.

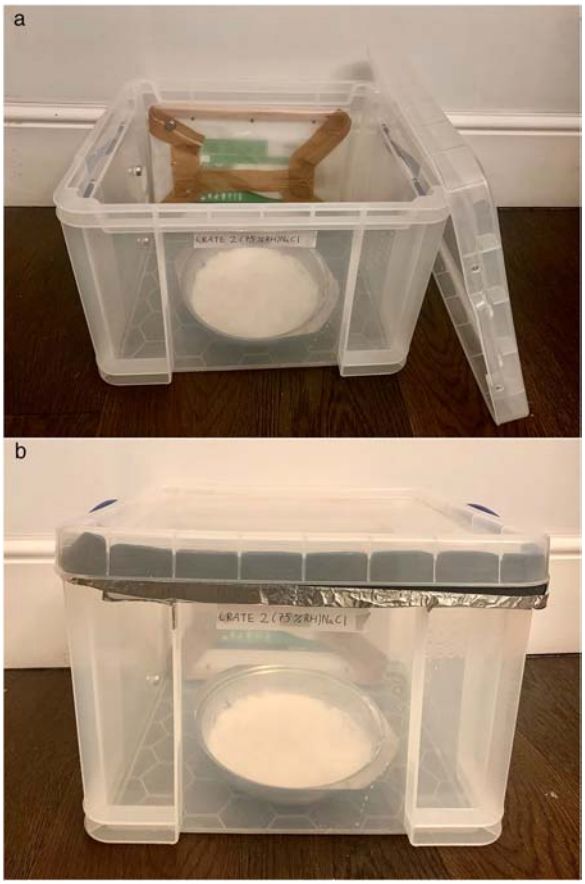


Figure 5. (a) Experimental set-up for testing of barrier films, showing Crate 2 (RH 75%) with strips of inert PE foam in PE attached to the crate with metallic tape. (b) Set-up of wrapped frame (taped), location of iButton® loggers and tray containing saturated salt solutions. Image: Victoria Ward.

conditions measured outside the barrier films. Good, moderate and poor performance were defined as the maintenance of the environment within bands of 7%, 12% and 18% respectively over the course of the testing period. Results are summarised in Table 3.

For comparative purposes, taped Westmount Packaging's medium duty 120-µm-thick PE was considered as the benchmark because this is what is commonly used, and this provided a minimally fluctuating environment of only 2% RH – the best of any of the films tested. The same material tied also maintained a steady environment with a 6% RH range inside wrapping (Figure 6a–b).

The performance of the other films tested varied from good to poor, and in almost every case taped barrier film performed better than the tied alternative. However, in the case of Tyvek®, the tied package provided a more minimally fluctuating environment. This may have been because the tying method resulted in a double thickness of Tyvek® around part of the frame.

Discussion

The research did not identify a similarly performing alternative to Virgin PE. However, taped 30% recycled PE (supplied by YPS) performed well and appears to be suitable for soft wrapping paintings. Recycled PE film can vary in granularity and transparency, depending on the quality and quantity of the PCW content. Opacity could impede quick checks for identification, more relevant for longer-term storage. Swapping virgin for recycled PE can save 20–50% of the carbon cost associated with the entire lifecycle of the material, when recycling is chosen as end-of-life fate in comparison to the linear system, where virgin material is produced and incinerated after disposal (Saleem et al. 2023). Regarding only the end-of-life stage, recycling plastics can reduce of up to 70% of carbon emissions with respect to other routes, such as incineration (Ashby 2021).

Therefore, swapping virgin for 30% recycled PE from a supplier using high grade PCW from local waste-streams is recommended. We suggest using a local supplier and the lowest gauge of polyethene which is adequate for wrapping.

Bioplastics (CompostaFilm) provided a good barrier. However, SMI Hub found issues with their sustainability criteria; it is currently not possible to recycle or compost polylactic acid (PLA) in the UK, meaning this is typically incinerated or sent to landfill. There is also the possibility that this encourages irresponsible disposal; in particular, PLA can contaminate PE waste streams, and the presence of only 2% of a biodegradable co-polyester in recycled films results in a significant decrease in the mechanical properties and the processability of the material (Titone et al. 2023). Additionally, if

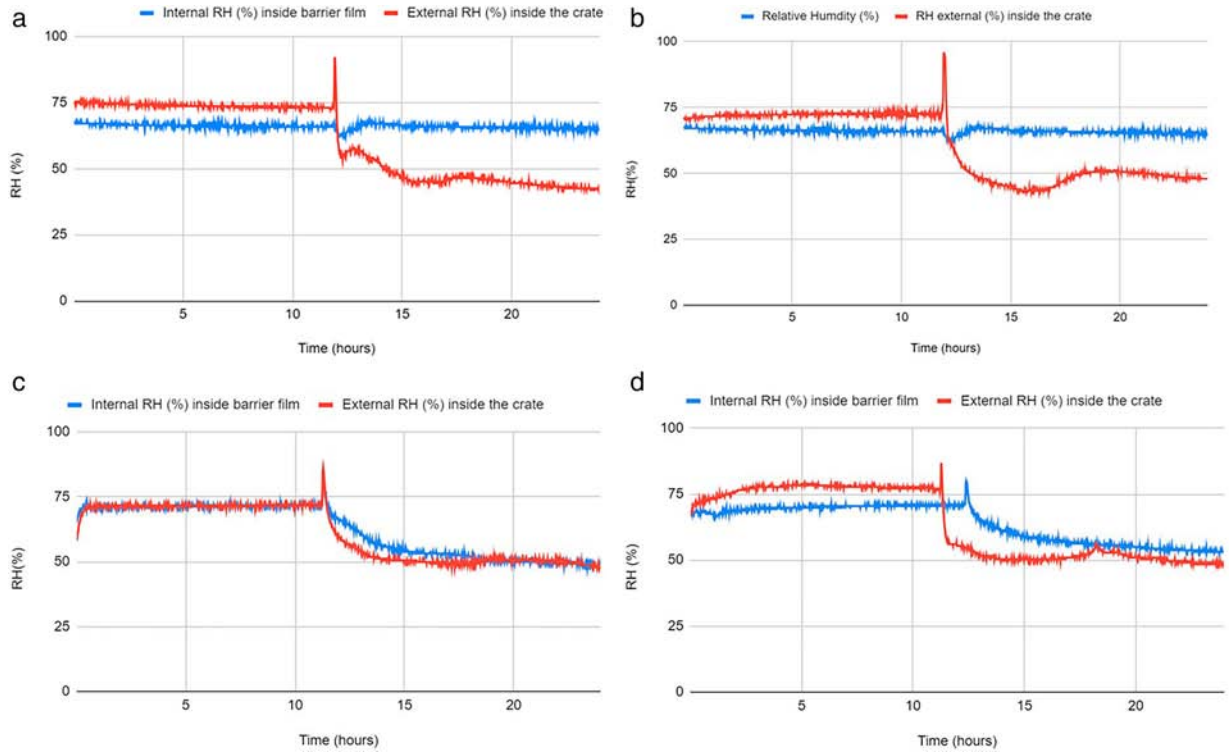


Figure 6. Overlay graphs of RH inside the barrier film material and RH inside the crates: (a) Medium Duty 120-µm-thick PE Westmount packaging (taped). (b) Medium Duty 120-µm-thick PE Westmount packaging (tied). (c) Premium White Glassine Paper, in rolls 900 mm × 500 m, 40 gsm (Preservation Equipment) (tied). (d) Premium White Glassine Paper in rolls 900 mm × 500 m, 40 gsm (Preservation Equipment) (taped).

biodegradable polymers are being incinerated there is no benefit in carbon cost when compared to fossil fuel-based polymers. In the case of bio-based polymers that are chemically identical to conventional polymers, no reduction in the production of micro-plastics is achieved. In fact, bioplastics can probably cause more environmental damage because land has been used to grow them, which could be used instead to grow trees or food to store carbon or improve food security. Ultimately, consumers need to divest from fossil fuel products which will become prohibitively expensive. When composting and recycling bioplastics become a reality in the UK, bioplastics will become a more sustainable option.

A fuller understanding of life cycle assessment of bioplastics should be considered before they are

Table 3. Results from testing buffering properties of barrier films. Green indicates good, amber moderate and red poor.

Wrapping material	RH range inside wrapping (%)	External RH parameters during 24-h testing period (%)	Overall performance of buffering properties of barrier film
Medium Duty 120 µm thick PE Westmount packaging (taped)	2	38–80	Good
Medium Duty 120 µm thick PE Westmount packaging (tied)	6	38–78	Good
Clear 160 g Pallet Top Sheets (Centre-folded on roll) 100% recycled content PE Westmount packaging (taped)	13	41–83	Poor
Clear 160 g Pallet Top Sheets (Centre-folded on roll) 100% recycled content PE Westmount packaging (tied)	12	44–83	Moderate
1000 mm 45 µm wide 30% recycled content PE YPS(taped)	3	38–81	Good
1000 mm 45 µm wide 30% recycled content PE YPS (tied)	15	38–78	Poor
Silicone-Coated Polyester Film Preservation Equipment. (taped)	4	45–71	Good
Silicone-Coated Polyester Film Preservation Equipment (tied)	6	45–77	Good
CompostaFilm® Industrial (Bioviron) (taped)	6	41–75	Good
CompostaFilm® Industrial (Bioviron) (tied)	14	40–72	Poor
212–1422 Tyvek 1442R 1524 mm x 25 m Preservation Equipment (taped)	16	40–77	Poor
212–1422 Tyvek 1442R 1524 mm x 25 m Preservation Equipment (tied)	10	39–77	Moderate
Premium White Glassine Paper Rolls 900 mm x 500 mm, 40gsm Westmount Packaging (taped)	11	45–85	Moderate
Premium White Glassine Paper Rolls 900 mm x 500 M, 40 gsm. Westmount packaging (tied)	17	48–86	Poor

embraced as viable alternatives, to avoid greenwashing in all museum departments, from conservation to catering and retail. The group recognises bioplastics are in their infancy and research in this area should continue.

Virgin PE is categorised as a 'soft plastic' in the UK. The majority is currently incinerated (Grice 2021). It remains the case that business waste streams need to be identified and improved, to encourage a higher proportion to be recycled, in turn making it more commercially viable. Museums and transport agencies could show leadership in this area by forming recycling hubs to make specialist collection of soft plastics worthwhile and maintain the quality of the plastic waste. With a high-quality waste stream, films can be re-recycled through up to 40 extrusion cycles whilst maintaining processability and mechanical properties (Jin et al. 2012).

If there is a PE recycling stream in existence but no space in the workspace to break down the materials and remove tape from the film, then 'like for like' clear PE tape is recommended as the film can be recycled with tape remaining adhered. Compatible tapes and barrier films can be selected by referring to the GCC tool *Advised Tape and Wrapping Material Combinations* (Titheridge 2021). Brown PVC tape should not be used because it reduces the quality of the resultant PCW. If brown PVC tape is used it should be removed before recycling. Paper tape has less environmental impact when incinerated than plastic tapes, but a higher carbon footprint in manufacture, and impedes recycling of the films (Navajas et al. 2014).

The results of the tie method testing allow conservators to consider avoiding use of adhesive tape entirely. It is important to note that during testing the tie method took sometimes twice as long as taping, but it saves time otherwise spent later in removing tape during unwrapping, and it promotes film reuse. Reuse is now a more accepted practice: the results of the workshop questionnaire indicated that 50% of participants would be willing to reuse virgin PE at least 5 times, representing an interesting step-change from previous practice. Additionally, 67% of respondents agreed that recycled PE could be reused 10 times and 33% would use it for even longer if it remains clean and dry.

Considerations for future work

This paper represents a pilot study, and a methodology is being refined for the next study. The group favoured an approach to make an active start in generating data, allowing identification of areas for others to take up. As the research was being conducted by multiple parties it grew organically.

One focus for future research is calculating hygrometric half times for a variety of soft wrapping approaches by repeating the experiment in a laboratory environment, with better control of variables. This would allow time spent wrapped, and likely ranges of RH experienced, to be considered. Lower-performing barrier film with a lower environmental burden could be considered in certain scenarios, such as transporting paintings a few miles across one city in an air-conditioned vehicle straight into a controlled museum environment. The barrier film could act simply as a rain barrier. Model scenarios for useful future research should measure film performance and RH change inside packages on real journeys.

This pilot study did not address cushioning alternatives and further investigation is recommended into the suitability of commercially available, reusable packing products, such as Artpakk™ padded bags, which show great potential for soft wrapping 2D works with plain frames.

Conclusion

During a typical art move within a UK city, wrapping contributes about 10% of the carbon cost of the operation, while the fuel emissions are much higher, although it would depend on the length of the journey, size of the painting and how many objects are being transported at once (Tate-Harte and Thickett 2023). Therefore, when mitigating the environmental impact of moving art, consolidating journeys and using electric and efficient vehicles should be addressed first. Although soft wrapping is a minor part of the carbon cost of shipping paintings, the plastic contributes to a wider environmental burden, creating soil, air and water pollution. It also forms a large proportion of the waste from museums' technical and conservation departments. Therefore, it is surely worth continuing to rethink this problem to reduce this unnecessary waste. Preparing this study highlighted simple improvements that could be made to working practice, such as using recycled content films, avoiding taping or using compatible tapes.

Future areas for the group's research will examine the social sustainability of introducing new practices, including what art handlers need from conservators and understanding how staff adapt to new practices. Reliance on workforces throughout the country means consensus must be built through training and guidance, as sites do not always have access to a conservator. Workshops proved an effective means of engagement around this topic. Physically assessing alternative materials fostered productive discussion. We anticipate they will be used as a model for future staff training at organisations like The National Trust.

Working as a group has been hugely effective: larger organisations have been able to support staff with time and money. The National Trust's Research Seed Fund allocated a grant to complete research, build partnerships and support next steps, proving

an enormous boost. Working with emerging conservators and seeking support from those involved in earlier studies into the transport of paintings (Mecklenburg 1991) has proved invaluable. Cultural and political shifts have been articulated in discussions. Research underpinning Mecklenburg (1991) proved artworks could be safely moved internationally for exhibition. Research questions in 2023 have substantially changed, balancing maintaining conservation standards with social and environmental sustainability.

Acknowledgements

The authors thank David Thickett, Senior Conservation Scientist, English Heritage, UK; Nigel Blades, Head Conservator, National Trust, UK; Stephen Hackney, Consultant Conservation Scientist, UK; Helen Roadnight, Assistant National Conservator – Preventive, National Trust; Daisy Green, Preventive Art Conservator, UK; Isabell Gill Brown, Collections Conservation Assistant, English Heritage; Dr Parnian Doostdar and Dr Jair Esquivel, Research Associates, SMI hub, Manchester, UK; Michaela Kiernan, Research and Business Engagement Officer, SMI Hub; and Adam Pierce, Industrial Liaison Officer, SMI hub.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the National Trust Research Seed Fund.

ORCID

Alexandra Gent http://orcid.org/0000-0001-7490-3008

References

Ashby, M. F. 2021. *Materials and the Environment: Eco-Informed Material Choice*. 3rd edn. Oxford: Butterworth-Heinemann.

Choi-Schagrin, W., and H. Tabuchi. 2022. "Trash or Recycling? Why Plastic Keeps Us Guessing". *New York Times*, 22 April 2022. Accessed December 11, 2023. https://www.nytimes.com/interactive/2022/04/21/climate/plastics-recycling-trash-environment.html.

Davis, H. 2022. *Plastic Matter*. Durham: Duke University Press.

Gill-Brown, I. 2021. *National Museums Liverpool: Paintings Storage and Wrapping Project. Unpublished Internal Report*. Liverpool: National Museums Liverpool.

Green, D. 2022. "An Investigation into Improving the Reuse of Soft Plastic Wrapping Materials Pertaining to the Short-Term and Repetitive Packaging of Framed Art for Art Fairs." Unpublished Masters diss., Newcastle, UK: Northumbria University.

Grice, N. 2021. "Recycling: Are Soft Plastics the Final Frontier?" *BBC News*. 12 December 2021. Accessed February 26, 2024. https://www.bbc.com/news/uk-wales-59373849.

Jin, H., J. Gonzalez-Gutierrez, P. Oblak, B. Zupančič, and I. Emri. 2012. "The Effect of Extensive Mechanical Recycling on the Properties of Low Density Polyethylene." *Polymer Degradation and Stability* 97 (11): 2262–2272. https://doi.org/10.1016/j.polymdegradstab.2012.07.039.

Kraczon, K. 2021. *Plastic Alternative Packing Materials Research*. Accessed December 11, 2023. https://galleryclimatecoalition.org/usr/library/documents/main/gcc_alternative_packing_materials_final.pdf.

McVeigh, K. 2023. "Recycling Can Release Huge Quantities of Microplastics, Study Finds". *The Guardian*, 23 May 2023. Accessed December 11, 2023. https://www.theguardian.com/environment/2023/may/23/recycling-can-release-huge-quantities-of-microplastics-study-finds.

Mecklenburg, M. F. 1991. *Art in Transit: Studies in the Transport of Paintings*. Washington: National Gallery of Art.

Navajas, A., A. Bernarte, G. Arzamendi, and L. M. Gandía. 2014. "Ecodesign of PVC Packing Tape Using Life Cycle Assessment." *The International Journal of Life Cycle Assessment* 19:218–230. https://doi.org/10.1007/s11367-013-0621-1.

OIML. 1996. *The Scale of Relative Humidity of Air Certified Against Saturated Salt Solutions. International Recommendation OIML R 121 1996*. Troyes, France: Organisation Internationale de Métrologie Légale.

Saleem, J., F. Tahir, M. Z. K. Baig, T. Al-Ansari, and G. McKay. 2023. "Assessing the Environmental Footprint of Recycled Plastic Pellets: A Life-Cycle Assessment Perspective." *Environmental Technology & Innovation* 32:1–11. https://doi.org/10.1016/j.eti.2023.103289.

Tate-Harte, A., and Thickett. 2023. "How to Calculate the Carbon Footprint of a Painting Conservation Treatment at English Heritage". Accessed December 11, 2023. https://www.english-heritage.org.uk/siteassets/home/learn/conservation/collections-advice–guidance/how-to-calcluate-the-carbon-footprint-of-a-painting-conservation-treatment_alice-tate-harte_david_thickett.pdf.

Titheridge, S. 2021. *Advised Tape and Wrapping Material Combinations*. Accessed December 11, 2023. https://galleryclimatecoalition.org/usr/library/documents/main/gcc_tape_material_combo_final.pdf.

Titone, V., L. Botta, M. C. Mistretta, and F. P. La Mantia. 2023. "Influence of a Biodegradable Contaminant on the Mechanical Recycling of a Low-Density Polyethylene Sample." *Polymer Engineering and Science*, 1–7. https://doi.org/10.1002/pen.26588.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S91–S97
https://doi.org/10.1080/00393630.2024.2339726

ORIGINAL RESEARCH AND TREATMENT PAPER

Reducing Energy Use Through Behavioural Change: Carbon Literacy Training for Archives in the UK
Reducción del Uso de Energía Mediante Cambios de Comportamiento: Alfabetización sobre Carbono para Archivos en el Reino Unido

Lorraine Finch[a], Tim Powell[b] and Helen Wilson[b]

[a]LFCP, London, UK; [b]The National Archives, Kew, London, UK

ABSTRACT

This paper reviews the process of adapting the *Carbon Literacy for Museums Toolkit* to develop a course specifically for the archive sector, *Carbon Literacy for Archives, Records and Special Collections*. This toolkit was launched to the sector in spring 2024. It discusses why carbon literacy (CL) is important, covering the benefits, co-benefits and what CL is. It examines the impact of carbon literacy training (CLT) on greenhouse gas emission and energy use reduction, and why CLT is so effective in generating the transformational behavioural change that is needed to create a sustainable future.

Este artículo revisa el proceso de adaptación del kit de herramientas *Carbon Literacy for Museums* para desarrollar un curso específico para el sector de archivos, *Carbon Literacy for Archives, Records and Special Collections*. Este conjunto de herramientas se lanzó al sector en la primavera de 2024. Se analiza por qué la formación sobre carbono (fC) es importante, abarca los beneficios, los beneficios colaterales y qué es fC. Examina el impacto de la capacitación sobre carbono (CsC) en la reducción de las emisiones de gases de efecto invernadero y el uso de energía, y por qué CsC es tan eficaz para generar el cambio de comportamiento transformador que se necesita para crear un futuro sostenible.

ARTICLE HISTORY
Received October 2023
Accepted March 2024

KEYWORDS
Sustainability; climate change; carbon literacy; energy; archives

Sostenibilidad; cambio climático; alfabetización sobre carbono; energía; archivo

Introduction

Energy usage is a necessity in archives. However, this usage generates greenhouse gas emissions that are accelerating, with catastrophic effect, the warming of the planet. Understanding the impact of energy use and working to decrease this at individual and organisational levels is essential to achieve the point at which 'human-made greenhouse gas emissions are in balance with those being removed from the atmosphere' (Carbon Literacy Project 2022, 50) referred to as 'net zero', in line with local, national and international policy and agreements.

The term 'carbon literacy' (CL) refers to:

> An awareness of the carbon costs and impacts of everyday activities, and the ability and motivation to reduce emissions, on an individual, community and organisational basis. (Carbon Literacy Project 2022, 6)

The *Carbon Literacy Project* (CLP) has created CL training to help individuals and organisations to alter their behaviour to reduce their greenhouse gas emissions (Carbon Literacy Project 2023a). To put it more succinctly 'Carbon literacy is about understanding what I actually need to do, where I can get help to do it, actually doing it and seeing that I've done it' (Carbon Literacy Project 2018, 4).

Since its launch in 2012, the CLP has certified over 72,000 citizens across over 5400 organisations as carbon literate (Figure 1) using an increasing number of tailored CL toolkits and sectoral courses. As of December 2023, 17 courses spanning nine unique sectors are available across the public and private sectors – civil service, healthcare, local authorities, museums, social housing, universities and colleges, automotive and sport – to 'ensure that organisations have the latest and best sectoral materials for delivering carbon literacy training' (Carbon Literacy Project 2023b). A CL course is an off-the-shelf, fully accredited suite of training that has been developed and tested by the sector, for the sector. It comprises a slide deck, trainer manual, activity resources, and a 'getting started' pack. 'Using a certified carbon literacy toolkit eliminates course development and accreditation time and costs as barriers to adoption. It also relieves the burden of updating training materials in line with developments in climate change science, impacts and policy' (Carbon Literacy Project 2023b).

CONTACT Helen Wilson Helen.Wilson@nationalarchives.gov.uk The National Archives, Kew, Richmond, Surrey, TW9 4DU London, UK
© 2024 Crown Copyright, The National Archives. This article is published under an Open Government Licence www.nationalarchives.gov.uk/doc/open-government-licence/



Figure 1. Carbon Literacy infographic. ©The Carbon Literacy Project. Reproduced with permission.

In 2022, the *Carbon Literacy for Museums Toolkit* was launched as part of the *Roots and Branches* project (MDUK 2021), supported by public funding from Arts Council England. The *Roots and Branches* project is a collaboration between the Carbon Literacy Project, Museum Development North West and Manchester Museum, and features case studies of how museums have reduced their energy use.

Led by Museum Development North West, the *Carbon Literacy for Museums Toolkit* is having a transformative effect in museums across the UK. In 2022 alone, 259 learners across 170 organisations were certified using the course, with five organisations delivering the training internally (Carbon Literacy Project 2023c, 23). There was immediate interest from the archives sector, with several archives professionals attending training run for the museums sector. While similarities between archives and museums exist, there are also significant differences, for example, in terms of access to heritage material (direct versus mediated) and documentation (archival cataloguing is structurally hierarchical). These differences were, understandably, not addressed in the museum-focused training. Greater impact for the archive sector could therefore be found in the creation of an archive, records and special collections CL course.

As the sector lead for archives in England and Wales and a member organisation of the Climate Heritage Network (Climate Heritage Network 2023), The National Archives (TNA) in the UK is committed to decreasing its own energy use and supporting the archives sector in achieving a more sustainable future (TNA 2023a). In support of this commitment, in early 2023, TNA, in partnership with the Archives and Records Association (UK and Ireland) Environmental Sustainability Group, and in collaboration with Lorraine Finch, consultant and certified CL trainer, began work to adapt the *Carbon Literacy for Museums Toolkit* for a *Carbon Literacy for Archives, Records and Special Collections* course.

The challenge

The UK government has pledged to reduce carbon emissions by 78%, compared to 1990 levels, by 2035. The UK net zero target was set out in June 2019 (UK Government 2019) as a commitment to 100% reduction of greenhouse gas emissions by 2050 compared with 1990 levels.

Energy is used throughout the cultural heritage sector for all aspects of its work. In archives energy is used in collections care, from accessioning to access, and to create a welcoming working environment for visitors and researchers. As we know, energy is used to bring items and collections into our archives, to light the building, to power the heating, ventilation and air-conditioning (HVAC) systems and other equipment, and for many other uses.

While the challenge is great, archive services can make considerable reductions in their energy output. In Britain, TNA achieved a 74% reduction in carbon emissions in 2019–2020 compared with the baseline year of 2009–2010, and against the government target of a 32% reduction (TNA 2023b). This is a start. We need to, and can, do more.

Why become carbon literate?

In this context, there is great value in developing the CL of organisations, their leadership teams and their staff. Reasons might include:

- It is a major step towards reducing the organisation's carbon footprint.
- It aligns with the mission and values of the organisation and the sector more widely.
- Individuals, organisations and the sector have a responsibility to act.
- The creation of a common level of knowledge, language and objectives encourages people to think about practical measures when it comes to reducing their impact on the climate. They are more likely to feel motivated and supported in contributing to organisational objectives that relate to reducing carbon emissions or adapting to the changing climate. This collective approach to reducing greenhouse gas emissions can improve teamworking among staff members.
- The introduction of more carbon literate ways of working is very likely to reduce running costs across the organisation – energy is expensive and the less you use, the more you save.
- CL helps to future-proof an organisation, address challenges and move to a future which benefits all.
- CL can offer significant benefits in terms of the organisation's reputation. We are all aware of the temptation to indulge in greenwashing, but the fact that this exists shows how important it is to

reassure stakeholders, customers, audiences and the general public that you have a concern for the environment and your impact on it.
- A commitment to reducing energy use and the organisation's carbon footprint can support funding applications, where funding providers ask for evidence of sustainable development from applicants.

Across an organisation, carbon-literate leaders, managers and board members will have greater decision-making powers and can use their influence to mobilise institutional shifts away from fossil fuel dependency and high emissions operations. Those who are carbon literate have an understanding of the ways in which everyday actions are having an impact on the climate and on our planet and what can be done to reduce their emissions in all of the spaces they are in – personal, community and workplace.

What is carbon literacy training?

CL training provides:

- Up-to-date information on climate science and the impacts of climate change on cultural heritage and communities locally and globally.
- An understanding of how organisations and individuals fit into the local, national and international efforts to address the climate crisis.

CL training is for everyone, including those working in the cultural and heritage sector. It empowers those taking it to recognise their role in moving towards a low-carbon society and giving them agency to take action.

What does carbon literacy training involve?

Although the toolkits and courses are designed to be suitable for those with little prior knowledge of the issues, they are still useful tools for those already knowledgeable and committed to addressing issues of environmental sustainability. Learners participate in a day of training delivered over four modules (Figure 2).

After participation in the training, learners are encouraged to submit a participant action form (PAF) to the CLP, in order to be certified as CL. The PAF asks for an individual pledge, and a group pledge, to take action to reduce greenhouse gas emissions.

There is no formal follow-up to check whether learners have fulfilled their pledges. The authors' experiences suggest that the success rate is likely to be high as learners are invested and motivated. They have embraced the need for change and seen examples of the types of changes that are relevant to their context, enabling them to envisage achievable actions for themselves.

The initial training is often delivered by specialist certified CL trainers but those who have successfully taken the course themselves can become trainers, thus ensuring that the material continues to be relevant and delivered by peers.

CL training can be provided in person and online, giving the capability of delivering it internationally. It is easy to adapt to ensure that it remains relevant to an international audience.

Process of creating a toolkit specifically for archives, records management and special collections

The creation of CL training for archives, records and special collections is evidence of the success of the pledges. As a result of their CL training, the authors independently pledged to:

- Raise awareness of CL training.
- Make a recommendation to relevant decision-makers that the TNA provide CL training for the archive sector.
- Set-up the project to provide an archive-specific version.

These developments were not happening in isolation, of course. The authors were aware of a wider concern in the sector and interest in mobilising to take action. For example, members of the Archives and Records Association (ARA) of the UK and Ireland set-up an Environmental Sustainability Group, various initiatives were underway at TNA, and the authors have been asked to talk about the risks to archive collections from climate change to a number of archives groups.

The toolkit itself includes training materials and supporting documents required to enable the trainer to provide the training effectively and to a level approved by the CLT. It includes for example, a trainer manual, slide deck, and resources document.

The first step in adapting the *Carbon Literacy for Museums Toolkit* into *Carbon Literacy for Archives, Records and Special Collections* was to get permission to do so and to purchase the licence to allow this to happen. After the formalities were completed, the next step was to work through the trainer manual to identify and remove inapplicable content, for example by replacing references to museums with archives. A call was made to ARA members by the ARA Environmental Sustainability Group for case studies to add to those collated by the UK National Archives' Archive Sector Leadership team, whilst the oversight group monitored progress and provided expert advice, guidance and feedback.

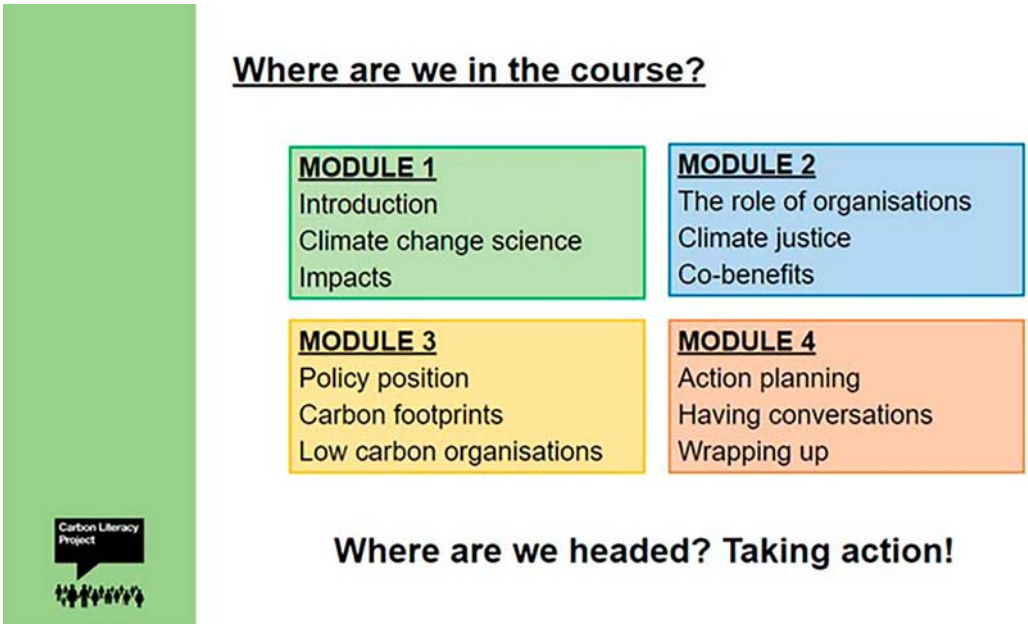


Figure 2. The four modules in CL training.

The creation of a CL course for archives, records and special collections has been a time-consuming and, at times, challenging project. The process has had to be fitted around busy day-to-day jobs and many other organisational demands. Crucially, however, TNA's senior managers have been supportive, allowing time and providing funding for the project.

Why does CL training work?

There are many behavioural change models but the *Awareness, Desire, Knowledge, Ability and Reinforcement* (ADKAR) model is one which has been proposed as especially relevant to securing the behavioural change needed for a sustainable future (Loddo et al. 2021). ADKAR follows five steps in creating behavioural change. The first is communicating *awareness* of the need for change and the benefits of the change as they apply to the people impacted. The second is the stage of creating the *desire* for the necessary change by showing how it offers practical benefits. The third stage, *knowledge*, is about providing information on how change can be achieved, which leads onto the fourth stage of ensuring the *ability* of all to make the changes by highlighting the resources required. The fifth stage is the crucial one of *reinforcing* the change to ensure it is embedded.

The ADKAR model does not require a top-down process; those promoting change need not be senior managers, indeed it may be better led by those who can understand how daily routines will be affected and are familiar with providing support and guidance within the organisation.

CL training can be seen to work to this ADKAR model through the inclusion of both relevant knowledge and impactful action. This combination has been shown to be more effective than providing the knowledge alone (De Meyer et al. 2021) because the very process of taking impactful action feeds back into greater motivation to understand more and to do more. Indeed, Jim Kwik (2018), a world leading expert in brain performance and accelerated learning, states that 'Knowledge × Action = Power' and that 'if you don't … apply the knowledge, it will be useless'.

CL training provides relevant, up-to-date facts on climate change, its effects on society in general and the particular sector for which the training is tailored. Rather than scaremongering, these facts are presented to ensure an intelligible and accurate picture of the ongoing crisis to help learners understand the urgency with which action is needed.

Importantly, a CL course does not itself give instructions on taking action. A set of ready-made, prescribed options would in fact weaken the training. It would encourage complacency – 'I've done what they told me, that's a task finished' – and also reduce the scope for imagination and innovation to see things differently and offer new ways of acting.

Instead, action in CL training is pledged by the participants, following their:

- participation in activities that encourage peer-to-peer discussion (Figure 3)
- consideration of the extensive range of practical and impactful actions presented during the training via case studies
- understanding of their own context.

The more sector-specific the case studies and discussions are, the better they speak to the learners' own circumstances and consequently, the more effective the training will be. This is why TNA embarked

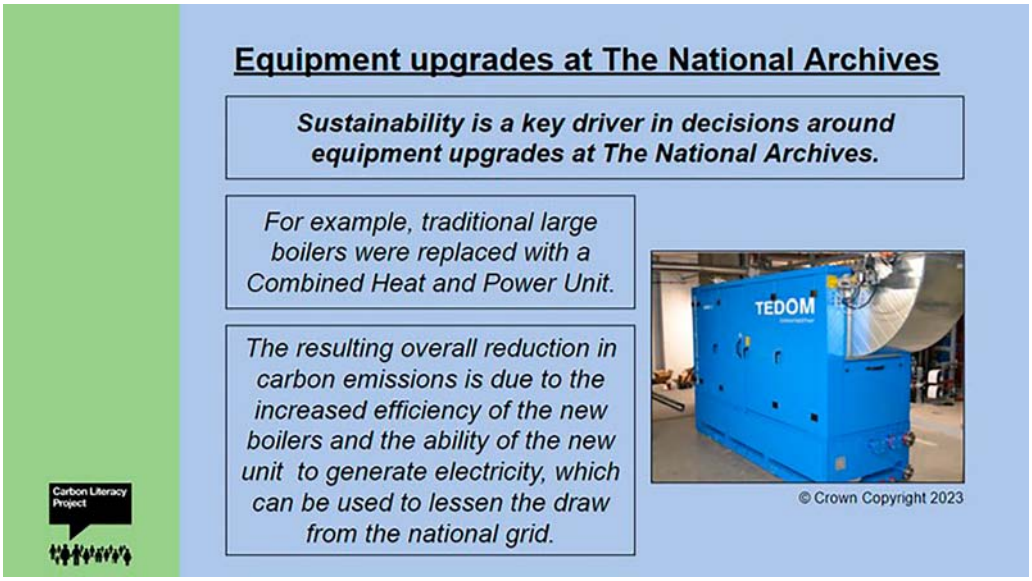


Figure 3. Example slide of low carbon archive activity from the Carbon Literacy Training for Archives, Records and Special Collections Toolkit slide deck.

upon the creation of a toolkit for CL training that is specific to archives, records and special collections. Mindful that participants are likely to be at differing stages of their carbon reduction journey and with differing levels of knowledge, the toolkit was designed to provide value to all. More advanced learners benefit from attending CL training through the discussions with peers, hearing about actions others are taking, by providing information, advice and encouragement to those coming to the issues less well informed, and through reputational benefit associated with completing the training.

What impact has CL training had on energy use and greenhouse gas emissions?

The principal way in which CL training reduces energy consumption is through the pledges and the actions that come from them. Carbon literate citizens understand how climate change will affect them – both geographically and by sector – and have acquired the knowledge and skills to lower their carbon footprint, with typical realised carbon savings of 5–15% per person (Carbon Literacy Project 2023d).

The CLP estimates that the 140,000 commitments pledged by their 70,000 learners from all of the CL courses have saved an estimated 252,000 tonnes of CO_2 e. CO_2 e is the carbon dioxide equivalent of all the greenhouse gases emitted, the four main greenhouse gases being carbon dioxide, methane, nitrous oxide and fluorinated gases (Carbon Literacy Project 2023e). This is calculated by taking an average of the predictions of the CO_2 e savings (10s, 100s, or 1000s of kg) collated from the pledges of over 12,000 attendees, and then extrapolating this to cover the pledged actions of all attendees (Carbon Literacy Project 2023a). The research page on the CLP website also provides a number of studies of the positive effect the training has had on those engaged with it (Carbon Literacy Project 2023f).

How can CL training reduce energy use in archives in the UK?

The pledges illustrate how CL training can, and does, reduce energy use. Examples are:

- Implement a switch-off campaign for lighting, computers, and any other electrical equipment
- Create carbon impact plans at the beginning of each project to ensure that the aims and objectives of each project fully cover looking at carbon reduction
- Calculate the carbon footprint of all of our work
- Review the sustainability of suppliers and ensure this is a mandatory evaluation criterion.

The pledges contain innovative ways of reducing energy consumption by changing how particular activities are approached. They cover imaginative reuse of materials, of deliberating sourcing locally, and of introducing the 'four Rs', namely *refusing, reducing, reusing* and *recycling*, into formal decision-making processes.

From the training provided by author Lorraine Finch alone, learners have been in the position to support or instigate the replacement of infrastructure that uses electricity or gas with more energy efficient choices, or to investigate ways to reduce the energy use in their collections stores. Others have pledged to use less energy on an individual level. Others have been in a position to introduce sustainability into policies

which will affect the organisation's carbon footprint. Whilst others have been in a position to raise awareness within an organisation's audiences of climate change and methods of mitigating this through tailored exhibitions, events, and education thereby potentially decreasing the energy usage and carbon footprint of their audiences.

As *Carbon Literacy for Archives, Records and Special Collections* is rolled out in 2024, TNA and its partners will gather evidence of the pledges made and seek to measure the impact of these. In addition, both TNA and ARA hope to build online resources that allow participants in the training to keep up to date with information on climate change and its effects plus providing examples of ways in which individuals and organisations continue to come up with solutions that reduce their carbon footprint.

We shall not be starting from scratch! There's a great deal of information already available on how the cultural and heritage sectors can make a difference. One place to go is ICCROM's *Our Collections Matter* (OCM) *Toolkit* (ICCROM 2023). This has over 300 freely accessible, online resources which it continues to increase. Specific day-to-day tips and tools for cultural heritage practitioners can be found in resources such as Low-cost/*No Cost Tips for Sustainability in Cultural Heritage* (Finch 2022). While as a sector there is still a long way to go to realising low carbon archival practice across the board, one crucial lesson of the toolkit is: 'don't be discouraged!'.

Conclusion

CL training is not only a way of spreading information about the facts and consequences of climate change; it is a means of instilling the behavioural change within archives, records and special collections management that, more widely, is needed to generate sustained energy reduction. CLT for our sector is not to be seen in isolation; it is one of a growing number of toolkits. Whilst each toolkit has been created with a different set of stakeholders in mind, they have a common core of knowledge content and a similar approach to encouraging action. As the number of people trained grows, and the number of toolkits increases, CL as a cultural phenomenon is gaining momentum. Those who have participated in it are much more likely to think about their actions and the effect these have upon energy use and carbon emissions and are able to speak more knowledgeably and advocate more effectively.

CLT is actually the start of the process of the individual and organisational behavioural changes that are required to address the climate crisis. It is a launchpad for individual and organisational transformation and the reduction of energy consumption and carbon emissions. CL is a valuable tool in the toolkit needed to create a sustainable future.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Carbon Literacy Project. 2018. "Carbon Literacy Standard. Version 2.5. Accessed 15 December 2023." https://carbonliteracy.com/wp-content/uploads/2018/12/The-Carbon-Literacy-Standard-Version-2.5.pdf.

Carbon Literacy Project. 2022. "Carbon Literacy for Museums Trainer Manual." Version 1. Carbon Literacy Project, unpublished.

Carbon Literacy Project. 2023a. "About Us." Accessed 15 December 2023. https://carbonliteracy.com/about-us/.

Carbon Literacy Project. 2023b. "Carbon Literacy Toolkits." Accessed 15 December 2023. https://carbonliteracy.com/toolkits/.

Carbon Literacy Project. 2023c. "Impact Report 2022." https://carbonliteracy.com/wp-content/uploads/2023/12/The-Carbon-Literacy-Project-2022-Impact-Report.pdf.

Carbon Literacy Project. 2023d. "What is the Carbon Literacy Project?" Accessed 15 December 2023. https://carbonliteracy.com/organisation/.

Carbon Literacy Project. 2023e. "70,000 Carbon Literate Citizens." Accessed 15 December 2023. https://carbonliteracy.com/70000-carbon-literate-citizens/.

Carbon Literacy Project. 2023f. "Research." Accessed 15 December 2023. https://carbonliteracy.com/about-us/research/.

Climate Heritage Network. 2023. "Empowering People to Imagine and Realise Low Carbon, Just, Climate Resilient Futures Through Culture – From Arts To Heritage." Accessed 15 December 2023. https://www.climateheritage.org/.

De Meyer, K., E. Coren, M. McCaffery, and C. Slean. 2021. "Transforming the Stories We Tell About Climate Change: From 'Issues' to 'Actions'." *Environmental Research Letters* 16 (1): 9–11. https://doi.org/10.1088/1748-9326/abcd5a.

Finch, L. 2022. "Low-cost/No Cost Tips for Sustainability in Cultural Heritage." https://lfcp.co.uk/publications.

ICCROM. 2023. "Our Collections Matter Toolkit. International Centre for the Study of the Preservation and Restoration of Cultural Property." Accessed 15 December 2023. https://www.iccrom.org/projects/ocm-toolkit.

Kwik, J. 2018. "How To Turn Knowledge Into Action". In KwikBrain, 30 October 2018. Podcast, MP3 audio, 15:22. https://www.jimkwik.com/podcasts/kwik-brain-077-how-to-turn-knowledge-into-action/.

Loddo, M., R. Ilaria, H. A. McGhie, and J. L. Pedersoli. 2021. "Empowering Collections-Based Organizations to Participate in Agenda 2030: The Our Collections Matter Toolkit." *Sustainability* 13 (24): 11–12. https://doi.org/10.3390/su132413964.

MDUK. 2021. "Roots and Branches. Museum Development United Kingdom." Accessed 15 December 2023. https://mduk.org.uk/roots-and-branches/.

TNA. 2023a. "Our Long Term Vision. The National Archives." Accessed 15 December 2023. https://www.nationalarchives.gov.uk/about/our-role/plans-policies-pe

rformance-and-projects/our-plans/archives-for-everyone/our-long-term-vision/.
TNA. 2023b. "Energy, Environment and Sustainability. The National Archives." Accessed 15 December 2023. https://www.nationalarchives.gov.uk/about/our-role/transparency/energy-environment-and-sustainability/.
UK Government. 2019. "Climate Change Act 2008 (2050 Target Amendment Order) 2019." https://www.legislation.gov.uk/ukdsi/2019/9780111187654.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S98–S107
https://doi.org/10.1080/00393630.2024.2379132

ORIGINAL RESEARCH OR TREATMENT PAPER

Data Collection for Cultural Heritage Risk Management: the *Damage Map through Heritage Building Information Modeling (HBIM)* Project Applied to the Façade of St Francis of Assisi, Ouro Preto, Brazil

Recopilación de Datos para la Gestión de Riesgos del Patrimonio Cultural: el Proyecto *Mapa de Daños Mediante el Modelado de Información de Edificios Patrimoniales* (HBIM) Aplicado a la Fachada de San Francisco de Asís, Ouro Preto, Brasil

Yacy Ara Froner [1], Willi de Barros Gonçalves [1], Luiz Antônio Cruz Souza [1], Antônio Gilberto Costa [1], Alessandra Rosado [1], Ana Regina Mizrahy Cuperschmid [2], Guilherme de Oliveira Walter [1], Ana Carolina Neves Miranda [3], Guilherme Michelin [4], Ana Carolina Montalvão [5] and Tiago Hardy [1]

[1]Federal University of Minas Gerais, Belo Horizonte, Brazil; [2]State University of Campinas, São Paulo, Brazil; [3]National Historic and Artistic Heritage Institute, Brasilia, Brazil; [4]Mackenzie Presbyterian University, São Paulo, Brazil; [5]Federal University of Ouro Preto, Ouro Preto, Brazil

ABSTRACT

The development of precise analytical methodologies, together with the systematic use of verifiable data, aims to raise standards for treatment, risk management, and maintenance programs. This endeavor aims to diminish the frequency of subsequent restoration cycles, thereby positively impacting public spending and fostering the preservation of the authentic characteristics of historical buildings, particularly by mitigating the effects of decay. The *Damage Map through Heritage Building Information Modeling (HBIM)* project, funded by the National Council for Scientific and Technological Development (CNPq) and Minas Gerais Research Support Foundation (FAPEMIG), both Brazil, aims to establish protocols for risk management in historical buildings, with a focus on decorative stone elements integrated into the construction. For this reason, the stone relief on the façade of the church of St Francis of Assisi in Ouro Preto, Brazil, was chosen as a case study. This paper outlines the data collection methodology applied to study the stone. This approach encompasses historical examinations of restoration cycles, along with preliminary findings derived from extensive fieldwork, conducted by a multidisciplinary team in 2023. It elucidates the data collection stage, employing photography and aerial photogrammetry, ultraviolet fluorescence photography, mobile laser scanning, and thermography. Subsequently, all collected data will be used to construct a diagnostic model within the HBIM.

El desarrollo de metodologías analíticas precisas, junto con el uso sistemático de datos verificables, tiene como objetivo elevar los estándares para el tratamiento, la gestión de riesgos y los programas de mantenimiento. Este esfuerzo tiene como objetivo disminuir la frecuencia de los ciclos de restauración posteriores, impactando así positivamente en el gasto público y fomentando la preservación de las características auténticas de los edificios históricos, particularmente mitigando los efectos del deterioro. El proyecto Mapa de Daños a través del Modelado de Información de Edificios Patrimoniales (HBIM), financiado por el Consejo Nacional de Desarrollo Científico y Tecnológico (CNPq) y la Fundación de Apoyo a la Investigación de Minas Gerais (FAPEMIG), ambos de Brasil, tiene como objetivo establecer protocolos para la gestión de riesgos en edificios históricos. con especial atención a los elementos decorativos de piedra integrados en la construcción. Por esta razón, se eligió como caso de estudio el relieve de piedra de la fachada de la iglesia de San Francisco de Asís en Ouro Preto, Brasil. Este artículo describe la metodología de recolección de datos aplicada para estudiar la piedra. Este enfoque abarca exámenes históricos de los ciclos de restauración, junto con hallazgos preliminares derivados de un extenso trabajo de campo, realizado por un equipo multidisciplinario en 2023. La etapa de recopilación de datos se resalta al emplear fotografía y fotogrametría aérea, fotografía de fluorescencia ultravioleta, escaneo láser móvil y termografía. Posteriormente, todos los datos recopilados se utilizarán para construir un modelo de diagnóstico dentro del HBIM.

ARTICLE HISTORY
Received November 2023
Accepted June 2024

KEYWORDS
Historic building information modeling; conservation science; damage map; architectural technology; stone façade

Modelado de información de edificios históricos; ciencia de la conservación; mapa de daños; tecnología arquitectónica; fachada de piedra

CONTACT Yacy Ara Froner yacyara.froner@gmail.com Rua Veredas das Macaúbas, 200 – Condomínio Veredas da Lagoa, Lagoa Santa, MG, 33239-665 Brazil

© The International Institute for Conservation of Historic and Artistic Works 2024

Introduction

The advancement of precise analytical methodologies, together with the systematization of verifiable data, seeks to raise the technical quality of conservation interventions, and fortify maintenance and risk management processes. The decreased frequency of subsequent restoration cycles contributes to a positive impact on both public spending and the preservation of the original characteristics of listed buildings, primarily by mitigating decay. Sustainable preservation programs require an accurate understanding of cultural heritage in time and space, including the use of new technologies and historical-documentary surveys, to support projects and public policies for protection (Froner 2017).

Considering these factors, the *Damage Map through Heritage Building Information Modeling (HBIM)* project, funded by the National Council for Scientific and Technological Development (CNPq) in Brazil, aims to develop protocols for effective risk management in historical buildings. This action is undertaken by formulating a methodology systematically to document degradation typologies over time, integrated within digital platforms. This in turn facilitates the ongoing monitoring of the condition of stone-integrated assets, providing valuable support for conservation interventions and long-term maintenance programs. The application of technology to heritage can yield high-quality analytical documentation, encompassing a systematic recording of information at various levels, including assessment protocols, the identification of materials and construction techniques, as well as the mapping of damage and risks.

The present case study focuses on the reliefs on the frontispiece of the church of St Francis of Assisi in Ouro Preto, Brazil (Figure 1). This church was one of the first architectural assets to be protected by national legislation, through its inscription in the *Book of Fine Arts of the National Historic and Artistic Heritage Institute (IPHAN)*, in 1938 (IPHAN 1937–1986). In 1980, it was included in the UNESCO World Heritage List, increasing its importance.

This paper presents the method used to collect data on the stone reliefs of the church façade. It covers historical restoration cycles and shares preliminary findings from the 2023 fieldwork conducted by a multidisciplinary team. The focus is on elucidating the data collection stage, highlighting key techniques, such as photography, aerial photogrammetry, ultraviolet



Figure 1. Façade of the church of St Francis of Assisi, Ouro Preto, Brazil. Image: the authors.

fluorescence photography, mobile laser scanning, and thermography. All collected data will be used to develop a diagnostic model in HBIM for the façade, providing a damage map of its current condition. This stage, scheduled for 2024, will occur after defining a proposed terminology of stone decay processes on monuments and the processing of all data collected using the methodology presented in this article.

Damage map

A 'damage map' is an illustrated document designed to provide a concise overview of the condition of a cultural asset, be it movable or immovable (IPHAN 2005). When applied to immovable cultural assets, such as buildings, ruins, archaeological sites, urban art, or fixed elements that define a historical occupation in a specific time and space, the map aims to summarize information about their overall condition. Costa and Baisch (2012) define the 'damage map' as an illustrative tool that presents material components together with identified damage, providing essential information to support treatment and consolidation efforts in conservation projects. This tool serves as a preliminary step preceding the development building interventions, conservation, and restoration, playing a crucial role in the identification, quantification, specification, and localization of faults in the structure. The analysis facilitated by the damage map typically involves plans, sections, and occasional perspective studies that use drawings or markings superimposed upon photographs to highlight damage or alterations. These representations adhere to codes or conventions associated with degradation typologies and are crucial to the architectural standards necessary to depict building projects, encompassing proportions and the spatial arrangement of elements.

Despite the systematization of damage characterization nomenclatures, using Italian standards for cultural heritage, such as Normal 1/88 and UNI 11182 (UNIRC 1988; UNIRC 2006), as well as the *Illustrated Glossary on Stone Deterioration Patterns* (ICOMOS 2008), there is currently no regulatory document addressing symbolic schemes and conventions formulated specifically for the creation of a damage map in historic buildings.

Construction history of the church of St Francis of Assisi

The earthworks for the site in the Largo de Coimbra, the central area of Ouro Preto, began in 1765. This task was entrusted to the Portuguese master mason, Domingos Moreira de Oliveira (c.1711–1794), with the contract dated 1766. Portuguese royal permission for the construction was only granted in 1771, several years after the Brazilian administration's request. However, as was usual, contracts and works had begun before the royal charter was given. Sculptural work was entrusted to the Portuguese craftsman, José Antônio de Brito (died 1793). The instructions detailing the techniques and materials for the construction were meticulously specified (Trindade 1951). According to the contract, the commissioned contractor was obliged to transport all the Itacolomi stone and soapstone rocks to the site and assemble them, following the design, and was responsible for all moldings and sculptures (Costa 2009, 220).

Upon completing the main chapel, the masons began the construction of the façade, featuring the entrance door designed by Antônio Francisco Lisboa (c.1738–1814), more commonly known as Aleijadinho (Lemos 2014). The façade's ornamentation has architectural impact, showcasing two distinct reliefs. The first, surrounding the entrance door, features a half-body medallion of Our Lady, surrounded by rosettes and cherubs alongside a large crown. The central detail of the crown is in harmony with the upper relief that fills the oculus. The second relief is distinctive, as it occupies the space of the oculus, imposing the weight of the ornamental sculpture over the transparency of a stained-glass window. This medallion, portraying St Francis receiving the stigmata from Christ on Mount Alverno, is positioned above the entrance door. The *rocailles*, irregularly overlapping and surrounding the oculus frame, interact with the inner clouds, creating a sense of movement, heightened by the recesses and masses of the relief. These, in turn, yield distinct visual effects, depending on the ambient light. Notably, a few details in this medallion are crafted from coarse sand mortar.

History of intervention and restoration cycles

When beginning the development of the proposed damage map for this project, an essential initial step involved delving into the history of conservation interventions, as well as examining the methodologies documented in previous efforts. This exploration relied on the examination of physical and digital documents, sourced from the archives of IPHAN and the João Pinheiro Foundation, supplemented by online databases. As a result, a compilation of approximately 67 documents, 130 photographs, and four architectural plans was amassed.

The earliest recorded interventions and repairs date back to 1822–1823, documented in payment records made to mason João Fernandes Coutinho for the repair of the stone entrance door. Subsequent records indicate restoration work on the entrance door ensemble during the early decades of the twentieth century. Notably, between 1935 and 1937, the

National Monuments Inspectorate, led by Gustavo Barroso (1888–1959), oversaw the church's restoration. The documentation of this intervention includes the initial photographic report of the St Francis of Assisi medallion (Figure 2(a)).

In the 1937 restoration, the façade underwent cleaning, and two ornaments from the entrance door were removed, sparking significant controversy over the authenticity of these pieces. This controversy led to discussions in contemporary newspapers and persisted in subsequent years. Members of the Historical Institute of Ouro Preto contended that the ornaments were original elements from the period of the entrance door's construction and were made of soapstone. Conversely, the National Monument Inspectorate argued that these pieces were crafted from mortar and were removed because they were considered 'dishonest and modern work', as indicated in the file titled *Obras na Igreja São Francisco de Assis* (IPHAN 1937–1986).

While there are no records documenting these interventions, it is assumed that they occurred before the establishment of the National Monument Inspectorate, the point at which modifications became officially documented. Even today, remnants of mortar ornaments can still be found in various areas of the entrance door, as we observed and recorded in 2023.

With the set-up of scaffolding for the removal of these elements, numerous images capturing intricate details were taken. Through these images, it becomes possible to compare the current decay as compared to a hundred years ago. In Figure 2, a crack on the left side of the face of St Francis is evident, with a small loss of material. The present condition reveals significant loss of material and a worsening of the crack (Figure 2(b)).

Between 1944 and 1946, the church underwent another round of restoration, although there are no references to direct actions on the entrance door during this period. It was not until 1975 that new records of conservation measures for the entrance door emerged. Additional conservation measures and studies of the entrance door were conducted in the 1980s and 1990s. In August 1987, the cleaning of the artistic elements of the entrance door involved aspirating accumulated dust particles. However, in November of the same year, during the restoration of the artistic elements of the church conducted by the Pro-Memory Foundation, the inspection report revealed that the entrance door elements had not been cleaned as recommended by IPHAN in 1987. This suggests that the managers did not adhere to the technical guidance, potentially due to a lack of financial resources.

From 1990 to 1994, the *Investigations into Devices against Environmental Attack on Stone* (IDEAS) project was undertaken in collaboration with universities in Germany, the Federal University of Minas Gerais (UFMG), and IEPHA, with funding from the Minas Gerais Research Support Foundation (FAPEMIG). The project aimed to analyze the degradation behavior of stone materials, propose damage assessment methodologies, and develop conservation recommendations for the artifacts in question. Five built assets in Minas Gerais were selected, including the stonework and



Figure 2. Detail of the face of St Francis of Assisi (a) 1937. Image: IPHAN (b) 2023. Image: the authors.

soapstone materials of the church of St Francis of Assisi. During this phase of the project, broader indications were provided regarding the condition of the stone in the church. The analysis emphasized the role of air quality in Ouro Preto as a contributing factor to deterioration. The advanced state of degradation of the stone was directly linked to pollutants, such as fluorides, sulfur dioxide, and particulate matter from the aluminum factory located in the city. The identified deterioration included granular disintegration, delamination, cracks, fractures, and biological colonization, with the most widespread issue being the discoloration of the soapstone (FJP 2001).

The compilation of archival sources and the investigation into the history of interventions on the entrance door, integral to the damage pathology, has significantly enhanced our comprehension of its construction processes. It has shed light on aesthetic modifications, deterioration, additions, and the removal of parts that continue to impact the object's composition today, providing an opportunity for their temporary marking. However, the absence of systematic documentation poses a challenge in establishing reliable parameters for risk analysis and management. This underscores the imperative for the development of a dedicated methodology for damage mapping, one that can be universally applied to monuments of similar scale.

Materials and methods

Between 28 August and 1 September 2023, a multidisciplinary technical team, consisting of researchers from the Federal University of Minas Gerais (UFMG), the Federal Institute of Minas Gerais, Campus Ouro Preto (IFMG-OP), the State University of Campinas (UNICAMP), and the Mackenzie Presbyterian University, Campus São Paulo, convened for initial field activity dedicated to the data collection of the façade. The team included art historians, architects, conservators, a chemical engineer, and a geologist, bringing a wide range of expertise to the research initiative.

Following agreements between the Municipality of Ouro Preto and the Archdiocese of Mariana, the entity responsible for the Church, 15 m high scaffolding was erected, which provided the necessary access for researchers to examine the reliefs. The field surveys incorporated various methods and techniques: close-range photogrammetry; photography and aerial photogrammetry, using an unmanned aerial vehicle (UAV), commonly known as a drone; structured light scanning, ultraviolet fluorescence photography, mobile laser scanning, and 3D printing; and thermography. It is crucial to underscore the significance of equipment sharing in projects of this nature in Brazil, particularly considering the substantial investment required for such infrastructure.

These integrated examinations, primarily forms of non-destructive testing (NDT), offer a comprehensive understanding of both the construction technology and the condition of cultural assets. NDT refers to methods and techniques where the test does not result in any change (damage) to the piece being tested. The primary objective of NDT is to identify defects and wear, often undetectable through conventional means. These methods can also be employed to discern the characteristics of various materials that compose or are embedded in these objects. In Brazil, this field is regulated by federal standards that cover both the equipment used and the training and certification of operators involved in these assessments.

Close-range photogrammetry using control points

The photographic survey used two high-resolution digital cameras, Nikon D7200 and Nikon D7000. The Nikon D7200 was employed to record and document damages and pathologies on the façade, while the Nikon D7000 documented the overall fieldwork. In the close-range photogrammetry procedure, the cameras were positioned at control points on the façade. These control points play a crucial role in assisting photogrammetry software to correct and align the images, enabling the generation of an accurate three-dimensional model.

A total of 378 images of the church's façade were captured across the five levels of the scaffolding, maintaining a consistent focal distance between the object of study and the camera. Special attention was given to ensuring that each subsequent image had, at a minimum, one control point as a reference in the previous image, ensuring continuity and precision for the photogrammetry process. This meticulous procedure resulted in the creation of detailed 3D models at each scaffolding level. To manage and calibrate colors in the captured images, a ColorChecker Passport was used.

Photography and aerial photogrammetry

In the photography and aerial photogrammetry process, using a UAV, the survey offered an angle of the frontispiece and the building that were not accessible from the scaffolding. This provided a detailed view of pathologies, including infiltrations and mortar repairs. This approach facilitated the examination of roofing issues that may well be contributing to pathologies in the oculus and frontispiece. The use of UAV is a valuable tool for data collection in hard-to-reach locations, thereby enhancing the breadth of essential information for research.



Figure 3. Details of the point cloud. Image: the authors

The acquisition of point clouds through photogrammetry, using a UAV, captured a series of aerial images of the target of interest from different angles and altitudes (Figure 3). In this study, the point cloud was generated by processing 953 images in with Agisoft Metashape software, resulting in an initial model with 318,487 points.

The image processing begins with the import of captured images, followed by the identification of corresponding points in various images (control points). This enables triangulation to estimate the three-dimensional coordinates of points in the scene. The software then conducts a 3D reconstruction of the target area, generating a point cloud that accurately represents the geometry of the surfaces. This point cloud can be subsequently used for geospatial analysis, 3D modeling, or other applications that require precise information about the mapped area, such as the generation of damage maps proposed in the research project.

Structured light scanning, ultraviolet fluorescence photography, mobile laser scanning, and 3D printing

The Shining Einscan SE scanner was selected for structured light scanning due to its precision (≤0.1 mm) and versatility, allowing for the scanning of larger areas with the aid of geometric alignment or manual control. Scaffolding was installed to access the portrayal of St Francis of Assisi in the church's oculus, providing the necessary positioning for the scanner. A tripod was adapted to support the scanner, ensuring stability during the scanning process, and scanning was scheduled for night-time, as the equipment performed better in low-light conditions.

However, scanning this unique sculpture presented distinct challenges. The intricacy of the forms sculpted by Aleijadinho required meticulous adjustments to the light patterns to ensure accurate capture. Additionally, limited access to the church's oculus and the need to work at elevated heights further complicated the process. The team adapted the equipment and developed strategies to overcome technical and logistical obstacles.

The detailed scanning of the portrayal yielded impressive and revealing results. The accuracy of structured light technology enabled a meticulous capture of details, offering essential insights into the sculpture's current condition and revealing elements that had been lost due to deterioration over time. Among the most notable observations are the visualization of elements that no longer exist in the original piece due to damage. Significant parts of the portrayal, such as the tip of the nose, part of the upper lip, part of the left cheek of the face, and part of the left ear (Figure 4), were meticulously recorded in the 3D model.

These areas, now absent in the figure, were digitally documented, providing a detailed record of what once was. The scanning also revealed small cracks on the figure's forehead, emphasizing the effects of the passage of time and environmental conditions. The ability to accurately capture these imperfections is crucial for understanding the deterioration process and developing effective conservation strategies.

In addition to visible observations, the scanning of the portrayal of St Francis of Assisi revealed a unique capability to identify pathologies caused by physical, chemical, and biological agents. This significantly expanded our understanding of the deterioration factors that affect works of art over time. Using RGB scanning to capture colors, it became possible to detect subtle variations in the hue of the scanned surface.

The generated 3D model unveiled the presence of pathologies caused by biological agents, specifically bird droppings. These affected areas exhibit distinct color patterns and subtle variations, indicating the locations where the action of these biological agents was more intense. The capacity to identify such damage in detail is of utmost importance for conservators, as it furnishes precise information about vulnerable areas and aids in developing strategies to prevent future damage. In addition to structured light scanning, ultraviolet fluorescence photography was also applied. This technique involved observing various areas of the artwork at night, using a Spectrum UV-Tritan 365 lamp. The images obtained through this process allowed for a more accurate identification of areas with microorganisms and surface alterations, such as the deposition of foreign materials and differentiation between the relief patching and sculpted stones (Figure 5).

Additional studies used LiDAR technology, employing applications such as Polycam and 3D Scanner on an iPhone, to generate three-dimensional mapping. The use of aerial and terrestrial photogrammetry along with LiDAR technology for archaeological heritage documentation has advanced rapidly over the past two decades (Crutchley 2010; Prümers et al. 2022). In particular, LiDAR technology accessible on smartphones can reveal aesthetic details and the condition of cultural assets.

In Brazil, the application of laser scanning began in the early twenty-first century, primarily used to scan historical monuments to support restoration projects approved by IPHAN. Two decades later, the combination of aerial photogrammetry, local photometry, and LiDAR provides a comprehensive view that helps identify both the construction technology and the degradation processes of cultural assets. In the case of the church of St Francis of Assisi, previously inaccessible details such as the lateral areas of the relief could be observed with greater precision.

Thermography

The application of infrared thermography in fieldwork plays a key role in capturing representative data of damage and pathologies, serving as an illustration of possibilities for integration into BIM methodologies – the primary focus of this research. However, it is part of a larger process aimed at developing a methodology for applying thermography to buildings.

For the successful development of this type of research, a comprehensive understanding of concepts, such as maintenance, condition monitoring, inspection, and structural health monitoring is crucial. Equally important is the grasp of concepts related to the thermographic system, which encompasses 'a set of equipment, accessories, and applications necessary



Figure 4. Losses on the nose, part of the lips, and cheekbone recorded in 3D modeling, (a) from the left side and (b) from the right side. Image: the authors



Figure 5. Detail in 365 nm UV fluorescence photography, showing on the left side an area of previous intervention, and on the right the forehead with remaining bird excrement on the top surface of the stone. Image: the authors

for the collection and processing of thermal information' (ABNT 2020) and its components.

The equipment used in this initial round of data collection consisted of FLIR E5 and FLIR E6, which are relatively affordable but have a limited working range when compared to so-called scientific cameras that come with prohibitive costs for conventional researchers and professionals. Therefore, understanding the limitations of each piece of equipment, the context, and the environment in which data is collected, along with practical knowledge of the observed subject, becomes crucial. For instance, an anomaly identified on the forehead of St Francis can be observed and confirmed from different angles and distances, revealing distinct material characteristics (Figure 6).

From this initial set of images with radiometric information, used as a control, it becomes possible to observe points of convergence or divergence with data from other methods. Simultaneously, the potential for replicating this study, using equipment of higher or lower quality, allows one to adjust the cost-effectiveness balance of infrared thermography for each case, considering the degree of uncertainty. It's worth noting that the decision to investigate a historical and heritage-listed building, the most restrictive type of structure within our scope of work, will contribute to establishing best practices and potential standards that can be applied to any other situation involving existing constructions.

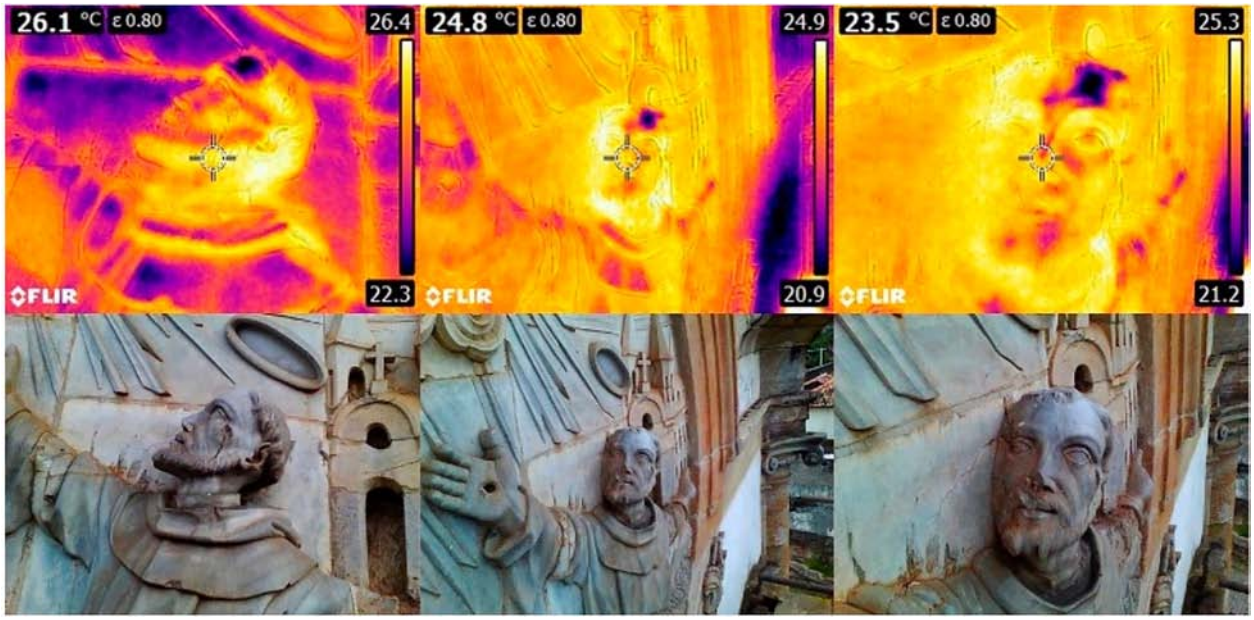


Figure 6. Compose image of the face of St Francis, obtained from different angles by FLIR-E5. Image: the authors

Conclusions and future work

The preliminary results in this paper are presented to clarify and systematize the applied method used in the field. Above all, the integration of archival research and new technologies, especially in terms of technical imaging, has enabled sharing of information and provided a holistic view of the subject over time.

Although preliminary, synergetic use of these imaging systems should be preceded by establishing the terminology, data systematization, and the development of a diagnostic model through HBIM.

As part of the research, we believe that the damage assessment, combined with an understanding of the materials and construction technology used in integrated architectural assets made of stone, can guide risk management protocols. This guidance includes understanding the degradation agents as well as enabling monitoring of deterioration processes over time through systematic and continuous images and records.

Acknowledgment

The authors would like to thank and acknowledge the support received from CNPq, FAPEMIG and CAPES (Federal Agency for Support and Evaluation of Graduate Education); Maria Raquel Alves Ferreira, from IPHAN; Angelo Oswaldo, mayor of the municipality of Ouro Preto; Father Edmar Pereira and employees of the church of St Francis of Assisi; and researchers Livia Freire and Paola de Macedo Gomes Dias from IFMG– Ouro Preto.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico [grant number 405146/2021-3]; Fundação de Amparo à Pesquisa do Estado de Minas Gerais.

ORCID

Yacy Ara Froner http://orcid.org/0000-0002-5675-6945
Willi de Barros Gonçalves http://orcid.org/0000-0002-2707-0610
Luiz Antônio Cruz Souza http://orcid.org/0000-0002-3241-211X
Antônio Gilberto Costa http://orcid.org/0000-0001-7976-4836
Alessandra Rosado http://orcid.org/0000-0002-6968-8283
Ana Regina Mizrahy Cuperschmid http://orcid.org/0000-0002-6792-174X
Guilherme de Oliveira Walter http://orcid.org/0000-0002-3676-5692
Ana Carolina Neves Miranda http://orcid.org/0000-0002-6915-4265
Guilherme Michelin http://orcid.org/0000-0002-8311-653X
Ana Carolina Montalvão http://orcid.org/0000-0001-6305-3191
Tiago Hardy http://orcid.org/0000-0003-2173-7477

References

ABNT. 2020. "NBR15424-Ensaios não destrutivos - Termografia Infravermelha –Terminologia." Accessed June 2023. https://www.normas.com.br/visualizar/abntnbr-nm/25611/nbr15424-ensaios-nao-destrutivos-termografia-infravermelhaterminologia.

Costa, A. G. 2009. *Rochas e histórias do Patrimônio Cultural do Brasil e de Minas*. Rio de Janeiro: Bem-Te-Vi.

Costa, L. G., and L. F. Baisch. 2012. "CRONIDAS: Proposta de padronização de representação em mapas de danos." In *A Conservação do Patrimônio no Brasil: Teoria e Prática - 1º Seminário Dda Rede Conservação BR Centro de Estudos Avançados da Conservação Integrada*, 145–156. Olinda: Centro de Estudos da Conservação Intergrada.

Crutchley, S. 2010. "The Light Fantastic: Using Airborne Lidar in Archaeological Survey." In *ISPRS TC VII Symposium-100 Years*, Vienna, Austria, 5–7 July 2010, edited by W. Wagner and B. Székely. IAPRS XXXVIII (Part 7B). Accessed May 2024. https://www.isprs.org/proceedings/XXXVIII/part7/b/pdf/160_XXXVIII-part7B.pdf.

FJP. 2001. *Projeto Ideas.* Fundação João Pinheiro, unpublished report.

Froner, Y. 2017. "International Policies for Sustainable Development from Cultural Empowerment." *Journal of Cultural Heritage Management and Sustainable Development* 7 (2): 208–223. https://doi.org/10.1108/JCHMSD-10-2016-0056.

ICOMOS. 2008. *Illustrated Glossary on Stone Deterioration Patterns*. Paris: International Scientific Committee for Stone. Accessed June 2023. https://www.icomos.org/public/publications/monuments_and_sites/15/pdf/Monuments_and_Sites_15_ISCS_Glossary_Stone.pdf.

IPHAN. 1937–1986. *Inventário da Igreja São Francisco de Assis*. Box OB-CX.0259P.01-B.01.

IPHAN. 2005. *Manual de elaboração de projetos de preservação do patrimônio cultural*. Brasília: Programa Monumenta.

Lemos, C. A. C. 2014. *A São Francisco de Assis de Ouro Preto*. Brasília: IPHAN.

Prümers H., C. J. Betancourt, J. Iriarte, M. Robinson, and M. Schaich, 2022. "Lidar reveals pre-Hispanic low-density urbanism in the Bolivian Amazon." *Nature* 606 (7913): 325–328. https://doi.org/10.1038/s41586-022-04780-4.

Trindade, C. R.. 1951. *São Francisco de Assis de Ouro Preto*. Rio de Janeiro: Ministério da Educação e Saúde.

UNIRC. 1988. *Raccomandazione NorMal 1/88-Alterazioni macroscopiche dei materiali lapidei: lessico*. Roma: UNIRC. Accessed June 2023. https://www.unirc.it/documentazione/materiale_didattico/597_2011_287_13564.pdf.

UNIRC. 2006. *UNI 11182- Materiali lapidei naturali ed artificiali - Descrizione della forma di alterazione - Termini e definizioni*. Milano: UNIRC. Accessed June 2023. https://www.unirc.it/documentazione/materiale_didattico/1463_2016_426_26713.pdf.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S108–S116
https://doi.org/10.1080/00393630.2024.2342162

CRITICAL ASSESSMENT/PERSPECTIVE

Greenwashing Revelations through Revision: Re-evaluating Sustainability Claims for Bioplastics

Revelaciones de Lavado Verde a Través de la Revisión: Reevaluación de las Afirmaciones de Sostenibilidad de los Bioplásticos

Bianca Gonçalves[1,2], Daisy Green[2,3], Kim Kraczon[2,4] and Talia Weiss[2,5]

[1]Atelier CurArte, Rotterdam, Netherlands; [2]Ki Culture, Amsterdam, Netherlands; [3]Greens' Art Conservation, London, UK; [4]Gallery Climate Coalition, London, UK; [5]DBR Limited, London, UK

ABSTRACT

Since its launch in January 2021, Ki Culture's *Waste and Materials Ki Book* has been downloaded over 5,000 times by practitioners of cultural heritage worldwide, establishing the online sustainability manual as one of the leading guides for mitigating the environmental burden of materials we encounter in conserving cultural heritage. The sustainability manual initially focused on finding alternatives to reduce waste and lessen the environmental impact of the plastic materials we encounter in collections care and transport. This led to exploring emerging alternative materials such as bioplastics as potential replacements for petroleum-derived plastics. Terms such as 'biodegradable', 'compostable', 'green', 'environmentally friendly', and 'sustainable' are commonly used in the marketing strategies for bioplastics and biobased materials. However, the question arises: are these alternatives better options for the environment and cultural heritage than their plastic counterparts? Some of the materials highlighted in the *Waste and Materials Ki Book* showed evidence of greenwashing. What constitutes a sustainable material, and how do we identify and trust the 'green' alternatives available? By honing our criteria for environmentally responsible materials and examining the terminology associated with bioplastics, we can identify greenwashing. This paper critically evaluates so-called green alternatives in conservation, with a focus on greenwashing associated with polylactic acid (PLA). Emphasizing the need for informed decision-making, the study directly reflects the ongoing revision of the *Waste and Materials Ki Book*.

Desde su lanzamiento en enero de 2021, el *Ki Book Residuos y Materiales* de Ki Culture ha sido descargado más de 5000 veces por profesionales del patrimonio cultural en todo el mundo, lo que establece al manual de sostenibilidad en línea como una de las principales guías para mitigar la carga ambiental de los materiales que encontramos en la conservación de los objetos de patrimonio cultural. El manual de sostenibilidad se centró inicialmente en buscar alternativas para reducir los residuos y aminorar el impacto ambiental de los materiales plásticos que encontramos en el cuidado y transporte de colecciones. Esto llevó a explorar nuevos materiales alternativos, como los bioplásticos, como posibles sustitutos de los plásticos derivados del petróleo. Términos como 'biodegradable', 'compostable', 'verde', 'ecológico' y 'sostenible' se utilizan comúnmente en las estrategias de marketing de bioplásticos y materiales de base biológica. Sin embargo, surge la pregunta: ¿son estas alternativas mejores opciones para el medio ambiente y el patrimonio cultural que sus contrapartes plásticas? Algunos de los materiales destacados en el Libro Ki sobre residuos y materiales mostraron evidencia de lavado verde. ¿Qué constituye un material sostenible y cómo identificamos y confiamos en las alternativas 'verdes' disponibles? Al reflexionar sobre nuestros criterios en cuanto a los materiales ambientalmente responsables y examinar la terminología asociada con los bioplásticos, podemos identificar el lavado verde. Este artículo evalúa críticamente las llamadas alternativas verdes en conservación, con un enfoque en el lavado verde asociado con el ácido poliláctico (PLA). Al enfatizar la necesidad de una toma de decisiones informada, el estudio refleja directamente la revisión en curso del *Ki Book de Residuos y Materiales*.

ARTICLE HISTORY
Received October 2023
Accepted April 2024

KEYWORDS
Bioplastics; polylactic acid; greenwashing; sustainable materials

Bioplásticos; ácido polilactico; lavado verde; materiales sustentables

Introduction

The *Waste and Materials Ki Book*, an online manual for sustainable practices within cultural heritage launched in 2021 by Ki Culture (Kraczon, Wuebold, and Southwick 2021), is undergoing an update. In the original edition, a range of alternatives to the petroleum-derived plastics we use in collections care, storage, transport, and conservation treatments, including bioplastics, was offered as more environmentally responsible, raising the pivotal questions: *How do we*

CONTACT Kim Kraczon kim.kraczon@kiculture.org Ackerstraße 169 10115 Berlin, Germany
© The International Institute for Conservation of Historic and Artistic Works 2024

determine whether a material is considered 'green', 'eco-friendly', and 'sustainable'? and *Are these alternative materials in fact suitable for use in cultural heritage?* The conservation and heritage industry faces an increasing conundrum surrounding consumer choices in the realm of sustainable materials, particularly concerning biodegradable plastics, bioplastics, biobased plastics, and compostable products. The confusion arises from the overlapping and ambiguous terminology used to describe these materials and the intricate balance that conservators must strike between preserving cultural artifacts and adopting environmentally friendly practices.

In this paper, we will analyze the challenges encountered during initial research for the *Waste and Materials Ki Book*. We will also explore the difficulties conservators face in defining what qualifies as a sustainable material and how to distinguish sustainable claims from greenwashing. Additionally, we will discuss the complexities associated with adopting new materials without rigorous testing and evaluation. The primary goal of the updated edition of the *Waste and Materials Ki Book* is to transcend conventional sustainable parameters by emphasizing a comprehensive and holistic approach to responsible material choices. We will delve into how conservators can recognize these essential features in their practices. The forthcoming edition will not only spotlight new materials but also assess recent trials and comprehensively evaluate their environmental impact. This analysis aims to provide valuable insights into navigating these challenges and making more informed decisions in the realm of sustainable cultural heritage practices.

Definitions, criteria, and complexities

At the time the *Waste and Materials Ki Book* was initially written, the metrics for determining whether a material was 'sustainable' were not addressed. The term 'sustainable' itself, defined by the United Nations (2023) as 'meeting the needs of the present without compromising the ability of future generations to meet their own needs' is rather unclear. We must also ask: *Meeting needs in what sense? What are we sustaining and for whom? Are we sustaining the continued availability of certain materials well into the future? Sustaining the role certain materials play in the development and trajectory of one particular society? What do the terms 'sustainable', 'green', and 'eco-friendly' mean in terms of materials?* When used as a descriptor for materials and products, these terms are widely understood as alleging one or more of the following: non-toxic, manufactured from natural resources, manufactured with recycled content, biodegradable, compostable, 100% recyclable, or reusable. The Collins Dictionary (2023) defines sustainability in the context of environmental impact as: 'to describe the use of natural resources when this use is kept at a steady level that is not likely to damage the environment'. However, the impact on the environment of the extraction, processing, and transportation of natural resources – both renewable and non-renewable – to keep up with our current demand for materials is inescapable. All materials generate a wide array of environmental burdens. Ethical and environmental justice concerns also arise surrounding the exploitation of workers, toxicity to human beings, and contamination of indigenous lands in all stages of a product's life cycle. The complexity of these issues requires a thorough discussion as a means to prompt professionals to question automatically whether a manufacturer has been forthcoming with details surrounding their product's lifecycle, or whether more investigation is necessary.

As will be discussed in detail later in this section, greenwashing marketing campaigns play into the lack of government regulation and public understanding of these terms, which leads to uninformed purchases often resulting in unintended deleterious environmental and social impacts. With carbon emissions currently surpassing global limits and irrefutably driving climate change, the focus within cultural heritage has been largely directed towards reducing the carbon footprint of our exhibition spaces, storage, laboratories, means of transport, exhibition-making, and materials. The Sustainability Tools in Cultural Heritage online materials carbon calculator (STiCH 2023) launched in 2020 is a useful tool to indicate the metrics for comparing the carbon footprint of materials we commonly encounter in cultural heritage, taking much of the guesswork out of mitigating the carbon emissions from our consumer choices. However, while choosing materials with a low carbon footprint is a foremost concern and undeniably instrumental in collectively reducing the carbon emissions generated by the cultural heritage sector, carbon footprint is only one impact category out of many we should consider when assessing the environmental and humanitarian burdens of a material or product.

The impact categories used for life cycle assessment (LCA) offer some insight into the environmental burdens of materials not addressed by the carbon footprint alone. An LCA is defined by the European Commission (2023a) as 'the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle' and encompasses the following impact categories: climate change, eutrophication, land use, resource depletion, acidification, ozone depletion, ecotoxicity, ionizing radiation, photochemical ozone formation, water depletion, and human toxicity. Materials that are 'naturally derived' and rank low in numerous impact categories and are seemingly environmentally friendly often reveal other socio-environmental

impacts that reverberate unexpectedly, necessitating the inclusion of environmental justice issues as an additional impact category. When assessing the environmental burdens of a material, one must also weigh its end-of-life scenario or options for the reuse, recycling, or disposal of a particular material at the end of its working life.

It must also be recognized that some wrapping and packaging materials are used in great quantities and very regularly in cultural heritage, making their disposal restrictions all the more environmentally impactful. Tyvek®, for example, is a plastic-based fabric made from spun-bound high-density polyethylene (PE), ubiquitously used in conservation treatments, storage, and transport because of its water resistance, softness, and versatility in protecting objects and their sensitive surfaces from dust accumulation and abrasion. Tyvek® has a relatively low carbon footprint in comparison to other common plastic films per square meter according to STiCH's online carbon calculator, as illustrated in Figure 1. The carbon footprint of Tyvek® decreases with each additional use of the product, however, Tyvek® is not curbside recyclable because so-called soft plastics like Tyvek®, plastic film, and Bubble Wrap® get caught in the machinery at recycling facilities and are sorted out for landfill or incineration. 75% of PE products are estimated to go to landfill, where the chemical stability of the plastic results in the material persisting in the natural environment, contaminating and disrupting both land and marine ecosystems (Yao, Seong, and Jang 2022). The same properties of plastic that wreak havoc on the natural environment: chemical resilience, waterproofing, and resistance to degradation, are often the properties we rely on as conservators and cultural heritage professionals. Certain plastics, such as polyvinyl chloride (PVC), are also known to be toxic to humans in both their production and use (Zimmerman et al. 2019). As cultural heritage turns towards greener paths – or at least attempts greener initiatives in moving away from plastics – it is easy to get caught up in the vast offering of alternatives. Alternatives to plastics and bioplastics have been at the forefront of sustainable initiatives for quite some time now, but they are also shrouded by terminology that lends itself to greenwashing.

Greenwashing and bioplastics

Challenge arises for consumers, firstly because of the lack of regulation surrounding the criteria for sustainability, and secondly because each criterion is subject to individual interpretation. However, giving conservators the tools to decipher sustainability claims inherently results in more autonomy when faced with a material choice. Strict regulations and high standards for materials in the field of conservation often restrict what conservators can use (Ratz 2022), thereby complicating the implementation of alternative materials that vary from the traditional, ubiquitous, and well-researched plastic products currently used in our field.

One of the main problems consumers face in choosing materials with the least environmental and humanitarian impact is the lack of regulation surrounding greenwashing in marketing and product branding. The term 'greenwashing' was established in 1986 in Jay Westerfield's essay which highlighted the hospitality industry's false promotions of towel reuse, claiming reuse principally had a positive environmental impact when economic savings were driving the initiative (de Freitas Netto et al. 2020). 'Green is often a ticket to higher sales in the marketplace' (McGill Environmental Systems 2023), which poses a barrier for those in the industry to reduce misinformation surrounding greenwashing (Delmas and Cuerel Burbano 2011). One particular issue with greenwashing, as PaperFoam® CEO Willem Derkman highlights in an interview (2021), is that products described as sustainable represent 'an indirect method that does not solve the problem'. Whilst bio-based products such as Green Cell Foam®, which is an alternative to synthetic packing foams used in fine arts transport, are environmentally-conscious in their disposal (Green Cell Foam 2022a), companies such as these are not clear about the

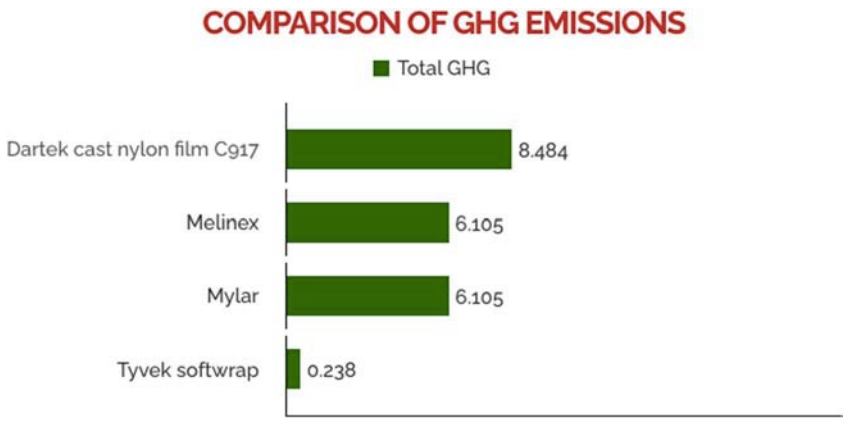


Figure 1. GHG emissions for Tyvek® in comparison to common plastic films, per square meter.

environmental impact in the manufacturing of their product. Green Cell Foam®, for example, is primarily made from 'US-grown cornstarch, an annually renewable resource' (Green Cell Foam 2022b), however what is challenging to identify is the environmental impact of the space allocated to grow the crop. We must consider not just the disposal of a product, which Green Cell Foam® does achieve well, but also the more complicated environmental consequences that allocating agricultural space can have on local communities. Criticizing Green Cell Foam® in this example should not be interpreted as a reason to disregard their product. However, disclosing clearer information about the impact of a manufacturer's process would create a new set of standards surrounding the company's environmental accountability, and would allow consumers to identify more easily when a company is not so forthcoming, which could suggest that further investigation or caution may be necessary. Labeling a product as 'sustainable' is an attractive marketing tagline, however, the term can be misleading.

BioViron markets CompostaFilm® as '100% compostable' (BioViron 2022) and it is marketed as a potential replacement for synthetic plastic films used for protecting objects from moisture and dust accumulation in storage and fine art transport. However, as this paper will continue to elucidate, polylactic acid or polylactide (PLA), although marketed as being biodegradable or compostable, can in fact only be composted at industrial composting facilities, and in practice is usually sorted out and incinerated instead. This particular greenwashing language is misleading to consumers because it implies PLA disposal is synonymous with domestic disposal processes. Whilst products such as PLA-based films or Bubble Wrap® are in some ways a more eco-conscious choice than the traditional plastic alternatives (BioPak 2022), the use of words such as 'biodegradable' or 'compostable' creates a green narrative. BioViron (2022) markets its products as being based on: 'a fully biodegradable polymer material … meets all European and international standards of biodegradability including specifications for compostable materials as per ASTM D6400 (USA), DIN54900 (Germany) and EN13432 (Europe)'. ASTM D6400, DIN54900, and EN13432 are all criteria for industrial compostable products (European Bioplastics 2016). To be clear, anything compostable has the *potential* to be broken down into 'water, carbon dioxide (CO_2), and a little biomass' (European Bioplastics 2019). However, industrially compostable materials cannot be broken down within household compost, as they require specific (high) temperature and pressure. Whilst industrially compostable products are in some ways less detrimental to the environment than their traditional plastic counterparts, consumers need to be fully informed about this from the outset so they can, at a minimum, ensure that they are disposing of their products through the correct waste stream. This ultimately feeds back into the inaccessibility of information; consumers are able to access this knowledge, however not without being aware that they need to research the marketing vocabulary further.

The term 'bioplastic' and advertising for bioplastic products marketed as sustainable is a salient example of the ambiguity of terminology in greenwashing campaigns. European Bioplastics defines bioplastics as material that 'is either biobased, biodegradable, or features both properties' (Buchholz 2022). Biobased plastics 'fully or partially made from biological resources, rather than fossil raw materials' (European Commission 2023b) are also considered to be bioplastics but are not always compostable or biodegradable (Ashter 2016). As seen in Figure 2, the 'bioplastic' umbrella term can therefore be used to describe an array of materials ranging from PE manufactured with corn-derived ethanol that has the same chemical composition and physical properties as traditional PE, to petroleum-derived plastics with additives to catalyze degradation to algae-based polymers that dissolve in water.

The terms 'biobased', 'biodegradable' and 'compostable' can be misleading if not properly understood (European Commission 2023b). These buzzwords are at the forefront of consumer advertisement and demand clarity for consumers to differentiate between greenwashing and less environmentally detrimental products. In order to practice clear and informative vocabulary, this paper will refer to products and their disposal characteristics more specifically. Biodegradable plastics have the 'ability to break down completely into substances found in nature, and in a reasonable time frame' (World Wildlife Fund 2022). The final decomposed product should include 'water, soil, [and] compost' (European Environment Agency 2020). However, it should be noted that it is also possible for fossil fuel-based plastics to biodegrade, although the time frame is not given, and this can take thousands of years while releasing methane gas (European Environment Agency 2020), urging a cautious approach to the 'biodegradable' label.

Plastics labeled as 'compostable' are either industrially composted or home-composted but more often than not require industrial composting in an 'industrial composting plant or an industrial anaerobic digestion plant with a subsequent composting step' (European Environment Agency 2020). Industrial composting is completed through the use of 'temperature, moisture and time frame – leaving nothing behind but water, biomass and CO_2' (Thérage 2023). There are two logos in particular that consumers should note when investigating the disposal of compostable plastics. The first (Fig. 3a) indicates that a material requires industrial composting, while the second (Fig. 3b) indicates a material that can be composted at home.

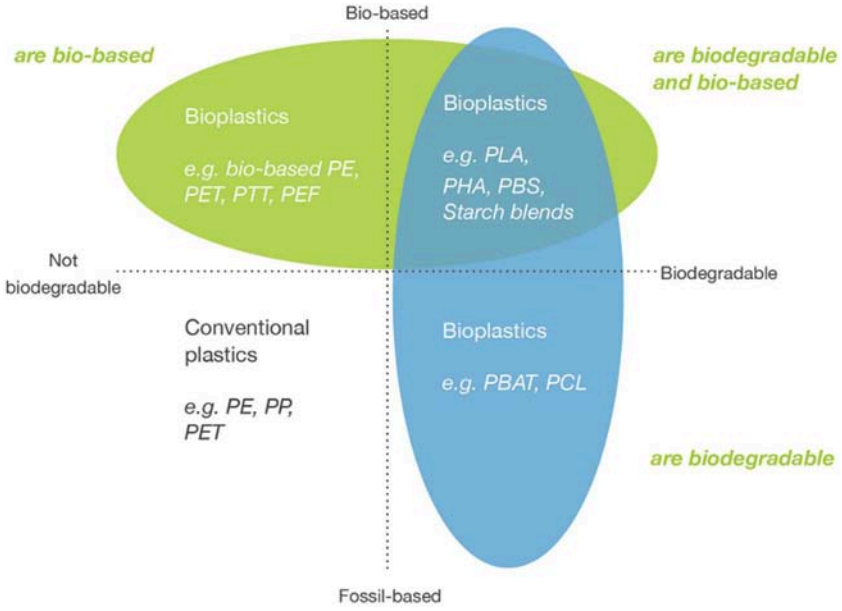


Figure 2. 'Bio' characteristics of commonly-used types of plastics.

Deciphering and debating the definitions of terms and symbols is an overwhelmingly confusing task and may lead to decisions that are not in line with environmentally responsible materials. These specifications are not easily accessible, as there is not a single source of information that outlines the complex terminology and symbols that are integral to understanding the life-cycle of a product.

Case study: PLA

Plastic alternatives such as PLA are often the first selection for a greener choice. PLA is made from renewable biomass, such as sugarcane, corn, or fermented plant starches from cassava (Rezvani et al. 2021). PLA plastics have gained popularity as a more sustainable option in response to the increasing global demand for alternatives to petroleum-based plastics. One reason for the rise in popularity of PLA use lies in the manufacturing process using renewable resources compared to that of traditional petroleum-based plastics. Some sources claim PLAs additionally boast a lower carbon footprint. For example, Inego PLA bioplastics products claim eco-friendly manufacturing that results in 80% lower emissions of greenhouse gases than conventional plastics (Choi, Yoo, and Park 2018). However, consultation in 2022 with the University of Manchester Sustainable Materials Innovation Hub revealed that PLA has a larger carbon footprint than many companies report, and additionally uses viable food crops for the production of the bioplastic, raising ethical concerns over the use of these resources.

Before diving into the specifics of biodegradability, it is essential to address the misconceptions surrounding PLA plastics and their environmental credibility. Energy consumption in PLA production plays a significant role in determining its overall environmental impact. PLA possesses the capability to undergo a process called thermal depolymerisation or hydrolysis, breaking it down into its original monomer form. This resulting solution can be refined and utilized for subsequent PLA production, maintaining its original quality during the recycling process (Rezvani et al. 2021). However, it is crucial to recognize that the infrastructure for recycling PLA is currently not in place to keep up with the recycling demands of the modern world. This is primarily due to the absence of well-established markets for recycled PLA materials. As a result, while recycling PLA holds promise for the future, it is not as widely practised as traditional plastic recycling. Because PLA products also resemble other polymer types, they are often mistakenly disposed of in plastic recycling, contaminating the recycling stream. At present, industrial composting is the preferred end-of-life option for PLA, particularly in food packaging, but the PLA is typically sorted out and either sent to landfill or incinerated before reaching the industrial compost facilities because it does not provide viable nutrient-rich fertilizer to the resulting compost (Deutsche Umwelthilfe 2023).

Despite bioplastic recyclability claims, PLAs and other alternative plastics are not quite as easily biodegradable or compostable as they may seem. Bioplastics are not intended to be composted in home composting; they are designed to degrade within industrial composting processes. As previously outlined, industrial composting is a regulated procedure that transforms organic waste into sterilized materials suitable for agricultural use. In the UK specifically, numerous compostable packaging options can only break down effectively within the confines of industrial composting facilities, but not all of these materials are currently directed to these types of facilities (Dean 2023).



Figure 3. (a) Improved Seedling logo for industrially compostable products. (b) TUV Austria – OK Compost and Seedling logo for home compostable products.

BioPak PLA has received certification for industrial compostability according to both Australian and European standards (BioPak 2023) but does this theoretical certification matter if the PLA is not even arriving at the composting facility? The company claims that PLA bioplastics will decompose within 12 weeks, which is significantly less than traditional plastics, however, there is industry skepticism about this amount of time and the overall biodegradability of PLA. Unfortunately, many bioplastics and compostable plastics end up either in landfill or in the natural environment, where they behave similarly to our conventional petroleum plastics (Deutsche Umwelthilfe 2023).

The theoretical compostability and seemingly low toxicity of PLA make it an approachable and common choice for an alternative plastic. Recent studies revealed, however, that PLA has toxicity levels equivalent to PVC and polyurethane (PU), which casts doubt on its continued use as a non-toxic alternative to plastics (Zimmerman et al. 2019). PLA is found in an array of products from packaging materials to poly-sheeting, but still has quite limited usability within the conservation and heritage sectors. This is largely in part due to the composition of this particular bioplastic, its shelf-life, and off-gassing. Oddy testing carried out on various bioplastics at University College London (UCL) in 2021 underscores the issues associated with adopting PLA into cultural heritage practices. BioViron, a company manufacturing an array of PLA and plant-based bioplastics partnered with a UCL researcher to conduct Oddy testing on a selection of their 100% compostable and biodegradable marketed materials. The Oddy test is an accelerated corrosion test to predict off-gassing from materials in order to determine their safety and usability with cultural heritage objects based on silver, copper or lead in enclosures (Korenberg et al. 2018). The materials tested along with a control were: BioViron BVC100/0.5 mm thick sheeting (PLA), BVF 101/60 µm thick industrial compostable film (PLA), BVF 103/30 µm thick home compostable film (composition unknown), BVN 101/0.5 mm thick opaque sheeting (PLA), Bubble Wrap® with small and large bubbles (composition unknown), and CompostaFoam® (Weiss 2021).

The results are shown in Figure 4. The bioplastics seem to have affected the copper coupons the most, followed closely by lead coupons. Two of the test materials, the BVF 101/60 µm thick industrial compostable film (PLA) and CompostaFoam®, showed some promise for use in certain cultural heritage applications as they are the only two test materials that did not corrode the copper coupon during accelerating aging. The CompostaFoam® additionally did not corrode the silver coupon, but the results of the lead coupon exposed to BVF 101/60 µm industrial compostable film (PLA) during accelerated aging were inconclusive. For this reason, the BVF 101/60 µm thick Industrial compostable film (PLA) and CompostaFilm® can be interpreted as potentially suitable for short-term applications, although they are not necessarily suitable for ongoing treatment, storage or archival use. This particular study was conducted prior to the writing of this paper, and may prompt further testing of bioplastics within the field of conservation. In particular, the parameters for short-term versus long-term use of these materials in collections care and fine art transport have yet to be established and necessitate further research.

In addition to concerns over material compatibility, the physical properties of aging bioplastics also merits consideration. As with traditional plastic materials in collections care and transport, monitoring not only

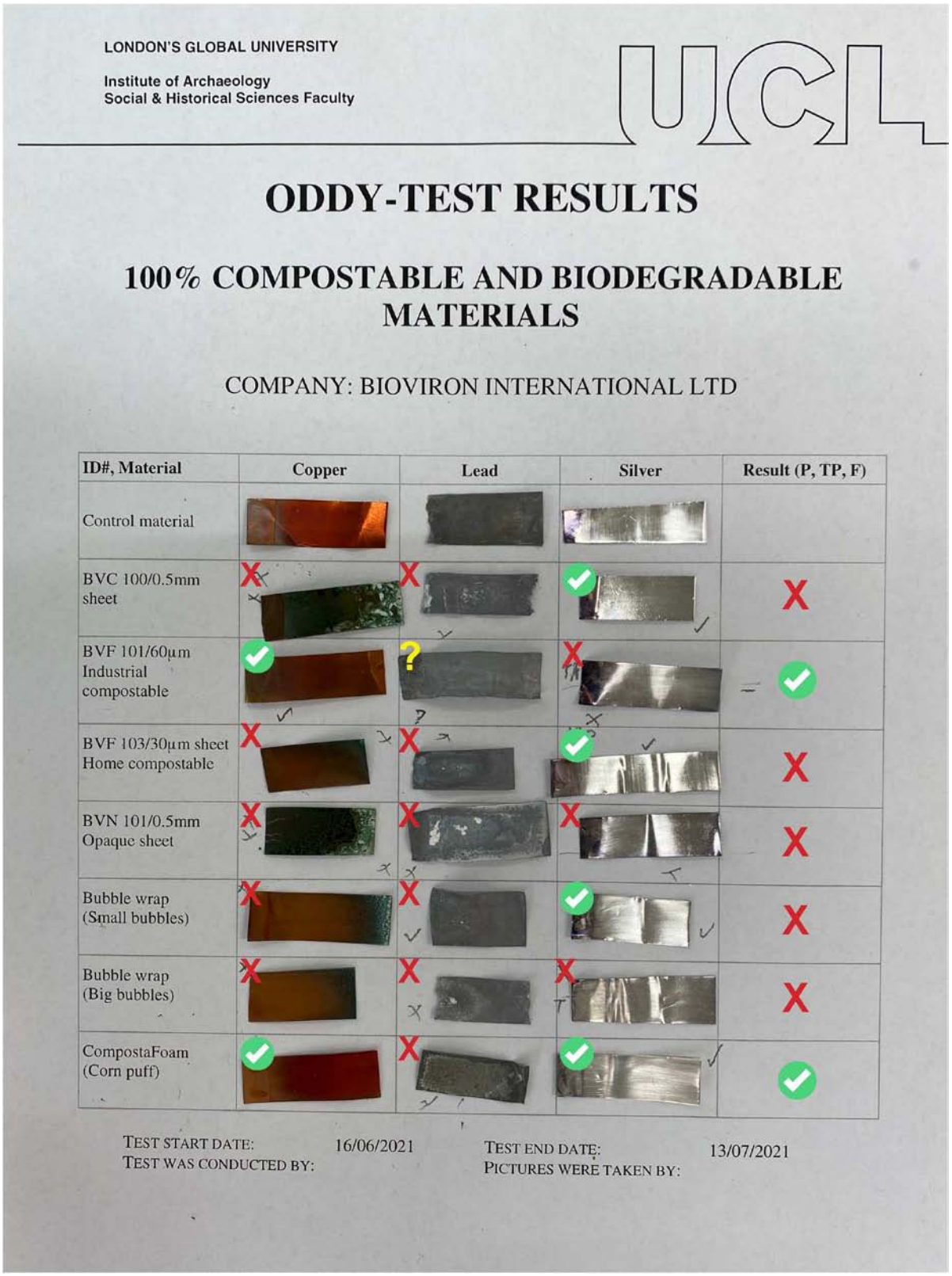


Figure 4. Results of Oddy testing BioViron bioplastic films, sheeting, and foam. A red X indicates off-gassing and a green tick indicates its absence.

off-gassing but also alterations over time to the physical properties of bioplastics in long-term applications becomes necessary. PLA bioplastic films, such as Bioviron CompostaFilm®, have a shelf-life of 12 months according to the company (Bioviron 2022). While PLA and plant-derived bioplastics can potentially offer alternatives to traditional plastic films and foams for short-term transport as protective soft-wrapping of cultural heritage objects, the alterations to mechanical properties of these materials as they age makes them a precarious choice for long-term storage applications.

There is still potential to extend the use of certain bioplastics in the cultural heritage sector. For example, products manufactured from renewable resources like starch offer eco-friendly end-of-life attributes. While these products often lack the requisite performance and properties of conventional plastics, limiting their application in cultural heritage settings, their potential to reduce our dependance on the fossil fuel industry as well as to reduce solid waste in cultural heritage practices offer solutions that can help lead us towards greener paths, both in the conservation studio and on-site. The potential limitations of bioplastics in the cultural heritage sector underscore the current best practice of avoiding single-use plastic materials and keeping materials already in stock in use for as long as possible. Although curbside recycling is not a solution and should be seen as a last resort, many specialized recycling facilities now offer services for soft plastics. For example, TerraCycle is a system known for presenting recycling solutions for harder-to-recycle materials, including disposable gloves and other PPE clothing, but this service is limited and not available in every region.

Future perspectives

With confusion and ambiguity surrounding what constitutes a sustainable material, a set of criteria for selecting materials with the least amount of environmental and humanitarian detriment will be disseminated in the revised edition of the *Waste and Materials Ki Book*. Direct reuse or repurposing of a material is by far the most impactful action one can take to mitigate all environmental and social impact categories, however, when faced with the decision to purchase new materials, it is important to refer to the criteria below:

- manufacture as locally as possibly with renewable resources that are managed responsibly
- non-toxic in extraction practices, sourcing of raw materials, and production methods
- ethical and non-exploitative in extraction practices, sourcing of raw materials, and production methods
- non-toxic to human beings and ecosystems during their working life
- good potential for reuse/circularity
- favorable end-of-life management, either curbside recyclable or compostable, and non-toxic and non-polluting in their disposal, recycling processes, and decomposition.

It is clear that the notion of sustainability, while well-intentioned, has been appropriated and manipulated by various entities, leading to the widespread problem of greenwashing. The complexity of sustainability necessitates a clear and reliable methodology for identifying greenwashing. Such a methodology is crucial to ensure that cultural heritage practitioners and others can make informed choices and avoid deceptive practices. We must approach sustainability with caution, thinking twice before using it as a label, and researching thoroughly before believing in its claims. Sustainability should be viewed as a valuable but complex concept that needs close examination and consideration. Moreover, the integration of sustainability into the cultural heritage sector is imperative for comprehensive environmental responsibility. It is not enough to merely preserve artifacts; cultural heritage practitioners must also discern outdated or deceptive practices in the pursuit of sustainability. This underscores the importance of including sustainability education in training curricula, to equip future practitioners with the knowledge and tools needed to navigate the complex landscape of ecological considerations.

Conservators must also consider not only the environmental impact of product disposal but also the environmental impact of product manufacture. Sustainability criteria are dynamic, subject to changes in technology, natural landscapes, industry regulations, and language standards. However, by giving professionals the resources to make their own investigations less daunting, we can make important steps to increase awareness and encourage conservators to make wise and well-informed decisions about their product consumption. Without more precise specifications of sustainability, it is near impossible to proactively move forward to produce modern standards that not only reflect the high quality of a good conservation practice but also allow conservators to make more environmentally informed decisions within their profession.

On a closing note, recognizing the fact that sustainability goes beyond ecology is crucial in our effort to create a future that is both inclusive and environmentally responsible. While this article has not delved deeply into social aspects, it acknowledges the importance that accessibility and social justice are equally important considerations. We must be mindful of regional considerations because solutions developed in one area may not be appropriate for the demands of the global community. It's essential to consider the unique needs and perspectives of diverse communities, promoting climate justice alongside social justice. In summary, to achieve a more environmentally responsible and inclusive future, we must commit to continuous learning, adaptation, and collaboration. Cultural heritage preservation plays a vital role in this endeavor, as it reflects our shared heritage and the responsibility to safeguard it for future generations. By approaching sustainability with diligence, recognizing greenwashing, and embracing a broader perspective that encompasses inclusivity and social justice, we can work together to ensure a sustainable world for all.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Ashter, S. A. 2016. "New Developments." In *Introduction to Bioplastics Engineering*, edited by S. A. Ashter, 251–274. Norwich, NY: William Andrew Publishing. https://doi.org/10.1016/b978-0-323-39396-6.00010-5.

BioPak. 2022. "What is PLA Plastic?" https://www.biopak.com/uk/resources/what-is-pla#:~:text=Lower%20Carbon%20Footprint&text=Ingeo%20PLA%20bioplastic%20produces%2080.

BioPak. 2023. "How to Dispose of BioPak Packaging." www.biopak.com. 2023. https://www.biopak.com/uk/disposal.

BioViron. 2022. "CompostaFilm Compostable Packaging." BioViron International. https://www.bioviron.com/composta-film.

Buchholz, O. 2022. "United Nations Recognise Bioplastics as Sustainable Alternative to Conventional Plastics." European Bioplastics E.V. 28 January 2022. https://www.european-bioplastics.org/united-nations-recognise-bioplastics-as-sustainable-alternative-to-conventional-plastics/.

Choi, B., S. Yoo, and S. Park. 2018. "Carbon Footprint of Packaging Films Made from LDPE, PLA, and PLA/PBAT Blends in South Korea." *Sustainability* 10 (7): 2369. https://doi.org/10.3390/su10072369.

Collins Dictionary. 2023. "Sustainable." HarperCollins. https://www.collinsdictionary.com/dictionary/english/sustainable#:~:text=(s%C9%99ste%C9%AAn%C9%99b%C9%99l,likely%20to%20damage%20the%20environment.

Dean, E. 2023. "The Difference Between Compostable, Home-Compostable and Industrial-Compostable Packaging." Macfarlane Packaging, 14 March 2023. https://macfarlanepackaging.com/blog/the-difference-between-compostable-home-compostable-and-industrial-compostable-packaging/.

de Freitas Netto, S. V., M. F. F. Sobral, A. R. B. Ribeiro, G. R. da, and Luz Soares. 2020. "Concepts and Forms of Greenwashing: A Systematic Review." *Environmental Sciences Europe* 32 (1). https://doi.org/10.1186/s12302-020-0300-3.

Delmas, M. A., and V. Cuerel Burbano. 2011. "The Drivers of Greenwashing." *California Management Review* 54 (1): 64–87. https://doi.org/10.1525/cmr.2011.54.1.64.

Derkman, W. 2021. "PaperFoam: Eco-Friendly Packaging Solutions Interview by Zero Packaging by Paxpring." https://www.zero-packaging.com/post/paperfoam-eco-friendly-packaging-solutions.

Deutsche Umwelthilfe. 2023. "Bioplastic." Accessed 2 October 2023. https://www.duh.de/bioplastik/.

European Bioplastics. 2016. "What Are the Required Circumstances for a Compostable Product to Compost?" European Bioplastics. Accessed March 2, 2016. https://www.european-bioplastics.org/faq-items/what-are-the-required-circumstances-for-a-compostable-product-to-compost/.

European Bioplastics. 2019. "Composting." European Bioplastics. 2019. https://www.european-bioplastics.org/bioplastics/waste-management/composting/.

European Commission. 2023a. "European Platform on LCA." Accessed 4 September 2023. https://eplca.jrc.ec.europa.eu/lifecycleassessment.html.

European Commission. 2023b. "Biobased, Biodegradable and Compostable Plastics." Environment.ec.europa.eu. https://environment.ec.europa.eu/topics/plastics/biobased-biodegradable-and-compostable-plastics_en#:~:text=The%20umbrella%20term%20%E2%80%9Cbioplastics%E2%80%9D%20is.

European Environment Agency. 2020. "Biodegradable and Compostable Plastics — Challenges and Opportunities — European Environment Agency." Accessed 27 August 2020. https://www.eea.europa.eu/publications/biodegradable-and-compostable-plastics.

Green Cell Foam. 2022a. "Disposal." Green Cell Foam. https://greencellfoam.com/disposal.

Green Cell Foam. 2022b. "Environmentally Friendly Packaging | Green Cell Foam." Green Cell Foam. https://greencellfoam.com/about.

Korenberg, C., M. Keable, J. Phippard, and A. Doyle. 2018. "Refinements Introduced in the Oddy Test Methodology." *Studies in Conservation* 63: 2–12. https://doi.org/10.1080/00393630.2017.1362177.

Kraczon, K., J. Wuebold, and C. Southwick. 2021. "Waste and Materials, Collections Care: Packing, Storage and Transport: A Step-By-Step Guide for Sustainable Action, vol. 1." https://kibooks.s3.us-east-2.amazonaws.com/2021/january/Waste+and+Materials+Ki+Book+-+KiCulture.pdf.

McGill Environmental Systems. 2023. "Is Biodegradable Plastic Compostable Plastic.?" https://mcgillcompost.com/resources/is-biodegradable-plastic-compostable-plastic/#:~:text=Look%20for%20the%20labels&text=As%20most%20folks%20know%2C%20plastics.

Ratz, W. 2022. "Sustainability: Choosing Materials for Conservation – Difficulties with Decay." *News, Articles and Stories from the V&A* (blog). Accessed 16 November 2022. https://www.vam.ac.uk/blog/museum-life/choosing-materials-for-conservation-difficulties-with-decay.

Rezvani, E. G., F. Khosravi, A. S. Ardahaei, Y. Dai, R. E. Neisiany, F. Foroughi, M. Wu, O. Das, and S. Ramakrishna. 2021. "The Life Cycle Assessment for Polylactic Acid (PLA) to Make It a Low-Carbon Material." *Polymers* 13 (11): 1854. https://doi.org/10.3390/polym13111854.

STiCH. 2023. "Sustainability Tools in Cultural Heritage." Accessed March 3, 2023. https://stich.culturalheritage.org.

Thérage, M. 2023. "Improved Seedling Logo for Industrially Compostable Products." European Bioplastics E.V. Accessed August 1, 2023. https://www.european-bioplastics.org/improved-seedling-logo-for-industrially-compostable-products/.

United Nations. 2023. "Sustainability." United Nations. https://www.un.org/en/academic-impact/sustainability.

Weiss, T. 2021. "Reconciling and Honouring Intangible Values in Spaces of Negative Heritage. Identifying a Sustainable Conservation Approach to Fire-Damaged New Cross and Grenfell." Master's thesis. University College London.

World Wildlife Fund. 2022. "Is Biodegradable and Compostable Plastic Good for the Environment? Not Necessarily." World Wildlife Fund. Accessed 8 April 2022. https://www.worldwildlife.org/blogs/sustainability-works/posts/is-biodegradable-and-compostable-plastic-good-for-the-environment-not-necessarily.

Yao, Z., H. J. Seong, and Y. Jang. 2022. "Environmental Toxicity and Decomposition of Polyethylene." *Ecotoxicology and Environmental Safety* 242: 113933. https://doi.org/10.1016/j.ecoenv.2022.113933.

Zimmerman, L., G. Dierkes, T. A. Ternes, C. Völker, and M. Wagner. 2019. "Benchmarking the *in Vitro* Toxicity and Chemical Composition of Plastic Consumer Products." *Environmental Science & Technology* 53: 11467−11477. https://doi.org/10.1021/acs.est.9b02293

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S117–S126
https://doi.org/10.1080/00393630.2024.2350239

CRITICAL ASSESSMENT/PERSPECTIVE

Amplifying Indigenous Australian Voices in the Conservation and Management of Rock Art

Ampliando las Voces de los Indígenas Australianos en la Conservación y Gestión del Arte Rupestre

Darren Griffin[1], Michael Douglas[1], Stuart Harradine[1], Janine Coombs[1], Chrystle Carr[1], John Clarke[2], Billy Briggs[2], Nathalia Guimaraes[2], Emily Corris[2], Bill Bell[3], Troy Lovett[3], Leigh Malseed[3], Jake Goodes[4], Wendy Luke[4], David Lucas[4], Charlie Richardson[4], Dylan Clarke[4], Melissa Marshall [5], Lloyd Pigram[5] and Cissy Gore-Birch[6]

[1]Barengi Gadjin Land Council Aboriginal Corporation (BGLC), Horsham, VIC, Australia; [2]Eastern Maar Aboriginal Corporation (EMAC), Warrnambool, VIC, Australia; [3]Gunditj Mirring Traditional Owner Aboriginal Corporation (GMTOAC), Heywood, VIC, Australia; [4]Parks Victoria (PV), Melbourne, VIC, Australia; [5]University of Notre Dame Australia (UNDA), Broome, Australia; [6]Kimberley Cultural Connections, Kununurra, Western Australia, Australia

ABSTRACT

Rock art is internationally recognised as a tangible connection to cultures past, whose conservation, and management programmes should be developed accordingly. When these heritage places are located within living cultural landscapes and are part of the continuing culture of First Nations people as they are in Australia, there is a fundamental requirement for programmes to be owned and implemented by the relevant communities. However, giving primacy to the voices of those with cultural authority and agency does not always amplify these efforts. To address this challenge, Traditional Owners came together, supported by a land management agency and researchers, to stage a rock art forum for Indigenous Australians in early 2023. This ground-breaking initiative is significant, because the first manual on conserving and managing rock art that gives primacy to the worldviews of Australia's First Peoples will be an output from the forum. Past Australian publications om this subject have been authored by non-Indigenous scholars and practitioners who considered only an international framework for conserving and managing rock art as a cultural treasure. This paper considers discussions from the forum and the developing manual as shared stories of resilience to manage, protect and celebrate rock art through Indigenous-led initiatives to inform the present and prepare us for future advances in the discipline.

El arte rupestre es reconocido internacionalmente como una conexión tangible con culturas pasadas, cuyos programas de conservación y gestión deben desarrollarse en consecuencia. Cuando estos lugares patrimoniales están ubicados dentro de paisajes culturales vivos y son parte de la cultura continua de los pueblos de las Primeras Naciones como lo son en Australia, existe un requisito fundamental para que los programas sean propiedad de las comunidades relevantes y sean implementados por ellas. Sin embargo, dar primacía a las voces de quienes tienen autoridad y agencia cultural no siempre amplifica estos esfuerzos. Para abordar este desafío, los propietarios tradicionales se unieron, con el apoyo de una agencia de gestión de tierras e investigadores, para organizar un foro de arte rupestre para los australianos indígenas a principios de 2023. Esta iniciativa innovadora es importante, porque del foro resultará el primer manual sobre conservación y gestión del arte rupestre que dé primacía a las visiones del mundo de los primeros pueblos de Australia. Las publicaciones australianas anteriores sobre este tema han sido escritas por académicos y profesionales no indígenas que consideraban únicamente un marco internacional para la conservación y gestión del arte rupestre como un tesoro cultural. Este artículo considera las discusiones del foro y el manual en desarrollo como historias compartidas de resiliencia para gestionar, proteger y celebrar el arte rupestre a través de iniciativas lideradas por indígenas para informar el presente y prepararnos para futuros avances en la disciplina.

ARTICLE HISTORY
Received October 2023
Accepted April 2024

KEYWORDS
Australia; First Peoples; Traditional Owners; ownership communities; rock art; cultural landscapes

Australia; Primeros Pueblos; Propietarios Tradicionales; comunidades de propietarios; arte roquero; paisajes culturales

Introduction

> Rock Art is one of the most valuable links to our Old People that we have today. A direct link. This is not art as we know art to be. These are libraries full of our communal resources. They inform us of our place on Country. They inform us of our obligations, roles and rights. They give us our law and legitimacy. They instil into us our identity: Who we are. If our sovereignty was 'written', it was written here, by our Ancestors. By

CONTACT Melissa Marshall melissa.marshall@nd.edu.au Nulungu Research Institute, University of Notre Dame Australia (UNDA), Broome, Australia

© The International Institute for Conservation of Historic and Artistic Works 2024

> our law holders and still it is here, embedded into the solid rock that is our home. (John Clarke.[1])

The protection and preservation of rock art is vital, due to increasing pressure from climate change, industrial development and public visitation. In Australia, where Aboriginal and Torres Strait Islander nations continue over 65,000 years of unbroken living culture, the right to do so is often determined by others through legislative frameworks, policies and political will. With emphasis on the conservation and management of tangible paintings and engravings, intangible cultural values are often regarded as secondary.

In contemplating the rising role and involvement of communities and different social entities as active caretakers of their heritage, we share our reflections of the collective experience alongside wisdom shared by individual participants at the Gariwerd Rock Art Management Forum (GRAMF). Here we seek to amplify these voices alongside many others, to reorient and advance conservation practice in Australia. Cultural authority and agency should own, direct and inform conservation strategies that impact the Gariwerd Cultural Landscape.

Background

> The imagery is there but the understanding of what that imagery is, is not there. But the clues to that are in the intangible, in the story that belongs to those particular art sites and to why the art sites were placed where they are. (Julie Freeman (Booderee National Park) at GRAMF)

The Western scientific approach to the conservation and management of rock art in Australia was first considered in earnest at a workshop for conservators in Perth in 1973 (Pearson and Pretty 1976), followed by a second workshop dedicated to conserving rock art in 1977 (Pearson 1978). These informed the subsequent development of techniques and strategies specific to an Australian context, primarily to address environmental pressure, but also reactive responses to human impacts (Clarke 1976; Gillespie 1979; Hughes 1978; Hughes 1979). Throughout the following decade, further trials were conducted particularly in the newly-established Kakadu National Park (CORLAB 1986, 1987, 1988, 1989; Gillespie 1983) and the first academic publication on rock art conservation (Rosenfeld 1985) was followed by a manual for rangers (Lambert 1989; 2007). With academics focusing on protecting, preserving and conserving tangible rock art images as discrete entities in consultation with Indigenous Australians, voices from individual Aboriginal communities increasingly entered discussions to inform practice for traditional repainting and refreshing techniques, as well as articulating intangible cultural values and narratives (Blundell and Woolagoodja 2005; Doring 2000; Mowaljarlai and Malnic 2001; Mowaljarlai and Watchman 1989).

In the decades since, Aboriginal and Torres Strait Islander culture is increasingly implicitly considered as part of conservation and management practices. However, there continues to be an emphasis placed on Western scientific practices in consultation with First Peoples, rather than the latter's ownership and direction emerging as their direct cultural responsibility (Marshall 2020). Numerous workshops and fora have also been held during this time to discuss the management and conservation of rock art. However, whilst this has involved Indigenous people to varying degrees, as these have been driven by specialists in the field they have predominantly been delivered through Western perspectives (Agnew et al. 2015).

In 2017, Murujuga Aboriginal Corporation came together with researchers to stage *Marnda Gardairri*, an Indigenous ranger rock art forum funded through partnership agreements (Marshall, Wallis and Golson 2019). The initiative provided an opportunity for Indigenous rangers and Elders to come together to discuss the conservation and management of rock art in a culturally-secure space, one that invited contributions from academic specialists but with an agenda developed through an Indigenous perspective. Sixty rangers and Elders from across Australia came together for the week-long event at Dampier in Western Australia, where presentations and discussions took place and there were site visits to the rock art on Murujuga. This initial event was attended by Traditional Owner representatives from the southern state of Victoria, who identified significant value in continuing the conversation by working towards a second such forum.

Bringing together the three Gariwerd Traditional Owner groups, namely Barengi Gadjin Land Council Aboriginal Corporation (BGLC), Eastern Maar Aboriginal Corporation (EMAC) and Gunditj Mirring Traditional Owner Aboriginal Corporation (GMTOAC), alongside land co-managers (Parks Victoria) and researchers (Nulungu Research Institute, University of Notre Dame Australia), the second Indigenous ranger rock art forum was developed to support the broader management of rock art across the state. Collectively the authors of this paper and their organisations have been planning for this event since 2019 (interrupted by Covid-19). Integral to the event, the organisers jointly developed the programme to explore existing management strategies with Indigenous land managers across Australia, from Djab Wurrung, Jardwadjali (Wotjobaluk Nations) and Gunditjmara Country and other locations. Issues such as graffiti, visitor and fire management were key themes at the forum.

Seeking to give primacy to Indigenous worldviews and to focus on the care and protection of rock art places and cultural heritage sites, the collective acquired funding through an Australian Heritage

Grant to stage the event. It was an opportunity for rangers looking after National Heritage Listed places and World Heritage sites to share knowledge and practices with other groups, many of whom are working towards recognition and National Heritage Listing. Importantly, It provided an opportunity for all to discuss, plan and implement best practice in rock art conservation, management and tourism practices at nationally important places including Gariwerd (the Grampians) where the event was held. To ensure that this event would be translated into action, outputs were integral to the planning, including the production of a communal painting on canvas produced to illustrate our journey through the event; a photographic exhibition to showcase images of the Gariwerd Cultural Landscape by renowned photographer John Gollings; and crucially, the development of a *Practical Guide for Indigenous Rangers in the Management of Rock Art Cultural Landscapes in Australia* (BGLC et al. 2024). Reflections on the event and shared experience are given below, along with implications for the future of Indigenous-led co-management strategies for heritage places such as Gariwerd.

> Our ancestors led the way for us, they are still here with us. Their integrity and connection to culture through rock art at Gariwerd … show a deep connection to Country (Bill Bell at GRAMF).[2]

Gariwerd Rock Art Management Forum (GRAMF)

> 'You know there is a voice in this room. How do we use this voice to our advantage, to be able to make a change moving forward?' (Cissy Gore-Birch at GRAMF)

GRAMF was successfully held in Gariwerd in western Victoria in March 2023. More than 150 Indigenous rangers and Elders from across Australia (Figure 1) gathered on the lands of the Djab Wurrung, Jadawadajali and Gunditjmara peoples to share knowledge and experiences of rock art in the Gariwerd Cultural Landscape. The logo created for the forum by David Flagg (Figure 2) illustrated the significance of this location.

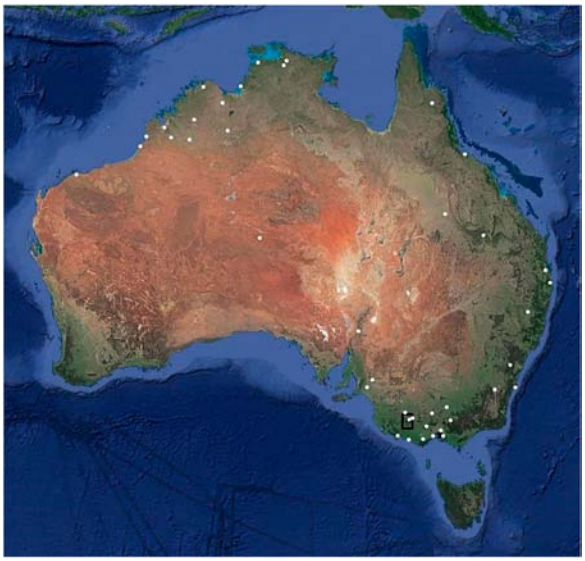


Figure 1. Map of where all the delegates came from across Australia.

The GRAMF included presentations from Indigenous Elders and rangers caring for UNESCO World Heritage listed places who shared knowledge and practices on specific issues including graffiti, visitor and fire management, and was an opportunity for delegates to discuss a range of key themes including rock art conservation practice, cultural tourism, customary management, cultural mapping, strategies for sustainability and lessons learned from overseas. As well as powerful discussions across the week, the participants spent a day visiting some of the rock art in Gariwerd to experience the cultural landscape and to discuss the management issues faced at these places.

Each day of the forum was hosted by one of the three Gariwerd Traditional Owner groups, with the final day being hosted by Parks Victoria's Managing Country Together Team. Each Traditional Owner group shared information about their organisation, including what formal recognition they have and the journey their Community had to take to get this. Fortuitously, the event coincided with Eastern Maar Aboriginal Corporation celebrating their Native Title win on Tuesday 28 March 2023, which was shared and celebrated with participants on the Wednesday.

The forum opened with a smoking ceremony and welcome to Country on the Monday morning. In a marquee on the grounds of the Brambuk Cultural Centre, the discussions commenced with a panel that included representatives from each of the Gariwerd Traditional Owner groups, and Traditional Owners from Uluru-Kata Tjuta National Park and New South Wales South Coast, with a representative from Parks Victoria's park planning. This panel discussed the struggle to decolonise significant cultural places and landscapes, and to have Aboriginal places recognised and prioritised for their intrinsic significance, rather than that of the dominating (Western) culture. In recent years there has been a shift in thinking in the wider community, with growing recognition and understanding of Indigenous rights and the significance of Indigenous culture, including greater respect for cultural places. This had led to changes of recreational use such as a stop to climbing Uluru, and at cultural places in Gariwerd. However, it was recognised that many of the inappropriate uses of cultural places, such as rock climbing, started before Traditional Owners had the right to say anything about it: only in recent years have some Traditional Owners been able to have their opinions considered in the planning of parks. There is still a long journey to make before all Traditional Owners have their

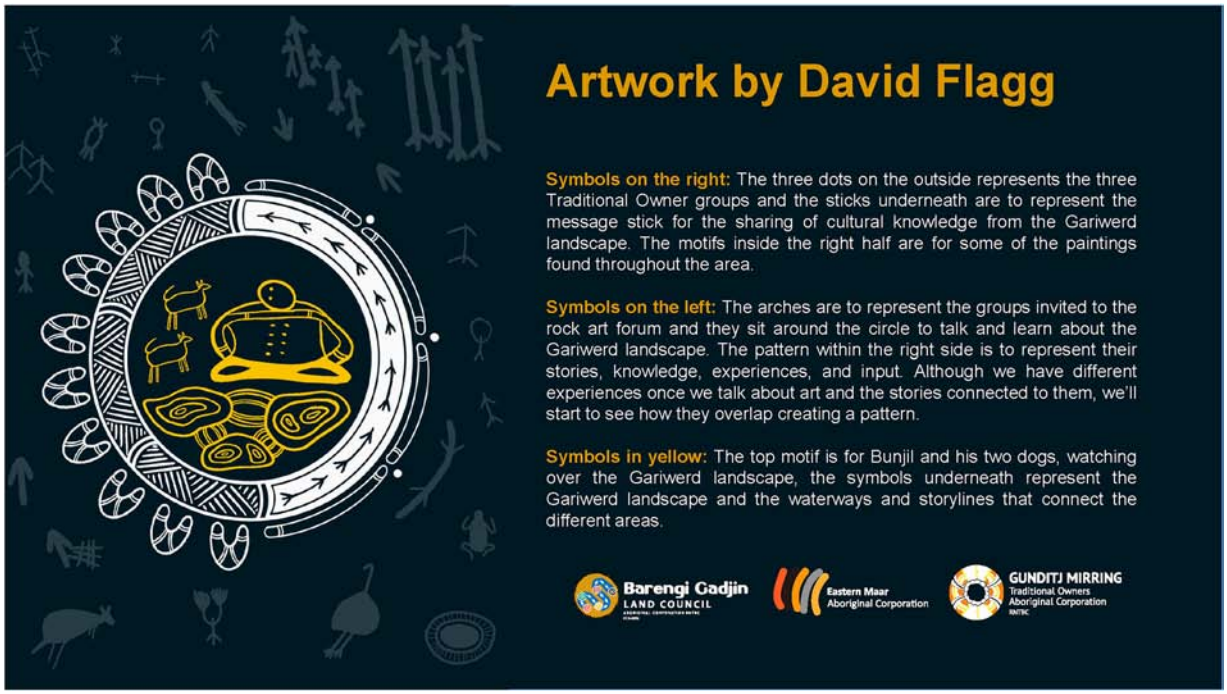


Figure 2. Logo developed for GRAMF.

assertions recognised and respected. There was a call for National Parks and the governments responsible for managing land to reinvestigate the purpose of national parks, prioritising Indigenous peoples' values and concerns over the activities of tourists and recreational users.

Later presentations explored themes including: conservation and management of rock art; intangible heritage; and lessons learned from around the world. Key common issues that emerged included graffiti, visitor and fire management, framed by intangible heritage. A greater understanding emerged that everyone faced comparable issues in their own context, and that individuals were not alone in their efforts to address complex challenges.

There was a full-day field trip visiting two rock art places in Gariwerd: Burrunj (Black Range State Park), and the rock art precinct at Lil Lil (Red Rock Bushlands Reserve). The different status of these two places granted by the state government, and what that meant for visitor access and use, was discussed at each. Lil Lil is managed under the Crown Land (Reserves) Act 1978 (Vic.), with no regulations to manage visitor activities. However, Lil Lil is within the BGLC Registered Aboriginal Party area, and the Recognition and Settlement Area. Lil Lil will soon be under joint management between BGLC and the state of Victoria.

The forum concluded with further discussions about the presentations throughout the week. This included separating into a group for the men and another for the women to discuss issues and challenges, as well as aspirations and assertions important to each of them. Coming together to frame where to go next, the event concluded with a final smoking ceremony to say farewell to participants and travellers (Griffin et al. 2024a, Griffin et al. 2024b) (Figures 3 and 4).

Experiences shared

> What we do today, will impact tomorrow and it's going to be there for our young people. You know, just the way our old people wanted to be. So, let's keep telling our story. (Jake Goodes at GRAMF)

The above quotation from the final day of the GRAMF highlights the importance of preserving rock art and cultural landscapes for future generations, while amplifying Indigenous voices in the conservation and management of rock art. This sentiment was shared amongst the delegates on the final day with again a men's and women's group to share final thoughts, discuss ways to continue the conversations and how to continue to support each other. Collectively the participants were recognised as experts in managing rock art, and champions for rock art protection into the future.

The discussions led to the formulation of several key messages that underscore the urgency and significance of preserving rock art and cultural landscapes (Figures 5 and 6). These messages serve as a roadmap for collective action:

- a call to action: a collective effort to protect and preserve rock art
- self-determination, cultural authority and agency: acknowledging the rights and responsibilities of Indigenous peoples in caring for rock art.
- empowering younger generations: empowering the next generation to assume responsibility for their cultural heritage



Figure 3. GRAMF at Brambuk Cultural Centre in Halls Gap, Victoria.

- integration of knowledge: incorporating oral histories, narratives, and languages to understand and care for cultural landscapes
- building cultural heritage teams: encouraging collaboration and knowledge exchange
- equitable resource commitment: allocating resources for the protection of cultural heritage
- public education: educating both decision-makers and the broader public about the significance of rock art



Figure 4. Welcoming participants to GRAMF.

- developing a national framework: establishing a rock art framework based on Indigenous worldviews.
- Indigenous leadership: forming Indigenous state-based or national councils to lead the management of rock art
- future fora: planning for future rock art management fora to ensure sustained progress.

One of the key outcomes of GRAMF will be utilising the presentations, discussions and activities that took place and developing them into a *Practical Guide for Indigenous Rangers in the Management of Rock Art Cultural Landscapes in Australia* (BGLC et al. 2024). This guide will not only address the tangible aspects of rock art sites but also their intangible cultural values, and the agency and authority embedded in Indigenous worldviews. The importance of Indigenous voices leading the conversation on the management of rock art cannot be overstated and is long overdue.

The framing of this initiative for transformative action is of national significance as the First Peoples of Australia seek to conserve and manage rock art, cultural heritage and landscapes as valuable libraries encapsulating, as John Clarke noted: 'our obligations, roles and rights … our law and legitimacy … our identity: Who we are. If our sovereignty was 'written', it was written here, by our Ancestors'. The amplification of Indigenous voices to lead discussion on conservation and management is imperative, not solely through consultation, engagement and aspirations but rather through self-determination, empowerment, assertion and action. In this way, it is not only the tangible fabric of sites, as considered and guided by Rosenfeld (1985) and Lambert (1989; 2007), but the cultural values, agency and authority encapsulated in the intangible heritage of people and place shared through Indigenous worldviews that will frame and inform conservation and management practices into the future.

Thus, advancements in the management of rock art (collaboratively, jointly or otherwise) must be holistic approaches where the intangible directs and guides the conservation and protection of the tangible. The *Practitioner's Guide* will provide a model for a national conservation and management framework, balancing Indigenous and Western views, highlighting the significance of incorporating Indigenous worldviews in contemporary land management. This transformative project is wide-reaching. Its impact will be felt at both a national and international scale, benefitting First Nations people and the Australian community specifically, while providing a best-practice framework for international efforts to conserve, manage, protect, share and celebrate Indigenous heritage in all its forms.

Gariwerd Cultural Landscape

> Gariwerd is a member of our family – like our grandmother, our mother, our sister, our daughter. This is

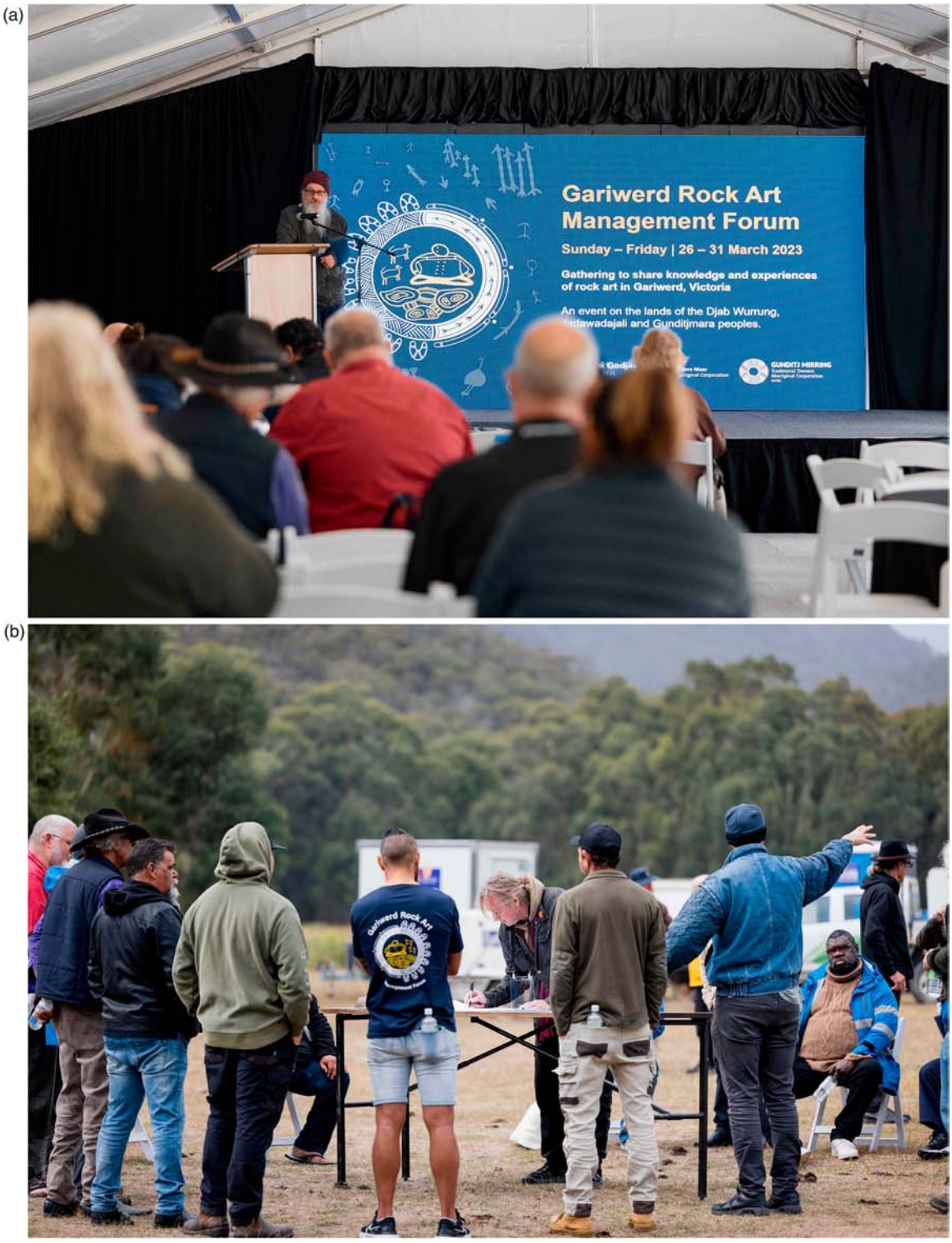


Figure 5. Engaging discussions at GRAMF.

> important to us. This is not just park management to our people. This is the return of a stolen family member. This is why it is so important to decolonise the management of land, water, fire, wildlife and the place names of our bio-cultural landscapes. Our reunion with Gariwerd reaffirms our obligations to look after our family member, our Country. (John Clarke (Parks Victoria 2021, iii))

Building on the discussions and experiences at both the forum and its legacy of impactful change, the implications for those who have been directly involved should be considered. For the Traditional Owners of the Gariwerd Cultural Landscape, the above quotation firmly states the authority and agency the Djab Wurrung, Jardwadjali (Wotjobaluk Nations) and Gunditjmara peoples require to look after, conserve and manage both tangible rock art and the intangible significance of this place. Contained within the Gariwerd Cultural Landscape is evidence of thousands of years of continued occupation, and thousands of generations of economic activity, material culture and



Figure 6. Visiting cultural places as part of GRAMF.

settlement patterns (Parks Victoria 2021). The place engenders reflections on the way Aboriginal people engage with their world and experience their surroundings. In addition to 90% of Victoria's rock art heritage being contained within this unique landscape, there are also significant flora and fauna represented here, making it one of the state's primary national parks. The rights and responsibilities of caring for this cultural landscape underpin the co-management arrangements between the three Traditional Owner organisations and Parks Victoria:

> We, the Traditional Owners of Gariwerd land and waters, have deep respect for Country and hold a cultural responsibility to care for it. We are rights-holders for Gariwerd, and our culture and heritage are central to its future management. Our spiritual and cultural connection to plant and animal species, the rock formations, night skies and the wider setting of the mountain ranges are expressed in the largest concentration of rock art in Victoria. Gariwerd is also a place of mounds, scarred trees, stone quarries, and artefacts that sit alongside our stories, places of creation, lore and knowledge. Our relationship with our creator, our ancestors and our Country is self-evident in all that Gariwerd is. (Gariwerd Traditional Owners' statement (BGLC et al. 2024; Parks Victoria 2021, iii))

Understanding these deep connections have not only influenced the co-management practices within Gariwerd, but likewise the conservation and management of rock art in Victoria. Between 2018 and 2020 Parks Victoria completed a condition assessment of all rock art places in Gariwerd, and detailed information was recorded including identifying any human or natural activities, their extents, and whether they impact the art.[3] This information was utilised to underpin the state-wide Rock Art Action Plan 2022–2024 (Parks Victoria 2022) which aims to work closely with Traditional Owners to improve knowledge and the condition of rock art within Victoria's network of parks and reserves, while developing tools, plans, and systems to manage rock art in the future. By combining the collective wisdom and knowledge shared during the GRAMF alongside the amplified voices of Elders and rangers articulated through the *Practitioner's Guide*, the management of rock art in the Gariwerd Cultural Landscape can be further improved.

Existing responsibility is carried by Parks Victoria through an established co-management arrangement with the three Traditional Owner representative bodies (BGLC, EMAC and GMTOAC). Recontextualising this as a model that can contribute to a national conservation and management framework that gives primacy to culture whilst facilitating the integration of Western conservation science, collective effort has tremendous potential to advance further the rock art conservation and cultural heritage management disciplines.

> We work on Country and you know we trying to right the wrongs of the past but also stop that mission management you know so we can control and how to stay on land and you know continue to practice Culture and pass it on the young ones because you know what we do today impacts tomorrow. (Jake Goodes at GRAMF)

Conclusion

> So it's not just about having the opportunity to be able to go and just care for our cultural assets. Today we have to be economically independent. We have to find ways that we can and not be so reliant on government but we can find our way to care for 'em and protect our cultural assets. (Susanne Thompson (Yambangku Aboriginal Cultural Heritage and Tourism Development Aboriginal Corporation) at GRAMF)

For all involved as authors on this paper and collaborators in this initiative, the conversation continues. Activities and efforts are underway to continue to bring Indigenous Australians together at future events, in recognition that many share the collective journey. Seeking to reshape and reorient knowledge and practices of the conservation mechanisms used to manage rock art, connections with intangible cultural landscapes are coming to the fore. Striving to improve and strengthen practice through the amplification of Indigenous Australian voices and worldviews is critical to impactfully protect, preserve, celebrate and when appropriate, share the valuable heritage of Aboriginal Australia. Through this initiative, we are making a call to action as we seek to effect change for future generations.

> Great leaders are not the ones who say 'follow me' but those who say 'come along with me'. (Shane Clarke (Bunurong Aboriginal Corporation) at GRAMF)

Notes

1. BGLC, EMAC, GMTOAC, PV, UNDA. 2023. *Gariwerd Rock Art Management Forum Program*. Unpublished program.
2. See note 1.
3. See note 1.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by Department of Climate Change, Energy, the Environment and Water (DCCEEW), Australian Government; and Parks Victoria.

ORCID

Melissa Marshall http://orcid.org/0000-0002-3431-9007

References

Agnew, N., J. Deacon, N. Hall, T. Little, S. Sullivan, and P. S. C. Taçon. 2015. *Rock Art: A Cultural Treasure at Risk*. Los Angeles: Getty Conservation Institute.

BGLC, EMAC, GMTOAC, PV, UNDA. 2024. *Practical Guide for Indigenous Rangers in the Management of Rock Art Cultural Landscapes in Australia*. Melbourne: Parks Victoria.

Blundell, V., and D. Woolagoodja. 2005. *Keeping the Wanjinas Fresh: Sam Woolagoodja and the Enduring Power of Lalai*. Fremantle: Fremantle Arts Centre Press.

Clarke, J. 1976. "Two Aboriginal Rock Pigments from Western Australia, Their Properties, use and Durability." *Studies in Conservation* 21: 134–142. https://doi.org/10.1179/sic.1976.023.

CORLAB. 1986. *Conservation of Post-Estuarine Period Rock Art in Kakadu National Park: Report on Phase 1 Study: Pigment Identification*. Wilson: Australian Nature Conservation Agency.

CORLAB. 1987. *Conservation of Post-Estuarine Period Rock Art in Kakadu National Park: Final Report on Phase 2 Study: Conservation Treatment Trials*. Wilson: Australian Nature Conservation Agency.

CORLAB. 1988. *Conservation of Post-Estuarine Period Rock Art in Kakadu National Park: Final Report on Phase 3 Study: Conservation Treatment Trials*. Wilson: Australian Nature Conservation Agency.

CORLAB. 1989. *Conservation of Post-Estuarine Rock art in Kakadu National Park: Nourlangie Gallery Rock art Restoration Project*. Canberra: The International Centre for the Preservation and Restoration of Cultural Property and CORLAB Pty Ltd.

Doring, J., ed. 2000. *Gwion Gwion Dulwan Mamaa: Secret and Sacred Pathways of the Ngarinyin Aboriginal People of Australia*. Köln: Könemann.

Gillespie, D. 1979. "The Rock Art and Archaeological Sites of Ubirr, Kakadu National Park, Northern Territory: The Beginning of a Management Strategy." Unpublished report to Australian National Parks and Wildlife Service, Canberra.

Gillespie, D., ed. 1983. *The Rock Art Sites of Kakadu National Park: Some Preliminary Research Findings for Their Conservation and Management. Special Publication 10*. Canberra: Australian National Parks and Wildlife Service.

Griffin, D., M. Douglas, S. Harradine, J. Coombs, C. Carr, J. Clarke, B. Briggs, et al. 2024a. "Gariwerd Rock Art Management Forum." *Nulungu Insights*. https://www.notredame.edu.au/research/institutes-and-initiatives/nulungu/publications/editions.

Griffin, D., M. Douglas, S. Harradine, J. Coombs, C. Carr, J. Clarke, B. Briggs, et al. 2024b. "The Gariwerd Rock Art Management Forum: A Call to Action to Reorient/Reframe Rock art Conservation and Management." In *Exploring Conservation and Management in Australian Aboriginal Rock Art: Social, Political and Cultural Dimensions*, edited by M. Marshall, H. Jones-Amin, J. A. González Zarandona, and L. Ormond-Parker. Abingdon: Routledge.

Hughes, P. J. 1978. "Weathering in Sandstone Shelters in the Sydney Basin and the Survival of Rock art." In *Conservation of Rock Art: Proceedings of the International Workshop on the Conservation of Rock Art*, Perth, September 1977, edited by C. Pearson, 36–41. Perth: ICCM.

Hughes, P. J. 1979. "The Deterioration, Conservation and Management of Rock Art Sites in the Kakadu National Park, NT. Unpublished report, Australian National University, Canberra.

Lambert, D. 1989. *Conserving Australian Rock Art: A Manual for Site Managers*. Canberra: Aboriginal Studies Press.

Lambert, D. 2007. *Introduction to Rock Art Conservation*. Sydney: Department of Environment and Climate Change, New South Wales.

Marshall, M., L. A. Wallis, and K. Golson. 2019. "Marnda Gardairri: Facilitation of an Indigenous Ranger Rock Art Workshop."

Nulungu Insights 3. Broome, Western Australia: Nulungu Research Institute. https://researchonline.nd.edu.au/cgi/viewcontent.cgi?article=1002&context=nulungu_insights.

Marshall, M. 2020. "Rock Art Conservation and Management: 21st Century Perspectives in Northern Australia." Doctoral thesis, Australian National University, Canberra. https://doi.org/10.25911/5f969812a2f22.

Mowaljarlai, D., and J. Malnic. 2001. *Yorro Yorro: Everything Standing up Alive. Rock Art and Stories from the Australian Kimberley*. Broome: Magabala Books.

Mowaljarlai, D., and A. Watchman. 1989. "An Aboriginal View of Rock art Management." *Rock Art Research* 6 (2): 151–153.

Parks Victoria. 2021. *Greater Gariwerd Landscape Management Plan*. Melbourne: Parks Victoria.

Parks Victoria. 2022. *Rock Art Action Plan*. Melbourne: Parks Victoria.

Pearson, C., ed. 1978. *Conservation of Rock Art: Proceedings of the International Workshop on the Conservation of Rock Art, Perth, September 1977*. Perth: ICCM.

Pearson, C., and G. L. Pretty, eds. 1976. *Proceedings of the National Seminar on the Conservation of Cultural Material, Perth 1973*. Perth: ICCM.

Rosenfeld, A. 1985. *Rock Art Conservation in Australia*. Canberra: Australian Government Publishing Service.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S127–S134
https://doi.org/10.1080/00393630.2024.2336787

Check for updates

Nothing Lasts Forever? Considering Lifespans in a Contemporary Collection

¿Nada dura para Siempre? Considerando la Esperanza de Vida en una Colección Contemporánea

Isobel Griffin, Lorraine Maule and Jacqueline Ridge

National Galleries of Scotland, National Gallery of Modern Art One, Edinburgh, UK

ABSTRACT

For many European museums, caring for their collections 'in perpetuity' was implied or stated explicitly in their founding acts. However, as heritage science has developed as a discipline, the reality of eternal lifespans began to be questioned, and work on lighting guidelines led to a target lifespan of 500 years being adopted by many museums. This is often not feasible for the ephemeral materials more frequently found in contemporary artworks, which can break down quickly. Furthermore, for contemporary artworks with relevance to particular social or political circumstances, keeping them into the distant future may not feel essential. These factors, coupled with concerns about the financial and environmental impact of storing and caring for an ever-expanding volume of heritage material, have sparked new conversations about collection lifespans. This paper discusses lifespans for contemporary art, referring to the collection belonging to the National Galleries of Scotland (NGS), and outlining several potential approaches. A nuanced and honest approach is arguably required, which should include exploring the artist's intent, identifying the critical elements of each artwork, and deciding how to manage change, while factoring in stakeholder perspectives and resourcing considerations. Such an approach would involve accepting the reality and inevitability of shorter lifespans for some artworks and could be considered the epitome of environmental sustainability.

Para muchos museos europeos, el cuidado de sus colecciones 'a perpetuidad' había estado implícito o declarado explícitamente en sus actas de fundación. Sin embargo, a medida que la ciencia del patrimonio se desarrolló como disciplina, la realidad de la esperanza de vida eterna comenzó a ser cuestionada, y el trabajo sobre pautas de iluminación llevó a que muchos museos adoptaran un objetivo de una vida útil de 500 años. A menudo, esto no es factible para los materiales efímeros que se encuentran con mayor frecuencia en las obras de arte contemporáneas, las cuales pueden descomponerse rápidamente. Además de esto, para las obras de arte contemporáneas que son relevantes para circunstancias sociales o políticas específicas, mantenerlas en un futuro lejano puede no parecer esencial. Estos factores, junto con las preocupaciones sobre el impacto financiero y ambiental del almacenamiento y cuidado de un volumen cada vez mayor de material patrimonial, han provocado nuevas conversaciones sobre la vida útil de las colecciones. Este artículo analiza la duración del arte contemporáneo, haciendo referencia a la colección perteneciente a las Galerías Nacionales de Escocia (NGS) y considerando varios enfoques. Podría decirse que se requiere un enfoque honesto y matizado, que debería incluir explorar la intención del artista, identificar los elementos críticos de cada obra de arte y decidir cómo gestionar el cambio, teniendo en cuenta al mismo tiempo las perspectivas de las partes interesadas y los recursos. Este enfoque implicaría aceptar la realidad y la inevitabilidad de una vida útil más corta para algunas obras de arte y podría considerarse el epítome de la sostenibilidad ambiental.

ARTICLE HISTORY
Received October 2023
Accepted March 2024

KEYWORDS
Lifespan; artist's intent; authenticity; contemporary art; inherent vice

Esperanza de vida; intención del artista; autenticidad; arte contemporáneo; vicio inherente

Introduction

Most heritage organisations in Europe have a statutory purpose to preserve their historic assets. Sometimes, as for The National Trust, UK, and The National Trust for Scotland (National Trust 1907; National Trust for Scotland 1935), the requirement for 'permanent preservation' is noted in their founding acts, and a 1986 publication about Queensland Museum emphasises its board's aim of '[maintaining] the existing collections … to ensure their preservation in perpetuity' (Bartholomai 1986). Evidence that this expectation has continued to some extent into the twenty-first century is found in the standard reference book *Preventive Conservation in Museums* (Caple 2011), which states that 'when [artefacts] enter a museum collection, they cease to fulfil their original function and become part of collections which are to be preserved in perpetuity'. When discussing the

CONTACT Lorraine Maule lmaule@nationalgalleries.org National Galleries of Scotland, National Gallery of Modern Art One, Edinburgh EH4 3DR, UK

© The International Institute for Conservation of Historic and Artistic Works 2024

beneficiaries of this permanent preservation, many organisations and museum codes of ethics use the concept of 'future generations', although as has been shown by Lelyveld and Taylor (2021), there are several potential interpretations of this term.

Beginning of discussions about lifespan

An important milestone was reached in the late twentieth century when the reality of preserving everything forever began to be questioned, and this was due at least in part to the development of heritage science as a discipline. In particular, the work on lighting guidelines undertaken at the Victoria and Albert (V&A) Museum, London, UK, and the National Museum of Australia (Ashley-Smith, Derbyshire, and Pretzel 2002; Ford and Smith 2011) forced discussions about the lifespan of museum collections. It was recognised that exposure to light, which is obviously necessary for museum objects to be accessed, will result in colour changes for many museum objects. Ashley-Smith *et al.* therefore proposed that the V&A should accept a rate of colour change of one perceptible change in 50 years, which was considered to '[satisfy] current government demands for access to be "not only for the present but also for future generations"'. The V&A research indicated that after undergoing 10 perceptible changes, a typical object would become unsuitable for display, and it was therefore concluded that 'the expected life of an object [is] 500 years'. This target lifespan of 500 years has subsequently been adopted by many other museums.

The work on lighting guidelines was a good starting point in conversations about lifespans, but it did not address the fact that some objects last for longer, and other types of deterioration also need to be considered. Object colour change is relatively easy to measure, but light can result in other chemical and structural changes, and for many organic materials, the weakening of fibres caused by light exposure may be a greater concern. Furthermore, degradation may be caused by agents other than light; an example is the deterioration of film, which occurs due to the inherent instability of the materials, and is accelerated by the presence of moisture and heat (Image Permanence Institute 2023). For artworks, deterioration may arise due to the choice of materials or the method of application, often referred to as an inherent vice or defect. And all objects are vulnerable to physical damage caused during handling and transportation.

Shorter lifespans

A target lifespan of 500 years is achievable for some types of museum object, but it may not be feasible for inherently unstable materials, which can break down very quickly. Unstable materials are particularly likely to be found in the world of modern and contemporary art, where experimentation and innovation have occurred at unprecedented levels, and these materials include certain plastics, such as cellulose acetate, plasticised polyvinyl chloride and polyurethane foam (Shashoua 2008); some photographic formats, such as chromogenic colour prints (Fenech et al. 2013); and organic materials such as food and plants. Artworks displayed outdoors may also prove difficult to preserve, since the extreme environmental conditions can cause deterioration to proceed rapidly.

Leaving material specifics aside, there are certain formats of contemporary art which are prone to short lifespans, namely media art, performance art and installation art. The definitions developed by NGS for these artforms are that media artworks '[depend] on technology and [have] duration as a dimension' for example using 'video, film, audio, 35 mm slide and computer-based technologies'; performance artworks '[consist] of time, space, the performer's body, and a relationship between audience and performer', often incorporating 'some other kind of visual art, video, sound, or props', and the term installation artworks is used to describe 'mixed-media constructions or assemblages, often designed for a specific space'. The first and second of these categories are known in some institutions as 'time-based media artworks'. The challenges associated with preserving these artforms are numerous and complex, forcing the organisations that collect them to address target lifespans head-on, and acting as a springboard for other conversations about lifespan.

Expectations around ageing

When discussing target lifespans for the NGS collection, we are locked into western expectations around collecting and ageing and collecting. The V&A's assumption that 10 perceptible changes renders an object unsuitable for display provides an interesting starting point: there are types of objects where this can be argued robustly, for example artworks such as Mark Rothko's colour field abstractions where subtle colour contrasts are fundamental. However, there are many object types where a colour change of considerably more than 10 perceptible fades would be considered acceptable or even desirable – for example historic documents, where audiences generally agree that damage, such as fading, 'is to be expected and accepted' (Dillon et al. 2013). Another example is colour change resulting from the development of a patina on the surface of a painting or sculpture, as vigorously defended by Brandi in his extortions against over-cleaning (Brandi 1949).

Perhaps our expectations regarding an aged appearance depend on the nature and aesthetic of

the cultural heritage in question. When considering historic buildings, the acceptance of an aged appearance was advocated for strongly by John Ruskin and William Morris and gained popular acceptance with the founding in London, UK, of the Society for the Protection of Ancient Buildings (SPAB) (Woodcock 2020). This perspective is likely more contentious for modernist architecture employing crisp, white lines and 'smooth jointless surfaces', which some building conservationists are reluctant to see with a patina (MacDonald 1997). And we may have the same expectations of art with a modernist aesthetic: an example in the NGS collection is *Untitled (Pair)* by Rachel Whiteread (Figure 1). The large blocks comprising this sculpture have smooth, white painted surfaces, which have developed an etched and stained surface due to the decision taken by NGS to display them outdoors, compromising what is understood as the desired aesthetic. Repainting to return the sculpture to its original appearance is therefore being considered, with input from the artist's studio.

However, other contemporary artworks may contain found or pre-aged materials, and may be deliberately dirty or distressed, or intended to decay visibly as they age. Examples include *The Death of St John* by Damien Hirst, a sculpture consisting of a stainless-steel vitrine which was smeared with butter to encourage tarnishing and strewn with earth inside (Hale 2004) and installations by Gu Dexin incorporating rotting meats and fruits (Moy 2016). Hence for the organisation owning the artwork, understanding the critical elements of the work and how to allow change over time is key.

Artist's intent

For a public collection, comprehensive documentation is required to record the circumstances of the creation of contemporary artworks and identify their most critical aspects: physical, conceptual, political or otherwise connected to a particular point in time. Wherever possible the artist's intent and sanction should be considered, and for contemporary art, there can be an opportunity to conduct interviews directly with the artist or their studio. Information collected often informs debate about the care and display of the artwork, including the management of the ageing process, and within a collecting organisation this is likely to be a multidisciplinary dialogue, involving curators, conservators, heritage scientists and other specialists (Doherty et al. 2016).



Figure 1. Rachel Whiteread, *Untitled (Pair)*, 1999, bronze with white cellulose paint. NGS is discussing the possibility of repainting these sculptures with the artist's studio. Image: NGS. © The Artist.

In a collection, weighing up the significance of the artist's intent against the views of other stakeholders, including the organisation's own vision for the artwork, can raise interesting questions. The pros and cons of involving the artist in conservation decision-making have been discussed by van Wegen (2005), who concludes that the time which has passed since the artwork was made should be factored in, while Henderson and Nakamoto (2016) also question the artist's right to have an ongoing influence over the artwork's future.

An example from NGS is the decision-making around *Work No. 370 (Balls)* by Martin Creed. The artwork consists of almost 1,000 balls, in a range of sizes, types and colours. Following its acquisition, the artist was interviewed, providing useful information which suggested to NGS that the key concept was the range of colours and sizes of balls, rather than the physical integrity of the individual balls. Some of the balls are made from unstable materials, such as rubber and foam, and the gallery which sold the artwork to NGS in 2005 advised that 'if any of the balls are broken or damaged … they should be replaced'. However, when a display of the artwork was proposed in 2022, NGS asked Creed about the 33 balls which had visibly deteriorated, and he advised that replacements had to be exact, making them impossible to source. Creed then suggested that the artwork should either be exhibited with fewer balls than originally intended, or with the inclusion of the deteriorated balls, which NGS felt might compromise the display aesthetic. This demonstrates how ongoing consultation of the artist can affect the artwork's future in potentially unanticipated ways.

First approach: preserve by implementing stringent controls

So, what are the options for NGS and other cultural heritage organisations when dealing with artworks which if approached in the same way as the rest of the collection, would be unlikely to have a lifespan even vaguely approaching 500 years?

The first approach could be to attempt the long-term preservation of the artwork by implementing controls around display and storage. This could be severely restricting access to slow down the rate of light-induced change, as NGS and Tate, London, UK, have done with the hand coloured monoprints by Andy Warhol in their jointly owned Artist Rooms collection. The monoprints are extremely sensitive to light, and so it has been proposed that they should only be displayed for very limited periods, with careful management of viewing for research purposes.

For some types of artwork, the crucial environmental factors influencing the artwork's longevity are the temperature and relative humidity, and prolonging the artworks' lifespans could entail providing targeted environmental conditions while they are in storage and potentially also on display. An example at NGS is *Wir Sind Frei* by Joseph Beuys, which is also part of the Artist Rooms collection. This artwork incorporates five degrading spools of cellulose acetate film, which are kept in cold storage to slow down the deterioration process.

Downsides of this approach are that the provision of access to the artwork is likely to be compromised, and that considerable energy consumption is often required to provide the target environment.

Second approach: preserve through repeated conservation interventions

A second approach could be to prolong the lifespan of the artwork through conservation interventions. A common example in the art world is the repeated restoration of some paintings, resulting in artworks whose appearance might be judged as close to the original aesthetic, but whose material authenticity has changed considerably. Amongst such paintings at NGS is *The Virgin Adoring the Christ Child ('The Ruskin Madonna')* (about 1470), attributed to Andrea del Verrocchio and Workshop (Figure 2), which has been altered by several interventive treatments including transfer from panel, and repeated consolidation, retouching, cleaning and varnishing.

Frequent cycles of conservation interventions often required for contemporary art include the repainting of outdoor sculpture and the repairing of disintegrating organic materials, as described by Soraluze, Chen, and Lu (2016) for artworks made from banana skins. When prolonging life through such interventions, care must be taken to avoid the authenticity of the original becoming compromised over time.

Third approach: employ 'substitutes' in place of the original

A third approach to achieving a long target lifespan is to exhibit a substitute in place of the original object. Substitutes vary in terms of their correspondence to the original: they may be an exact replica or replacement which is physically indistinguishable from the original, such as an exhibition copy of a photograph printed from the same negative as the original; they may be a copy which is physically similar but not identical, such as a convincing plaster cast of a stone sculpture; or they may be 'created from ideas or processes and not just by making an exact copy' (Desvallées 2023). The latter category is very broad and could include photographic recordings of a performance piece and reconstructions of temporary installations.



Figure 2. Andrea del Verrocchio and Workshop, *The Virgin Adoring the Christ Child ('The Ruskin Madonna'),* about 1470, oil on canvas. The materiality of this painting has been altered by several interventive treatments. Image: A Reeve.

The use of substitutes is complex and raises many practical and ethical questions, particularly around authenticity. Facsimiles may be considered inauthentic on the grounds that they lack some of the intangible qualities belonging to the original, but this is overly simplistic, because authenticity is a subjective quality which is influenced by a particular society or audience's values. The status and context of the substitute are also important, but they may be difficult to define and liable to change over time, potentially causing confusion (Norton 2016).

Further complexities are introduced by certain formats of contemporary artworks, such as time-based media and performance artworks, for which authenticity may hinge upon ensuring that a work is manifested in 'compliance' with the artist's wishes (van de Vall 2015). However, as noted by Castriota

et al. (2023) 'in cases when an artist's directives or instructions are vague, self-contradictory or revised', determining the artist's intention and assessing whether a particular manifestation complies with it may be extremely subjective.

However, despite these significant issues, substitutes may confer various benefits. Displaying a copy may allow the original to be preserved in good condition; NGS shows a facsimile of the annotated *Yellow Pages* phone directory as part of *The Lamp of Sacrifice* by Nathan Coley (Figure 3), due to the extreme light sensitivity of the original. And where the original has been lost – for example in the case of street art on a building that has been demolished – a substitute may be the only option to allow the artwork to be displayed, giving access to audiences who 'will never have the chance to interact with the mural in person' (Soulioti and Chatzidaki 2022). NGS has seven editions of *Calcium Light Night,* a set of nine screen prints by Eduaro Paolozzi, and has loaned one to the Royal Infirmary in Edinburgh, for enjoyment by an audience who might not otherwise have access to art.

Fourth approach: remake the artwork entirely or in part

Closely related to the second and third approaches is the option of remaking an artwork over the course of its life, either entirely or in part. This must take legal and ethical considerations into account. The organisation that owns the artwork must be confident that the artist would sanction remaking, either because adequate archival evidence exists, or because the artist or their representative is being consulted and potentially actively involved, or because the organisation has purchased a license for the artwork. As with the use of facsimiles and multiple copies, questions of authenticity must be addressed.

An example in the NGS collection is The *Lamp of Sacrifice* by Nathan Coley, which consists of 286 cardboard models of churches. While away from NGS premises the original set suffered severe water damage, rendering it un-displayable. Following extensive discussions the artist remade the artwork, replicating every over-cut and pencil mark, and defined this as a renewal of the original artwork, rather than a replica. Another example where some form of remaking is being considered is *Positive Pattern,* a set of carved, foam sculptures by Christine Borland (Figure 4). NGS was aware prior to acquisition that the foam would darken, but this has now proved disturbing because some sculptures are made from two pieces of foam, which have discoloured to differing extents. Both Borland and NGS view this change to the sculptures' appearance as unacceptable.

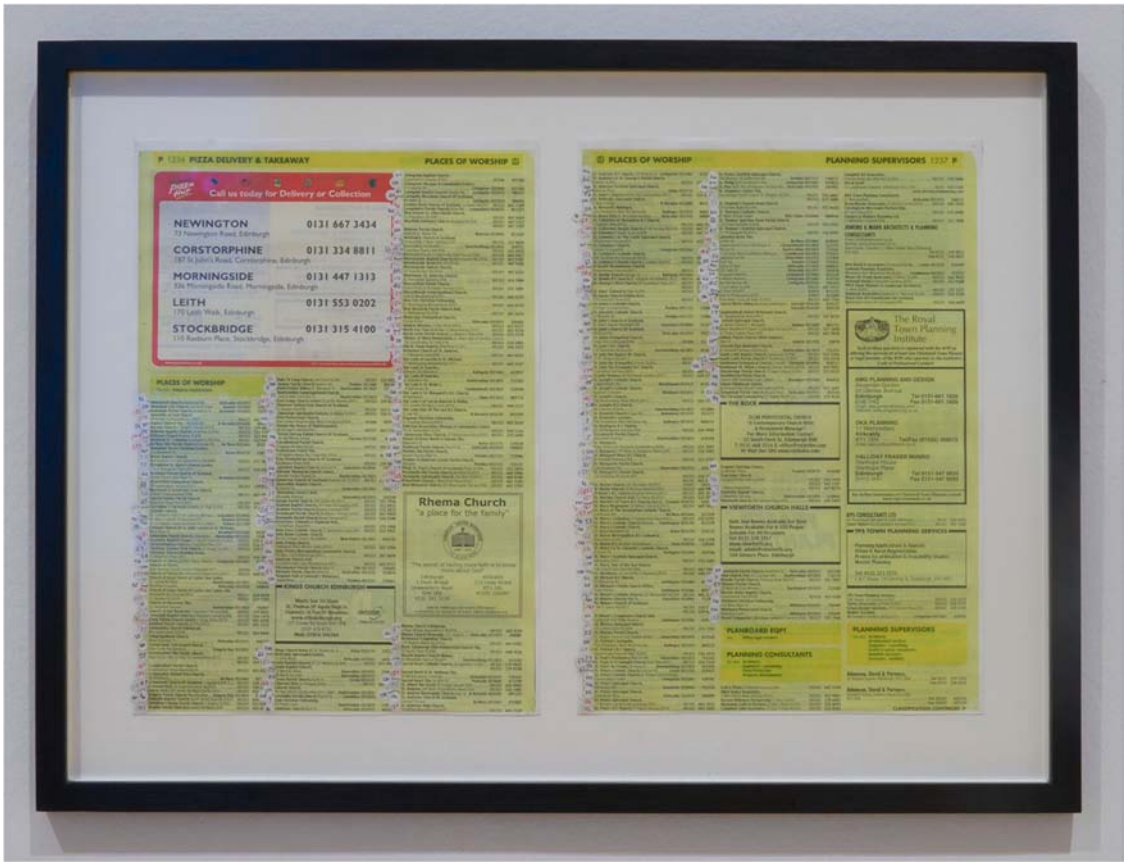


Figure 3. Facsimile of the annotated *Yellow Pages* phone directory which forms part of Nathan Coley, *The Lamp of Sacrifice,* 2004, cardboard, paper and ink. Image: NGS. © Studio Nathan Coley.



Figure 4. Christine Borland, *Positive Pattern*, 2016, foam, Perspex, MDF and paint. NGS is discussing some form of remaking with the artist, because of the uneven discolouration. Image: NGS. © Christine Borland.

Fifth approach: accept changes

However, rather than trying to keep an artwork looking the same, we could accept that its appearance will change and not attempt to intervene. In some cases, change is part of the artist's intent: according to Llamas-Pacheco (2018) the inevitable decay of the butterfly wings in Yolanda Gutiérrez Acosta's *Ephemera* installation 'does not affect its significance, but rather, serves to accentuate the visual aspects that the artist sought'. The organisation owning the artwork may also view the change as a positive thing, as for the two reclining bronze figures by Henry Moore in the NGS collection. They have a distinctive variegated patina due to their prolonged display outdoors, which NGS has embraced because Moore viewed it as 'of great importance' (Morgan and van der Molen 2023).

Allowing the appearance of the artwork to change without intervening may result in the artwork becoming un-displayable within a relatively short period, or in the words of Llamas-Pacheco (2020), reaching its 'death'. NGS is currently considering the status of *Sycamores, Chestnuts and Oaks above the Water of Leith, by* Paul Nash, which is an outdoor work made from living trees (Figure 5). A group of trees was planted and pruned to create an archway effect, but over time the trees have resumed their natural form of growth and become obscured by new saplings. Hence although the actual trees still exist, the concept has been lost and cannot be brought back. In these circumstances, we could consider de-accessioning the artwork, which would include documenting its current condition and recording the reasons for de-accessioning. This would avoid expending organisational resources on an artwork which is arguably no longer viable.



Figure 5. The area where the living trees which made up Paul Nash, *Sycamores, Chestnuts and Oaks above the Water of Leith,* 1988, were originally planted. NGS is considering the status of this artwork because the original concept of an archway of trees has been lost. Image: NGS.

Sixth approach: define a shorter lifespan

A logical philosophical progression from allowing an artwork to change and potentially 'die' is to define a realistic lifespan at the point of acquisition.

The Artist Rooms collection which NGS owns jointly with Tate is a prime example: it was created in 2008 with the express purpose of touring to museums and galleries throughout the UK, and a 250-year lifespan was therefore agreed, even though NGS currently assumes a 500-year lifespan for the rest of its collections, while Tate aims to preserve its collections in perpetuity. Another example in the NGS collection is *6 Times*, an installation by Antony Gormley consisting of six life-size figures, some of which are sited in a river. A target lifespan of 30 years was initially specified due to concerns over how long the sculptures would retain their structural integrity.

Conclusions

When it comes to determining our approach with regards to collection lifespans, hoping for a 'one size fits all' solution is not feasible for contemporary art, and can prompt discussions about other parts of a collection. It is helpful to reflect on our core purpose – NGS is publicly funded and mandated through its governing legislation, to 'care for, preserve and add to the objects in our collections' while also '[ensuring] that objects are exhibited to the public', (National Galleries of Scotland 2023) and we must seek to balance these potentially conflicting aims. We want to promote access now, particularly for artworks with strong contemporary relevance, but we do not want to deprive future generations through what could be perceived later as a lack of care or foresight. Attempting the preservation of everything in perpetuity may therefore appear the logical and responsible approach. However, this requires considerable resources: storage space for a vast and potentially ever-expanding collection, conservator time to monitor objects and implement repeated cycles of conservation interventions and energy usage to provide the environmental conditions most favourable to preservation. And even if these resources are expended, some materials are simply too ephemeral to survive for hundreds of years.

Arguably, a more nuanced and honest approach is to take the time when acquiring a contemporary artwork and in subsequent collection reviews to ask challenging questions and make difficult decisions. This includes identifying the aspects of the artwork that are fundamental to its existence; specifying how long these elements can realistically be expected to exist for; and exploring whether the artwork can be kept alive by replacing its physical components as they fail, making or acquiring alternative versions, or using documentation to capture the memory of the physical entity. We must also set out our understanding of the artist's intent and how it fits with the perspectives of other stakeholders, including the generations who will access the NGS collection in the future.

An even bolder question for some art is whether its impact could be maximised by a conscious decision to accept a short lifespan. 'Not all contemporary art will survive, nor is it intended to' (Hess Norris 1999), so can we enjoy or even celebrate an artwork that is experienced only briefly, and what would the implications be for future generations? Deciding to accept very short lifespans for some artworks could be considered the epitome of environmental sustainability, because by allowing these artworks to 'have their day' and by not intervening in the ageing process, we are not filling up stores or expending resources imprudently. With this approach, future generations would not experience certain artworks, but would have resources available to make their own acquisitions.

The logical conclusion of this line of reasoning is that trying to keep everything at any cost will disadvantage future generations, and that a responsible organisation can embrace impermanence for some parts of its collection.

Acknowledgements

We are grateful to colleagues in NGS who have contributed their ideas to this paper, in particular Brian Castriota, Kirsten Dunne, Lucy Askew and Julie-Ann Delauney.

References

Ashley-Smith, J., A. Derbyshire, and B. Pretzel. 2002. "The Continuing Development of a Practical Lighting Policy for Works of Art on Paper and Other Object Types at the Victoria and Albert Museum." In *ICOM-CC 13th Triennial Meeting Rio de Janiero*, edited by J. Bridgland, 3–8. Paris: ICOM. https://www.icom-cc-publications-online.org/2181/The-continuing-development-of-a-practical-lighting-policy-for-works-of-art-on-paper-and-other-object-types-at-the-Victoria-and-Albert-Museum.

Bartholomai, A. 1986. "15 In Perpetuity: The Museum's continuing role." *Memoirs of the Queensland Museum* 24: 301–307.

Brandi, C. 1949. "The Cleaning of Pictures in Relation to Patina, Varnish and Glazes." *The Burlington Magazine* 91 (556): 183–188.

Caple, C. 2011. "A History of, and an Introduction to, Preventive Conservation." In *Preventive Conservation in Museums*, edited by C. Caple, 9–23. London: Routledge.

Castriota, B., R. F. Peters, H. Marçal, and S. Auffret. 2023. "Authenticity." In *Dictionary of Museology*, edited by F. Mairesse, 37–40. London: Routledge.

Desvallées, A. 2023. "Substitute." In *Dictionary of Museology*, edited by F. Mairesse, 520. London: Routledge.

Dillon, C., W. Lindsay, J. Taylor, K. Fouseki, N. Bell, and M. Strlic. 2013. "Collections Demography: Stakeholder Views on the Lifetime of Collections." In *Climate for Collections: Standards and Uncertainties*, edited by J. Ashley-Smith, A. Burmester, and M. Eibl, 45–58. London: Archetype Publications.

Doherty, T., H. Ingalls, A. Kerr, C. Maynor, and L. Umberger. 2016. "Conserving the Self-Taught Artists Collection at

the Smithsonian American Art Museum." *Studies in Conservation* 61 (sup2): 38–43. https://doi.org/10.1080/00393630.2016.1188616.

Fenech, A., C. Dillon, K. Ntanos, N. Bell, M. Barrett, and M. Strlic. 2013. "Modelling the Lifetime of Colour Photographs in Archival Collections." *Studies in Conservation* 58 (2): 107–116. https://doi.org/10.1179/2047058412Y.0000000081.

Ford, B., and N. Smith. 2011. "The Development of a Significance-Based Lighting Framework at the National Museum of Australia." *AICCM Bulletin* 32 (1): 80–86. https://doi.org/10.1179/bac.2011.32.1.011.

Hale, T. 2004. "Handling White Cube." *Studies in Conservation* 49 (sup2): 25–29. https://doi.org/10.1179/sic.2004.49.s2.006.

Henderson, J., and T. Nakamoto. 2016. "Dialogue in Conservation Decision-Making." *Studies in Conservation* 61 (sup2): 67–78. https://doi.org/10.1080/00393630.2016.1183106.

Hess Norris, D. 1999. "The Survival of Contemporary Art: The Role of the Conservation Professional in the Delicate Ecosystem." In *Mortality Immortality? The Legacy of 20th-Century Art*, edited by M. A. Corzo, 131–134. Los Angeles: Getty Conservation Institute.

Image Permanence Institute. 2023. "Storage Suitability." Accessed October 9, 2023. FilmCare.org.

Lelyveld, M., and J. Taylor. 2021. "What Do We Talk About When We Talk About 'Future Generations'?" In *Transcending Boundaries: Integrated Approaches to Conservation*, ICOM-CC 19th Triennial Conference Preprints, Beijing, 17–21 May 2021, edited by J. Bridgland. Paris: ICOM-CC. https://www.icom-cc-publications-online.org/4356/What-do-we-talk-about-when-we-talk-about-future-generations.

Llamas-Pacheco, R. 2018. "The Ephemeral, the Essential and the Material in the Conservation of Contemporary Art: Decision-Making for the Conservation of a Work of Art Made with Butterfly Wings." *Studies in Conservation* 63 (8): 441–449. https://doi.org/10.1080/00393630.2018.1501960.

Llamas-Pacheco, R. 2020. "Some Theory for the Conservation of Contemporary Art." *Studies in Conservation* 65 (8): 487–498. https://doi.org/10.1080/00393630.2020.1733790.

MacDonald, S. 1997. "Authenticity is More than Skin Deep: Conserving Britain's Postwar Concrete Architecture." *APT Bulletin: The Journal of Preservation Technology* 28 (4): 37–44.

Morgan, L. and R. van der Molen. 2023. *Henry Moore's Approach to Bronze*. Available: Lyndsey Morgan and Rozemarijn van der Molen, 'Henry Moore's Approach to Bronze' (Henry Moore: Sculptural Process and Public Identity) | Tate. Accessed October 9, 2023.

Moy, S. A. 2016. "2004-*6-16* to 2014-8-15: The Birth and Death of a Work by Gu Dexin". *Studies in Conservation* 61 (sup2): 137–141. https://doi.org/10.1080/00393630.2016.1196432.

National Galleries of Scotland. 2023. *Who We Are*. Available at: Who we are | National Galleries of Scotland Accessed October 9, 2023.

National Trust. 1907. "The National Trust Acts 1907–1971." Available at: The National Trust Acts 1907 - 1971 (nt.global.ssl.fastly.net). Accessed October 9, 2023.

National Trust for Scotland. 1935. "National Trust for Scotland, Order Confirmation Act, 1935." Available at: Appendix-1_NTS-Order-Confirmation-Act-1935.pdf (windows.net). Accessed October 9, 2023.

Norton, A. 2016. "Migrating Facsimiles: When Copies Disappear from Conservation Control." *Studies in Conservation* 61 (sup2): 160–166. https://doi.org/10.1080/00393630.2016.1181926.

Shashoua, Y. 2008. *Conservation of Plastics*. London: Routledge.

Soraluze, I. I., Y. Chen, and C. Lu. 2016. "Conservation of Ephemeral Art: Restoring Banana Skins in Works by Lo Yi-chun." *Studies in Conservation* 61 (sup2): 332–333. https://doi.org/10.1080/00393630.2016.1184050.

Soulioti, A. M. and M. Chatzidaki. 2022. "Double Trouble: Replicas in Contemporary Art and Their Impact in Conservation Decision-making." *Studies in Conservation* 67 (1-2): 21–29. https://doi.org/10.1080/00393630.2021.1974238.

van de Vall, R. 2015. "The Devil and the Details: The Ontology of Contemporary Art in Conservation Theory and Practice." *The British Journal of Aesthetics* 55 (3): 285–302. https://doi.org/10.1093/aesthj/ayv036.

van Wegen, D. H. 2005. "Between Fetish and Score: The Position of the Curator of Contemporary Art." In *Modern Art: Who Cares?*, edited by I. Hummelen, and D. Sille, 201–209. London: Archetype Publications.

Woodcock, D. G. 2020. "Preservation Philosophy and Approaches." *APT Bulletin: The Journal of Preservation Technology* 51 (1): 13–24.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S135–S145
https://doi.org/10.1080/00393630.2024.2336810

ORIGINAL RESEARCH OR TREATMENT PAPER

A Study of Protective Coatings for Archaeological Silver

Estudio de Revestimientos Protectores para Plata Arqueológica

Stephanie Guidera [1], Emily Kaplan [1], Caitlin Mahony [1], Thomas Lam [2] and Gwénaëlle M. Kavich [2]

[1]Smithsonian National Museum of the American Indian, Suitland, MD, USA; [2]Smithsonian Museum Conservation Institute, Suitland, MD, USA

ABSTRACT

This study investigates the sustainability and efficacy of coatings for archaeological silver. Building on a survey of current practices in silver conservation and a literature review, a group of Chimú (Peruvian north coast, 1100–1400 CE) silver alloy items in the National Museum of the American Indian collection serves as a case study. Assessing treatment options for 80 Chimú items led to the investigation into the implications of introducing a new coating campaign. Experimentation was carried out with coupons approximating the composition and manufacture of Chimú silver. Four conservation grade materials, Agateen® 27, Acrysol® WS24, Paraloid® B-72, and Regalrez® 1126, were tested for protection efficacy in a humid, sulfur-containing environment. Analysis with X-ray fluorescence spectroscopy (XRF), scanning electron microscopy energy-dispersive X-ray spectroscopy (SEM-EDX), and imaging at several phases throughout the experiment provided data on the interaction of the metal and the coating and the effects of coating and re-coating. Oddy testing and Fourier transform infrared spectroscopy (FTIR) conducted on these prepared coatings helped determine their suitability for long-term use. Results indicate that not coating is more appropriate for preservation than coating with any of the four materials tested.

Este estudio investiga la sostenibilidad y eficacia de los recubrimientos para plata arqueológica. A partir de un estudio de las prácticas actuales en la conservación de la plata y una revisión de la literatura, un grupo de objetos de aleación de plata Chimú (costa norte de Perú, 1100 -1400 d. C.) en la colección del Museo Nacional del Indígena Americano sirve como estudio de caso. La evaluación de las opciones de tratamiento para 80 objetos Chimú llevó a investigar las implicaciones de iniciar una nueva campaña de recubrimientos. Los experimentos se llevaron a cabo en cupones que se aproxima en composición y fabricación a la plata Chimú. Se probó la eficacia de protección de cuatro materiales de alto grado de conservación, Agateen® 27, Acrysol® WS24, Paraloid® B-72 y Regalrez® 1126 en un ambiente húmedo con azufre. El análisis con espectroscopia de fluorescencia de rayos X (XRF), espectroscopia de rayos X de dispersión de energía con microscopía electrónica de barrido (SEM-EDX) y la obtención de imágenes en varias fases a lo largo del experimento proporcionaron datos sobre la interacción del metal y el recubrimiento y los efectos de revestimiento y repintado. Las pruebas Oddy y la espectroscopía infrarroja por transformada de Fourier (FTIR) realizadas en estos recubrimientos ayudaron a determinar su idoneidad para un uso a largo plazo. Los resultados indican que no recubrir es más apropiado para la conservación que recubrirlo con cualquiera de los cuatro materiales probados.

ARTICLE HISTORY
Received October 2023
Accepted March 2024

KEYWORDS
Chimú; silver; conservation; archaeological silver; coatings; corrosion; silver sulfide

Chimú; plata; conservación; restauración; plata arqueológica; recubrimientos; corrosión; sulfuro de plata

Introduction

Alloy compositions, storage and display environments, manufacturing techniques, and object life history all contribute to the continuous corrosion of silver. Conservators often apply coatings to protect silver from exposure to pollutants and moisture, when passive mitigation techniques, such as dry microclimates with corrosion inhibitors, are considered impractical. Coatings can be successful with flawless application on homogenous alloys in flat forms and periodic assessment and reapplication (Pouliot et al. 2013). Microclimates can be successful in sealed environments with little need for access (Thickett and Hallett 2021). However, archaeological silver presents material and contextual challenges: variation in alloy composition, manufacture, and object shape complicate successful coating application. Chimú silver alloy items in the National Museum of the American Indian (NMAI) collection exhibit corrosion, aged and degraded coatings, and unstable repairs. The objective of this study is to inform recommendations for the care of these and similar archaeological silver objects.

The Chimú, heirs to thousands of years of Andean metalworking, excelled in sheet metal techniques,

CONTACT Stephanie Guidera steph.guidera@gmail.com Smithsonian National Museum of the American Indian, 4220 Silver Hill Road, Suitland, MD 20746, USA

© The International Institute for Conservation of Historic and Artistic Works 2024

making three-dimensional forms with thin, uniform sheets of silver alloy. Sheets were created by repeated hammering and annealing ingots of alloyed metal. Vessels were created by hammering over forms and cut sheets were joined by crimped seams. Surface techniques included embossing, *repoussé*, and engraving. Copper was an intentional part of the silver alloy, lowering the melting temperature and increasing the malleability and strength of the sheet metal (Lechtman 1996). The metal surfaces were depletion gilded, a process in which the silver or gold metal surface was enriched through oxidation of copper in the alloy. The final surface color and the metals incorporated into the alloys were a cultural and technical choice (Lechtman 1979).

A group of 80 Chimú sheet silver items at NMAI was selected for study based on the presence of aged repairs and coatings. Uncoated silver items appeared evenly gray from corrosion. Coated items displayed yellowed pools of aged coating at cut edges and areas of low relief, apparently encouraged by the complex surface topography and openwork from original manufacture (Figure 1). Localized corrosion was found in areas of uneven coating. Previous repairs were typically adhesive bandages, likely fairly transparent when applied but yellowed on ageing. These coatings and repairs, all undocumented, were assumed to be cellulose nitrate, based on appearance and the history of common restoration materials, supported by visible bright luminescence under ultraviolet (UVA) radiation. Unaged intact cellulose nitrate films do not luminesce. These coatings and repairs were applied at some point in the past, likely by collectors and dealers, and certainly before 1992 when the NMAI conservation department was established.

The implications of recoating were considered. The potential for accelerated corrosion correlated to copper content (Selwyn 2004), and the required resources and potential damage from removal and reapplication of coatings (Dandridge 2005) were concerning. Grissom et al. (2013) compared the performance of twelve coatings applied on flat sterling silver coupons exposed to hydrogen sulfide (H_2S) in a chamber. Five coatings were effective after H_2S exposure: Agateen® 27, Acrysol® WS24, HMG, PVA AYAT, and Mowiol® 2899. Agateen® 27 is the most commonly used silver coating due to its excellent leveling properties and visual results (Polidori et al. 2019). Agateen® 27 and other cellulose nitrate-based coatings have been the focus of previous studies (Grissom et al. 2013; Pouliot et al. 2013; Reedy et al. 1999). Notably, substrates considered in these studies were sterling silver or silver plate, without the variables of archaeological silver. Agateen® 27 can create an excellent vapor barrier against corrosive sulfides, but long-term stability depends on the batch of material (Polidori et al. 2019; Reedy et al. 1999; Ziegler et al. 2014). Imperfect coating application leads to localized preferential corrosion in missed spots (Sease et al. 1997). Over time, this leads to disfiguring streaks and blocks with hard edges difficult to reduce (Figure 2).

A questionnaire designed to collect data on current methods of silver treatment and care was sent to conservators in the US, Europe, and Latin America. Seventy-five responses provided a snapshot of trends and influenced the experimental design. 39% of respondents apply protective coatings to silver objects, 21% do not, and 40% answered 'sometimes.' 81% use Agateen® 27 or other similar locally-available nitrocellulose coatings (i.e. Frigilene®, Perlitol® RE 1260). Paraloid® B-72 and wax were used by 25% of respondents. Other respondents reported the use of Paraloid® – B-48N, mixtures of Paraloid® – resins, and one used 1:3 Regalrez® 1126:BeSquare® 195 microcrystalline wax.

In further conversations, colleagues at the Winterthur Museum, Metropolitan Museum of Art, Brooklyn Museum, American Museum of Natural History, Harvard Peabody Museum, and the Walters Art Museum reported that intact coatings (newly applied or aged) protected silver objects but were no longer successful as they began to degrade. Ideally, skilled application results in flawless coatings stable for decades. In practice, variability between batches of proprietary coatings causes uncertainty. One batch was reported to be stable for more than thirty years, another showed signs of degradation within weeks. Conservators still question the efficacy of silver coatings and their safety for the conservator and the object.

Materials and methods

Experimental: coatings

Four coatings (Table 1) were selected based on survey results, sustainability, and safety, and as a follow-up to the study by Grissom et al. (2013). Agateen® 27 lacquer mixed 1:1 with Agateen® Thinner levels smoothly over metal surfaces, has an appropriate gloss, and can age very well. Performance and long-term stability depend on the batch. Agateen® Thinner contains 22.7% toluene which presents serious health concerns (Sigma Aldrich 2023). Paraloid® B-72 is commonly used in conservation for various materials. Acrysol® WS24, the only waterborne option, used for ceramics and as a consolidant for wet fossilized material (Down 2015), posed the lowest health risk to the conservator, and was recommended for further study by Grissom et al. (2013). Regalrez® 1126, a low molecular weight resin used in furniture conservation (Piena 2001) and as a varnish for paintings is stable, clear, and glossy, but its performance as a barrier is unknown.



Figure 1. NMAI 18/6087 Chimú ornament with an aged coating from a previous treatment. In visible light (a) front (b) back, and ultraviolet-induced visible luminescence (c) front (d) back.



Figure 2. NMAI 15/7279 Chimú beaker with an aged coating from a previous treatment. (a) overall (b) detail of preferential corrosion from brush stroke misses in the coating application.

Experimental: coupon manufacture and analysis

Andean sources of silver, copper, and gold provided ancient metalsmiths with ingredients for alloy manipulation and surface enrichment (Lechtman 1979). To better understand the range of alloys and trace materials in Chimú silver items, portable X-ray fluorescence spectroscopy (pXRF) was conducted with a handheld Bruker Tracer 5i spectrometer using the internally calibrated Alloys2 setting. Data indicated a range of alloy composition with no average composition. However, one third of the objects surveyed had an alloy composition of over 90% silver, with the remaining amounts consisting mostly of copper and associated trace elements.

Table 1. Coatings evaluated in the study and their properties.

Coating proprietary name/Source	Material type	Glass transition temperature	Current published Oddy test result[1]	Concentration of solution used (weight % to volume)
Paraloid® B-72 Safety Data Sheet	Acrylic resin	40°C	Temporary (2019) tested as pellets	15% in xylene
Acrysol® WS-24 Safety Data Sheet	Acrylic emulsion	45°C	Not available	Undiluted
Agateen® 27 Agate lacquer	Cellulose nitrate	Not available	Pass (2003), Fail (2016)	1:1 lacquer to Agateen® Thinner #1
Regalrez® 1126 Safety Data Sheet	Hydrogenated hydrocarbon resin	67°C	Not available	30% in petroleum benzine

[1]AIC wiki Materials_Testing_Results

Based on the pXRF results, and under the guidance of metalsmith Michael Brehl, we replicated Chimú sheet silver with an alloy of 80% silver and 20% copper. This alloy composition was considered to be as representative as possible for the Chimú silver and allowed for surface enrichment. The raw silver and copper metals were heated in a crucible to produce an ingot which was then hammered and rolled into 0.3 mm strips, comparable to the collection items. During the rolling process, the work-hardened metal was annealed with a torch and dipped in a mild acid to realign the crystal structure and allow further working. The strips were planished with a hammer to finish the surface, then cut into 2.5 cm square coupons. To replicate the topography of the Chimú silver, we added a simple line of repoussé, hammered with a shaped tool from the back. Finally, the coupons were struck with numbered dies and a small hole punched to enable hanging within a chamber.

Though quantification of XRF analysis of layered systems such as worked sheet metal is not ideal, in cultural heritage this is often the only non-destructive option of analysis. In this study, pXRF was performed on the silver alloy coupons with a Bruker Tracer 5i in Alloys2 mode (40 kV, 10 µA, 8 mm collimator spot size) and a scanning Bruker Elio pXRF spectrometer set at 40 kV at 80 µA with an approximately 1 mm spot in air. Quantification was performed using the Bruker Esprit 2.5 software using fundamental parameters. The quantified data had 5% difference with one instrument reporting 87% silver and the other approximately 92%. The difference in the results was due to different sources and detector geometries resulting in a difference of X-ray information depths, noticeably observable in the data on layered systems. In this case, a cross-section of one of these coupons was prepared with similar protocols to Wachowiak (2004) and analyzed with scanning electron microscopy energy dispersion X-ray spectroscopy (SEM-EDX) with a carbon coating applied, under high vacuum at 15 kV. The EDX composite map of the alloy (Figure 3b) shows an approximately 3.68 µm thick layer of enriched silver, with a calculated composition of 94.20% silver. The bulk silver/copper alloy was measured as 81.5% silver and 18.5% copper (quantification by PB-ZAF in Esprit 2.5) and is consistent with the processing. The backscattered electron (BSE) image (Figure 3a) illustrates the crystalline structure of the alloy, particularly the voids formed from depletion gilding and continued preferential corrosion of the copper (Storme, Schalm, and Wiesinger 2015).

Experimental: coupon coatings and analysis

The coupons were intentionally not polished prior to coating so that the surface was a direct result of manufacture. Coupons were cleaned with acetone to reduce fingerprints before coating, and randomized. Two coats were brush applied, following responses from the questionnaire. To reproduce uncoated vessel interiors and imperfections in coating application, the coupons were coated in three ways:

- both sides were completely coated
- one side was coated
- both sides coated with a small area on one side masked with tape to ensure a *lacuna*.

Each of the four coatings was applied each way. Each coat was dried for 48 h to fully cure before the second application in an engaged fume extraction hood. The coupons were documented with photography before and after coating.

One coupon of each coating with the intentional *lacunae* was chosen for analysis with SEM-EDX. To obtain centimeter range EDX maps, stage scanning (rather than traditional beaming) was performed using a Bruker rapid stage: prior to coating; after coating; after corrosion; and after cleaning; in variable pressure mode with similar protocols to Vicenzi et al. (2022). This method allowed a visualization of the physical properties of the uncoated metal surface and the thickness, evenness, and completeness of each applied coating, along with any component elements in the coating.

Figure 3(c) shows a portion of four coupons visible in this orientation. Observations on thick or thin coverage, reported in Table 2, are based on the coatings' ability to prevent the EDX interaction with the silver signal from being mapped. Figure 3(d) is an elemental map showing thick, even coatings blocking the silver signal, while Figure 3(d) shows regions where the silver signal was detected through thin, uneven coatings. A small but unexpected amount of sulfur was detected in Acrysol® WS24.

To further characterize the four coatings, Fourier transform infrared (FTIR) spectroscopy data was collected from the coated coupons and as-cast films in both attenuated total reflectance (ATR) and micro-reflectance mode with similar protocols to Romano et al. (2020).

Corrosion chamber

A high-humidity sulfur-rich environment was created in a sealed acrylic chamber for maximum corrosive effect (Figure 4). Moisture is as much a factor in the corrosion of silver as pollutant levels (Pope, Gibbens, and Moss 1968) and sulfur compounds are the most common cause of silver corrosion (Costa 2001). We used elemental sulfur, which would sublime in a sealed container (Eggert et al. 2019; Kuhn-Wawrzinek, Eggert, and Schleid 2022) and allow the coupons adequate time to develop a low level of corrosion for the study. 65% relative humidity (RH) was maintained with saturated salts. Forty test coupons were hung in the

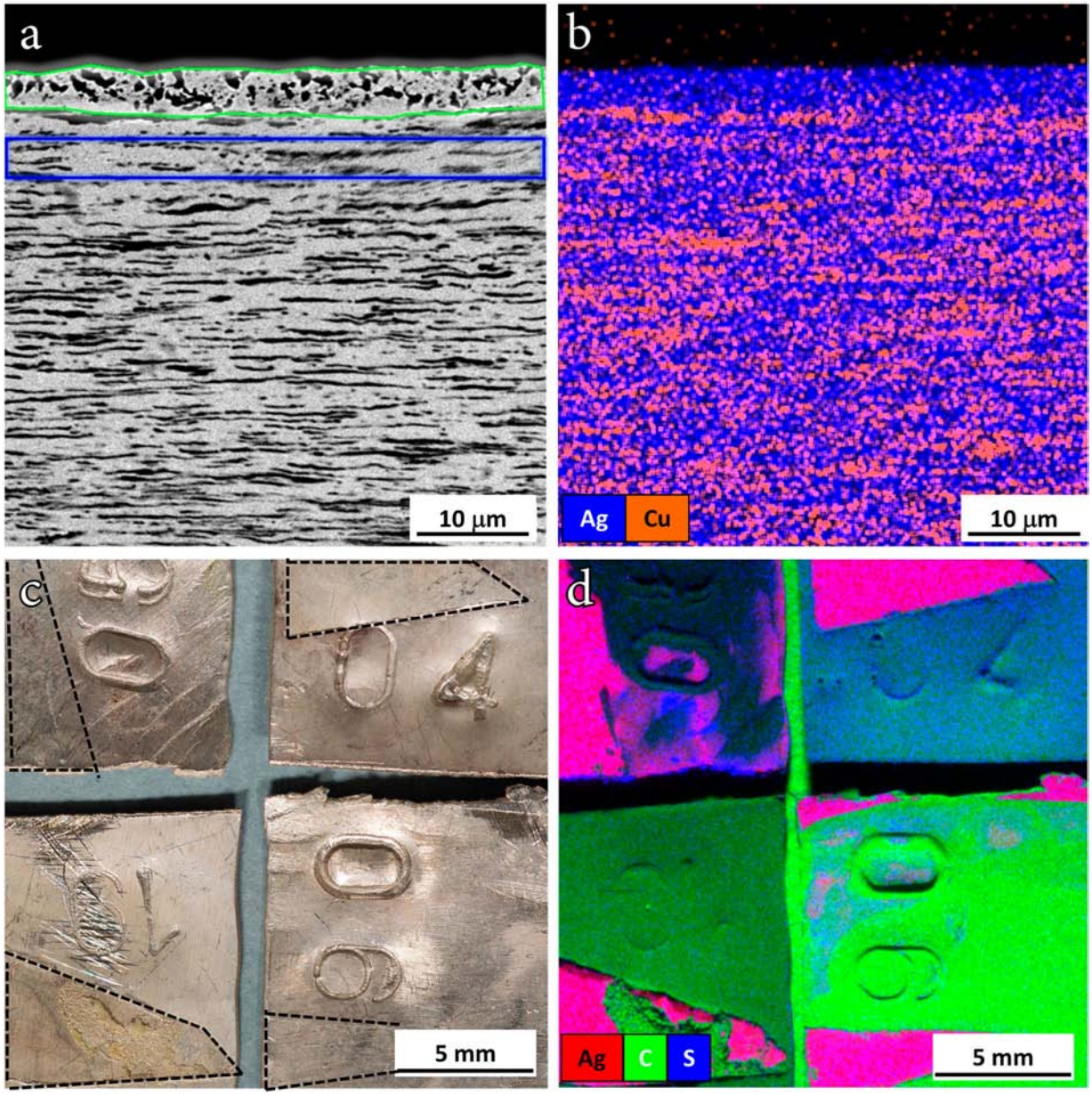


Figure 3. Top: cross-section of one coupon, the surface at the top. (a) BSE image, enriched silver layer highlighted in green; bulk alloy in blue. (b) Elemental map for silver (blue) and copper (orange). Bottom: coated coupons 4, 5, 6, and 19 in (c) visible light, triangular areas masked with tape (dashed lines) to create incomplete coatings and (d) elemental map for silver (red), carbon (green), and sulfur (blue).

chamber, which remained stable at 22°C and 65% RH for 15 weeks.

Results

As results for the coupons were not identical, evaluation was based on a subjective visual average.

Coatings

Agateen® 27

The areas fully coated with Agateen® 27 were protected from corrosion. The *lacunae* in coating and the backs of the coupons with one side coated displayed a higher visual degree of corrosion than the

Table 2. Oddy test results, application observations, and FTIR results.

Coating	Oddy Test Result	Application Observations	FTIR Absorbance Peaks (cm^{-1}) of Interest	ATR-FTIR Peak (cm^{-1}) Differences in Reflectance
Paraloid® B-72	Pass	Leveled well, even, thick, plastic look	712, 761, 859, 1022, 1136, 1380	Most peaks remained unshifted; 712 peak becomes a doublet and lack of a peak at 1136
Acrysol® WS24	Temporary	Thick bubbles formed, brown hue	755, 827, 891, 1147, 1380, 1440, 1712	Broad peak from 2300 and 3650. 755, 827, 891, 1712 are only peaks identifiable in reflectance
Agateen® 27	Unsuitable	Smooth, sheer, slight yellow hue	815, 989, 1049, 1277, 1630	Peak shifts and non-scaling of peaks observed; a doublet peak forms at 1630
Regalrez® 1126	Temporary	Too glossy, minor ripples and bubbles	761, 842, 891, 1021, 1239, 1418	Peaks are unshifted and scaling preserved.



Figure 4. Coupons in the sealed chamber with saturated salts (white, in beaker) and elemental sulfur (yellow, in beaker and watch glass).

fully uncoated coupons (Figure 5, coupon 17 and Figure 6, coupon 5). Black corrosion following a brush stroke pattern was unintentionally recreated on multiple coupons, suggesting the second coat resolubilized the first coat enough to drag it from the surface, and/or a too thin application. Where intact, the coating yellowed and dulled overall after exposure in the chamber. The coating was easily fully removed with acetone on cotton swabs and the coating residue on the swabs was yellow.

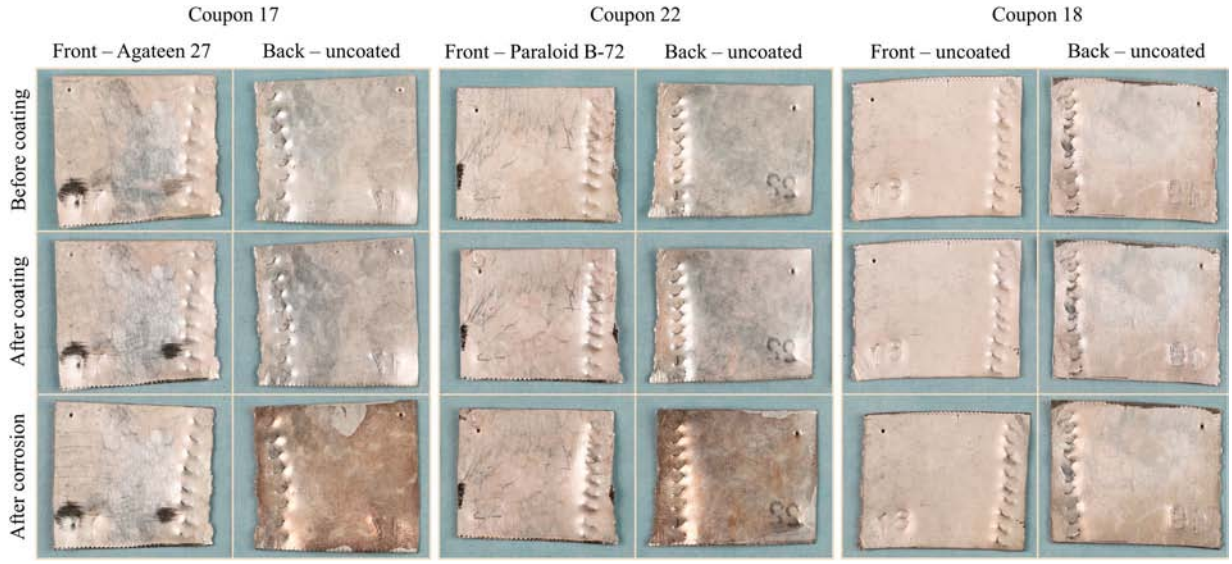


Figure 5. Three coupons (17, 22, and 18), coated on one side only, before coating, after coating, and after 15 weeks in the corrosion chamber. These coupons present the visual properties of coating on one side and the accelerated corrosion of the uncoated side. The coupons coated with Agateen® 27 (17) and Paraloid® B-72 (22) exhibit higher levels of corrosion on the uncoated, vulnerable side than the uncoated coupon (18).

Acrysol® WS24

Almost immediately after coating, coatings on some recessed areas appeared green, and overall the coatings were brown in tone. This color intensified over time in the corrosive chamber so that the coated coupons appeared dark brown. The uncoated sides and *lacunae* appeared more appropriately silver than the other coatings, similar in appearance to the uncoated coupons. Apparently, sulfur in Acrysol® WS24 affected the behavior in the chamber. When

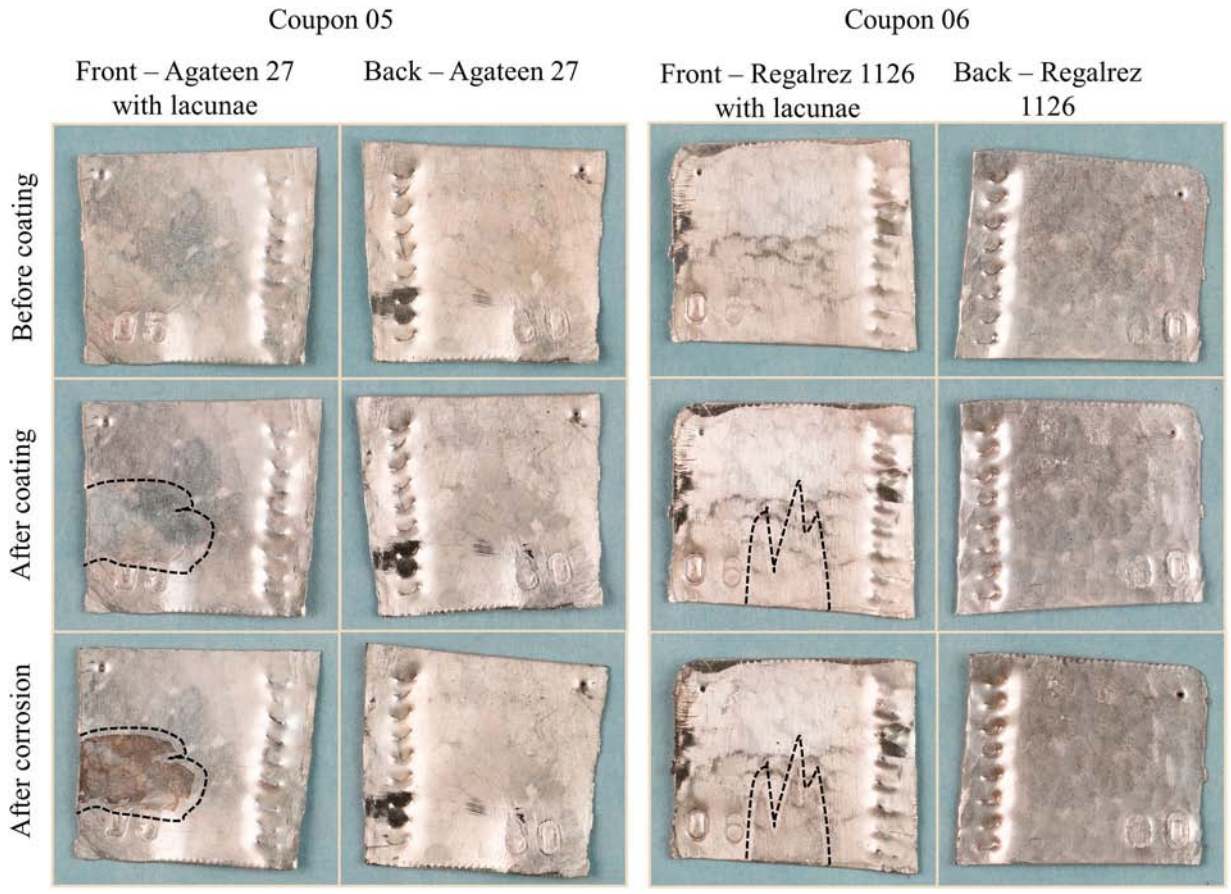


Figure 6. Comparison of the visual properties of coatings and the effects of lacunae in coatings (dashed lines). Two coated coupons with intentional *lacunae* before coating, after coating, and after 15 weeks in the corrosive chamber. Coupon 5, coated with Agateen® 27, exhibits a higher level of corrosion than coupon 6, coated with Regalrez® 1126.

the coating was removed, however, the silver remained brilliant and only slightly changed. The coating was difficult to remove; the coating residue on swabs was bright yellow-green and dark gray.

Paraloid® B-72

The coupons displayed a yellowish-brown hue overall, more significant in the recesses. Paraloid® B-72 protected against corrosion moderately well, however the coupons coated on one side and the intentional lacunae corroded significantly more than the uncoated coupons (Figure 5, coupon 22). The coated coupons remained glossy after corrosion. Paraloid® B-72 was difficult to remove with acetone, particularly in the thicker areas; the coating residue was yellow and brown.

Regalrez® 1126

Regalrez® 1126 protected against corrosion in the chamber moderately well. The uncoated backs and *lacunae* did corrode (Figure 6, coupon 6), but not as significantly as the other coatings tested. While there were irregularities and flaws in the application, these did not result in associated localized corrosion. The uncoated *lacunae* appear slightly darker than the coated portion of the coupons. The coating did not yellow or dull after corrosion and was easily removed with mineral spirits on cotton swabs.

Uncoated coupons

As expected, corrosion formed on the uncoated control coupons (Figure 5, coupon 18), particularly in the form of almost black edges and an even, dull brown-gray cast over the surface. Patterns in the corrosion followed the surface characteristics of the worked metal. The coupons maintained their glossy metallic nature, even after corrosion.

SEM-EDX

The coated coupons were analyzed with SEM-EDX to investigate the elemental composition of the coatings. A low level of sulfur was detected in the Acrysol® WS24, along with carbon and oxygen, prior to hydrogen sulfide exposure. Agateen® 27 showed carbon, oxygen and nitrogen. Paraloid® B-72 showed only carbon and oxygen. Regalrez® 1126 showed only carbon.

Analysis of the uncoated portion of the coupons indicated 0.13% sulfur, (normalized mass percentage). Sulfur levels rose to an average of 0.28% after 15 weeks in the chamber. After 15 weeks in the chamber, the coatings were removed with solvent and the coupons reassessed with SEM-EDX. Sulfur levels after coating removal averaged 0.24%, but there was not a statistically significant change in the chemistry resulting from the cleaning alone. The BSE image and elemental scans of the coupons overall afterwards confirmed these additional observations (Figure 3d). Coupons 5 (Agateen® 27) and 6 (Regalrez® 1126), showed localized sulfur content directly correlating to the thinly coated areas (Figure 3d). Coupons 4 (Acrysol® WS24) and 19 (Paraloid® B-72) exhibited small coating residues, invisible to the eye, in the areas of low relief. These two coatings were the most difficult to remove.

Oddy testing

Oddy testing of the selected coatings was conducted for one month using the 2020 IMA/Winterthur protocol and materials (American Institute for Conservation 2020). The coating materials were cast in a silicone dish and allowed to cure for two months before testing. After one week, the coupons in the test tubes containing Agateen® 27 showed an unacceptable level of corrosion and were removed. Oddy test results are shown in Table 2.

Reflectance FTIR and ATR-FTIR

Reflectance FTIR and ATR-FTIR analysis were performed to assess each of the four coatings as unaged cast films and as applied to metal coupons after corrosion. For Paraloid® B-72, shifts and scaling differences between the two techniques were observed, as expected (Romano et al. 2020), though in some cases the peaks remained unshifted. In general, the peaks in the range 2700 cm^{-1}–3200 cm^{-1} are more broadened in reflectance FTIR compared to ATR. Table 2 contains the summary of the FTIR results. With the amount of variation possible between the two methods, future work could include steps to provide the Infrared and Raman Users Group (irug.org) with raw data files. This will be pursued to develop a database for coatings under reflectance FTIR.

Discussion

This study provides a better understanding of the interaction of coatings and original silver alloy metal. Manufacturing a comparable alloy with similar surface treatment (depletion gilding and topographical relief) demonstrated the likely behavior of the coatings on collection items. As the objects are three dimensional and larger in size than the coupons, reflectance FTIR would be the ideal technique. In this study we documented the possible variation by both reflectance FTIR and ATR (in Table 2), so that if one of these coatings existed on another object it could be identified. A comparison of these coatings with an uncoated control further supported our hypothesis that there are no satisfactory coatings. However, XRF analysis of the

swabs used to remove each coating indicated trace amounts of silver, indicating removal of original metal. It will be useful to know if our results can be reproduced with different batches of Agateen® 27 and Acrysol® WS24. Agateen® 27 is known to vary in quality and longevity depending on the batch. The Acrysol® WS24 coated coupons in the previous study did not have this same discoloration (Grissom et al. 2013). The level of corrosion on the *lacunae* and backs of the Agateen® 27 and Paraloid® B-72 coated coupons is troubling: the coating appears to intensify the corrosion.

Conclusions

The results of this study and the survey and treatment of Chimú silver with aged coatings have informed new recommendations for the care of archaeological silver. None of the coatings evaluated in this study meet the requirements for responsible care. The degree of corrosion on partially coated coupons was unacceptable, and the process of removing the coatings caused loss of original material. This study supports prevention of corrosion by passive means such as low relative humidity, scavengers, and corrosion inhibiting cloths and bags (see Costa 2001; Dandridge 2005; Kristjánsdóttir 2020). Further work on coatings should include investigations into Regalrez® 1126 mixed with BeSquare® 195 or another mattifying material. Aged coatings on Chimú sheet silver items were mostly soluble in acetone, and upon their reduction, revealed the original characteristics of the metal. Moving forward, NMAI will use passive methods rather than coatings for the prevention of new corrosion.

Acknowledgements

We are grateful to Michael Brehl, Samantha Alderson, Sumru Aricanli, Gregory Bailey, Lisa Bruno, Kim Cullen Cobb, Gerhard Eggert, Angela Elliott, Lauren Fair, Carol Grissom, Judy Jungles, Dawn Kriss, Blythe McCarthy, Teresa Jimenez Millas, and Marlene Yandrisevits for their contributions to the study.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported in part by Stephanie Guidera's NMAI Andrew W. Mellon Fellowship.

ORCID

Stephanie Guidera http://orcid.org/0009-0009-2943-0710
Emily Kaplan http://orcid.org/0000-0001-7364-9925
Caitlin Mahony http://orcid.org/0009-0000-1834-1936
Thomas Lam http://orcid.org/0000-0002-0908-0938
Gwénaëlle M. Kavich http://orcid.org/0000-0002-7706-1173

References

American Institute for Conservation. 2020. *Oddy Test Protocols* Wiki. https://www.conservation-wiki.com/wiki/Oddy_Test_Protocols.

Costa, V. 2001. "The Deterioration of Silver Alloys and Some Aspects of their Conservation." *Studies in Conservation* 46 (sup1): 18–34. https://doi.org/10.1179/sic.2001.46.Supplement-1.18.

Dandridge, P. 2005. "The Exhibition of Unlacquered Silver at the Metropolitan Museum of Art." *Journal of the American Institute for Conservation* 44 (3): 175–183. https://doi.org/10.1179/019713605806082257.

Down, J. L. 2015. *Adhesive Compendium for Conservation*. Ottawa: Canadian Conservation Institute.

Eggert, G., R. Kuiter, C. Korenberg, J. Ziegler, S. Bette, and J. Stelzner. 2019. "Metal Conservation, Cellulose Nitrate, and the Oddy test." *Metal 2019 Proceedings of the Interim Meeting of the ICOM-CC Metals Working Group* September 2-6, 2019, Neuchâtel, Switzerland. Paris: ICOM. https://www.icom-cc-publications-online.org/3523/Metal-Conservation-Cellulose-Nitrate-and-the-Oddy-Test.

Grissom, C. A., N. Grabow, C. S. Riley, and A. E. Charola. 2013. "Evaluation of Coating Performance on Silver Exposed to Hydrogen Sulfide." *Journal of the American Institute for Conservation* 52 (2): 82–96. https://doi.org/10.1179/0197136013Z.0000000007.

Kristjánsdóttir, B. G. 2020. "Hydrogen Sulfide in Iceland and its Effects Within Museums: Protecting Silver Objects From Pollutants." Unpublished masters dissertation, Northumbria University, Newcastle, UK.

Kuhn-Wawrzinek, C. F., G. Eggert, and T. Schleid. 2022. "Sulfur, the 'Enemy Of Copper': Replication Of Sulfurous Efflorescence of Copper-Based Heritage Materials With Elemental Sulfur." *Proceedings of the Interim Meeting of the ICOM-CC Metals Working Group* September 5-9, 2022, Helsinki, Finland. Paris: ICOM. https://www.icom-cc-publications-online.org/5089/Sulfur-the-Enemy-of-Copper–Replication-of-Sulfurous-Efflorescence-on-Copper-Based-Heritage-Materials-with-Elemental-Sulfur.

Lechtman, H. 1979. "Issues in Andean metallurgy." In *Pre-Columbian Metallurgy of South America:* A Conference at Dumbarton Oaks, October 18th and 19th, 1975, edited by E. P. Benson, 1–40. Washington, D.C: Dumbarton Oaks Research Library and Collections, Trustees for Harvard University.

Lechtman, H. 1996. "Chimú: Analytical Notes." In *Andean Art at Dumbarton Oaks*, edited by E. H. Boone, 223–276. Washington, DC: Dumbarton Oaks Research Library and Collection.

Piena, H. 2001. "Regalrez in Furniture Conservation." *Journal of the American Institute for Conservation* 40 (1): 59–68. https://doi.org/10.1179/019713601806113111.

Polidori, T., K. Rovito, L. Fair, R. Grayburn, A. Wagner, and M. Crawford. 2019. *Current Silver Treatment Practices at Winterthur (White Paper)*. http://www.conservationaffair.com/uploads/1/7/4/4/17443603/appendix_2019_white-paper_12_2019.pdf.

Pope, D., H. R. Gibbens, and R. L. Moss. 1968. "The Tarnishing of Ag at naturally-occurring H_2S and SO_2 levels." *Corrosion Science* 8 (12): 883–887. https://doi.org/10.1016/S0010-938X(68)80141-6.

Pouliot, B., C. R. Matsen, J. L. Mass, W. Donnelly, K. Andrews, and M. Bearden. 2013. "Three Decades Later: A Status Report on the Silver Lacquering Program at Winterthur." *American Institute for Conservation Objects Specialty Group Postprints* 20: 32–48.

Reedy, C. L., R. A. Corbett, D. L. Long, R. E. Tatnall, and B. D. Krantz. 1999. "Evaluation of three protective coatings for indoor silver objects." *American Institute for Conservation Objects Specialty Group Postprints* 6: 41–69.

Romano, C., T. Lam, G. A. Newsome, J. A. Taillon, N. Little, and J. Tsang. 2020. "Characterization of Zinc Carboxylates in an Oil Paint Test Panel." *Studies in Conservation* 65 (1): 14–27. https://doi.org/10.1080/00393630.2019.1666467.

Sease, C., L. S. Selwyn, S. Zubiate, D. F. Bowers, and D. R. Atkins. 1997. "Problems with Coated Silver: Whisker Formation And Possible Filiform Corrosion." *Studies in Conservation* 42 (1): 1–10. https://doi.org/10.1179/sic.1997.42.1.1.

Selwyn, L. 2004. *Metals and Corrosion: A Handbook for the Conservation Professional*. Ottawa: Canadian Conservation Institute.

Sigma Aldrich. 2023. *Toluene*. Product number 244511. Version 6.21, 23 August 2023. https://www.sigmaaldrich.com/CA/en/sds/244511.

Storme, P., O. Schalm, and R. Wiesinger. 2015. "The Sulfidation Process of Sterling Silver in Different Corrosive Environments: Impact of the Process on the Surface Films Formed and Consequences for the Conservation-Restoration Community." *Heritage Science* 3 (1): 25. https://doi.org/10.1186/s40494-015-0054-1.

Thickett, D., and K. Hallett. 2021. "Managing Silver Tarnish." *ICOM-CC 19th Triennial Conference Preprints*, Beijing,17–21 May, 2021. Paris: ICOM. https://www.icom-cc-publications-online.org/4279/Managing-silver-tarnish.

Vicenzi, E. P., T. Lam, J. L. Weaver, A. Herzing, J. S. McCloy, R. Sjöblom, and C. Pearce. 2022. "Major to Trace Element Imaging And Analysis of Iron Age Glasses Using Stage Scanning in the Analytical Dual Beam Microscope (tandem)." *Heritage Science* 10 (1): 90. https://doi.org/10.1186/s40494-022-00707-4.

Wachowiak, M. J. 2004. "Efficient New Methods for Embedding Paint and Varnish Samples for Microscopy." *Journal of the American Institute for Conservation* 43 (3): 205–226. https://doi.org/10.1179/019713604806082447.

Ziegler, J., C. Kuhn-Wawrzinek, M. Eska, and G. Eggert. 2014. "Popping Stoppers, Crumbling Coupons: Oddy Testing Of Common Cellulose Nitrate Ceramic Adhesives." *ICOM-CC 17th Triennial Conference Preprints*, Melbourne, Australia 19-23 September 2014. Paris: ICOM. https://www.icom-cc-publications-online.org/1375.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S146–S152
https://doi.org/10.1080/00393630.2024.2346017

ORIGINAL RESEARCH AND TREATMENT PAPER

Strengthening Training in the Conservation of Cultural Heritage Through Academic Collaboration

Fortaleciendo la Formación en Conservación del Patrimonio Cultural a través de la Colaboración Académica

Tanushree Gupta and Gabriela Krist

Institute of Conservation, University of Applied Arts Vienna, Vienna, Austria

ABSTRACT

Conservation training is more sustainable if we join forces to utilise our resources efficiently and effectively. One such academic collaboration is discussed, which gains from the expertise of two institutions. *Cultural Heritage Conservation and Management* (CHCM) is an advanced master's degree programme offered by the Institute of Conservation, University of Applied Arts Vienna, Vienna, Austria and Silpakorn University International College, Silpakorn University, Bangkok, Thailand. Launched in 2021, this programme is designed for conservators who already hold a master's degree in conservation, enabling professionals to apply their skills globally and benefit from mutual learning. The programme allows students to gain experience in Europe and Asia, through the study in specialised conservation studios in Vienna and Bangkok, as well as through international projects in other cities. Local traditional knowledge plays a vital role in introducing sustainable approaches to both preventive and remedial conservation. However, to make sure that ethics and standards in conservation are not compromised in the process, critical thinking based on scientific reasoning is indispensable. This concept has been applied in practice by including in the curriculum aspects of transcultural communication and collaboration, presentation techniques and media, project and site management, as well as legislation and the function of UNESCO. This paper focusses on the planning of the CHCM programme through to its successful first implementation.

La capacitación en conservación es más sostenible si unimos fuerzas para utilizar nuestros recursos de manera eficiente y efectiva. Se analiza una de esas colaboraciones académicas, que se beneficia de la experiencia de dos instituciones. *Conservación y Gestión del Patrimonio Cultural* (CHCM) es un programa de maestría avanzado ofrecido por el Instituto de Conservación de la Universidad de Artes Aplicadas de Viena, Austria y el Colegio Internacional de la Universidad de Silpakorn, Universidad de Silpakorn, Bangkok, Tailandia. Lanzado en 2021, este programa está diseñado para conservadores que ya tienen una maestría en conservación, lo que permite a los profesionales aplicar sus habilidades a nivel mundial y beneficiarse del aprendizaje mutuo. El programa permite a los estudiantes adquirir experiencia en Europa y Asia, a través de estudios en estudios de conservación especializados en Viena y Bangkok, así como a través de proyectos internacionales en otras ciudades. El conocimiento tradicional local desempeña un papel vital en la introducción de enfoques sostenibles en la conservación tanto preventiva como correctiva. Sin embargo, para garantizar que la ética y las normas de conservación no se vean comprometidas en el proceso, es indispensable el pensamiento crítico basado en el razonamiento científico. Este concepto se ha aplicado en la práctica incluyendo en el plan de estudios aspectos de comunicación y colaboración transcultural, técnicas y medios de presentación, gestión de proyectos y sitios, así como la legislación y la función de la UNESCO. Este documento se centra en la planificación del programa CHCM hasta su primera implementación exitosa.

ARTICLE HISTORY
Received October 2023
Accepted April 2024

KEYWORDS
Academic collaboration; Cultural Heritage Conservation and Management; Austria and Thailand; masters degree programme

Colaboración académica; Conservación y Gestión del Patrimonio Cultural; Austria y Tailandia; programa de maestría

Introduction

Critical and innovative thinking by teaching staff plays an important part in inculcating the principles and skill sets needed by future conservators. The evolution of conservation training has not been uniform chronologically. Whereas Europe has the conservation of cultural heritage well established in university curricula, some countries in Asia are still aiming to launch this discipline. Rather than establishing such programmes from scratch, it is more efficient to collaborate with institutions that have a longer history and more experience in imparting conservation training. Such collaborations can be mutually beneficial because, with varied geographical locations for teaching, there is access to a plethora of local traditional knowledge which is an untapped source of information. Collaborations are

CONTACT Tanushree Gupta tanushree.gupta@uni-ak.ac.at Institute of Conservation, University of Applied Arts Vienna, Vienna, Austria
© The International Institute for Conservation of Historic and Artistic Works 2024

not only enriching but are also a sustainable way of working.

This paper focuses on academic collaboration between the Institute of Conservation (IoC), University of Applied Arts Vienna (UAAV), Vienna, Austria and the Silpakorn University International College (SUIC), Silpakorn University, Bangkok, Thailand. Together, these universities have launched a joint master's programme *Cultural Heritage Conservation and Management* (CHCM), which has been much appreciated and has proved itself to be successful, with students learning from each other through traditional knowledge, religious values, cross-cultural ideas, and of course networking internationally. The aim of this programme is to bring together students from different cultures in Asia and Europe, enabling the exchange of practices and ideas.

Launch of CHCM

The IoC began its first academic conservation programme in 1964. Today IoC has a five-year master's programme, where students choose a specialisation matching their skill set. IoC has four areas of specialisation: objects, paintings, stone, and textiles, and offers teaching in preventive conservation and collection care. It has run numerous successful projects to make museum storage better. IoC offers three-year PhD studies, focussing on topics such as conservation history, technical examination, climate change and preservation of outdoor stone, and other areas which supply the needs of institutions. The conservation work is supported by the in-house conservation science laboratory. Owing to the reputation the IoC has built over the years, the students always work on original objects which the IoC receives as work assignments from museums, monasteries and private collectors. In addition to having a UNESCO chair on Conservation and Preservation of Tangible Cultural Heritage, the IoC is an active member of regional and international networks such as the Austrian UNESCO Commission, IIC, ICOM, ICCROM and ENCORE. Moreover, it was a co-founder of the Heritage Science Austria platform. The Institute has a strong tradition of exchanging and sharing knowledge and has been host to many student and in-service internships. Moreover, the geographical span of the IoC covers not only Europe but is ever-growing to the East, with major international collaborations and active education and training projects in India, Nepal, Mongolia, Thailand and more recently in the Balkans.

SUIC is unique in offering various study programmes in collaboration with universities in Europe. This allows students to acquire a global perspective, as well as the confidence to establish themselves as global leaders. It was SUIC's long-term wish to start a master's programme in conservation and to open it to interested candidates from neighbouring countries. This is because there is a dearth of training in the conservation of cultural heritage, if not a complete absence, in the region.

CHCM started as a collaboration between Austria and Thailand, both rich in cultural heritage. Supported by the Austrian Embassy, Thailand; Embassy of the Kingdom of Thailand, Austria; and the Agency for Education and Internationalisation, as well as the ASEAN European Academic University Network, Austria, the two universities came in contact.[1] The two universities entered into a memorandum of understanding in 2019 and began to brainstorm a way forward. As the IoC already has a five-year master's programme, it aimed to provide students with an advanced master's degree which would complement their existing knowledge and enable them to apply this in a contrasting geographical location and culture and to become familiar with how conservation of cultural heritage can be approached globally. Silpakorn University has a bachelor's programme in conservation, and thus the SUIC was focused on establishing a master's programme. As the criteria for admission to the two universities differ, so would the duration of the CHCM. With an upper limit of 15 students per intake, a student-teacher ratio ensuring individual attention has been achieved. The curriculum of CHCM encompasses elements of conservation and management, where major inputs for 'conservation' come from the IoC, and those for 'management' come from the SUIC. Modules include – *Asian and World Cultural Heritage*, *Cultural Heritage Management and Communication*, *Conservation in the International Context*, and *Transcultural Studies and Competences* (University of Applied Arts Vienna 2023). In addition to teaching by the faculty of both universities, specialist lecturers are often invited to teach advanced modules (die Angewandte 2023). The language of instruction is English to encourage international participation, and students submit English proficiency certificates during the admission process. The students learn the difference in approaches in conservation in different continents. This experience combined with their existing skills allows them to conserve cultural heritage across the globe, more responsibly.

The first intake for CHCM

The first intake attended from October 2021 to September 2023 for students enrolled at the SUIC, and from March 2022 to September 2023 for students enrolled at the IoC. The group comprised 13 students from eight countries: Austria, Bangladesh, Germany, India, Iran, Thailand, Turkey, and Vietnam. There was an immediate challenge; the popularity of the programme was considerable as was reflected in the applications received. However, waves of Covid-19 travel restrictions were far from over. Every country had different regulations for visa, travel and entry

requirements. A solution was sought to move the theoretical courses online – which not only allowed students from far and near to join but also helped them reduce the costs of relocation and travel. However, the study programme is underpinned with intense practical sessions. Thus, two months of practical work in Vienna, approximately one month of practical work in Nepal and Albania as part of international projects, and then around two months of practical work in Bangkok, were indispensable.

To make the programme economically sustainable, costs were reduced as much as possible, and possibilities for funding were offered to the students. Since it is a public university, the tuition fee is quite nominal at the UAAV, and is calculated based on the nationality of the student. Also, the clearly defined online and on-site phases provided students with flexibility to move or not to Vienna. In this way, they could continue with their jobs in their desired location. Nevertheless, as students of the UAAV, students are welcome to relocate to Vienna and participate more in the day-to-day conservation work at the IoC. Students may be provided with full or partial funding by the UAAV to cover the costs of the on-site study phases. The UAAV offers two paid positions for students of CHCM to become student assistants during the entire study programme, as well as offering assistance based on financial need. The teaching staff applies to various funding organisations to secure travel costs for delivering training during international projects.

The last semester concentrated mostly on the master's thesis, the topic of which students were encouraged to choose from their practical experience or personal area of interest (Hietz, Haselberger, and Krist 2022). With the completion of 90 European Credit Transfer and Accumulation System (including mandatory modules, elective modules and the master's thesis) and a publication from the master's thesis, students earn a master's degree.

All courses run within the programme are evaluated anonymously by the University. Additionally, regular feedback is collected, after which the curriculum is accordingly upgraded.

Practical conservation: Austria, Albania, and Nepal

In July – August 2022, seven students enrolled at IoC and six students enrolled at SUIC came together for the first time to attend practical training in Vienna. They worked together in the IoC conservation studios – objects, paintings, stone, and textiles – under the supervision of experienced IoC conservators, and attended excursions to important museums and cultural heritage sites, to understand, in detail, Austria's cultural heritage and strategies for conservation.

Theory and discussions formed the basis of practical skill development. Students began with training in the conservation science laboratory where the significance and implementation of analytical support in conservation was elaborated. Having acquired this foundation, they could then join the practical sessions in different conservation studios. To ensure that they have the precision required to work on an original object, practice sessions always begin with work on mock-ups. Within the practical session, special teaching modules were conducted by the students where they used their former experiences to train their fellow students in a chosen conservation skill.

The practical training began in the stone conservation studio. Students worked in groups, focusing first on understanding stone as a material, its ageing properties, and thereby its mechanism of deterioration. Following this, a selection of treatments for cleaning and filling was carried out.

The following week brought everyone closer to the stored collection at the UAAV, where the students were split into two groups to cover collection care in object and textile storage, respectively. The students in the object group worked on the furniture collection, and those in the textile group worked on a significant carpets and tapestries collection. The main aim was to improve storage conditions for these collections. Students were introduced to the storage system – collection assessment and condition reporting, handling of objects, and investigating and implementing possible improvements for long-term storage. This was an exceptional opportunity where local history, art technology, and conservation practice could all be interconnected.

The fourth week was dedicated to training in the conservation of ceramics, glass and metals. Broken ceramics and glass objects were to be re-assembled. Students learnt about the properties of different adhesives, practised techniques, and then conserved the objects assigned to them (Figure 1). To learn



Figure 1. Students conserving ceramics in the IoC object conservation studio, under the supervision of Manfred Trummer. © IoC. Image: Meral Hietz.

metal conservation, the students had the opportunity to work on the medical instruments housed in the Josephinum, the medical science museum.

Painting conservation was the most extensive part of this programme. Each student was assigned a painting, a polychrome sculpture, or a decorated frame to work on. Starting with a detailed condition report, students proposed a conservation plan, and after discussion with the supervisors, commenced the work. Depending upon the requirements of the object, students learnt different techniques – dry/wet/solvent/gel cleaning, consolidation, thread-to-thread tear mending, strip-lining, filling, infilling losses to a frame by moulding similar material, or retouching. Afterwards, discussions were facilitated so each student could learn from the experiences of others.

To facilitate comprehensive understanding of cultural heritage in Austria – art history, conservation, management, and related research – various guest lectures were organised. Topics like *Introduction to Christian Iconography* and *Monuments Conservation in Austria* laid the foundation; and further lectures on *Art Storage Facilities in the Kunsthistorisches Museum Vienna* gave an insight into various conservation projects. Further lectures focused on international projects carried out by the Institute since 2004. To convey the rich cultural heritage of Austria as well as to explore the Asian collections in Vienna, excursions were planned regularly, with part of the coursework being seminars on *Cultural Heritage in Austria* and *Asian Cultural Heritage in Vienna*. From palaces, cathedrals, museums in Vienna to historical sites like Wachau and Mauerbach outside the city, all the visits were facilitated by tours led by experts in the field (Figure 2). Students could see the storage and conservation studios at various facilities, which often provoked interesting deliberations and discussions.

For most of the students the journey did not end here. In September 2022, they joined the Institute's team for UNESCO missions in Albania or Nepal



Figure 2. Tour of Schönbrunn Palace, Vienna, led by Dr Elfriede Iby. © IoC. Image: Gabriela Krist.



Figure 3. Cleaning historic textiles in Kruja, Albania, a UNESCO project. © IoC. Image: Pornganok Sadakorn.

where hands-on conservation continued on-site, together with colleagues from the respective countries (Figure 3). The training provided varied experiences including: working in teams to undertaking tasks independently; practising skills by leading course modules; assessing collections; analysing samples; and not least, understanding the conservation and management of cultural heritage in Vienna (Berger, Klinkert, and Pawar 2023).

Having completed the study phase in Vienna, the international group of students was then prepared to cross borders and meet in Bangkok in 2023 for the next practical training, exploring culture.

Practical conservation: Thailand

The CHCM team embarked on cross-cultural training in conservation in Bangkok in 2023, where again the coursework included intensive training in the conservation of original artworks. The emphasis was on understanding manufacturing techniques and the challenges of their immediate environment, to develop customised conservation solutions, both preventive and remedial. The sharp contrast in temperate and tropical climate zones offered a multitude of research opportunities to develop conservation in a sustainable manner.

The first CHCM intake entered into their last phase of practical studies at the beginning of 2023 in Bangkok. The task this time was to investigate the environment and apply principles of conservation commensurate with the year-round hot and humid climate in this region. Five weeks in January and February were dedicated to this. Various formats were explored to provide a holistic and meaningful experience of the conservation of cultural heritage to the students. Local experts in related disciplines were also invited to join the discussions, so that traditional knowledge could be tapped into. Some students prepared short teaching modules and led the group as

part of pedagogic training in conservation. Furthermore, lectures, often combined with site visits, were conducted by experts from Silpakorn University on topics such as *Cultural Heritage in Thailand*, *Cultural Heritage Management*, *Project and Site Management*, *Heritage and Environmental Issues*, and more, to familiarise the students with the system in Thailand.

As a first step, it was required to identify artworks in need of conservation, so the students could work on them. Silpakorn University has a collection of its own, housed in the Silpakorn University Art Centre. The collection is growing as they regularly organise art competitions and acquire the prize-winning artworks every time. This is to promote art and culture in Thailand by honouring the talent within the country. Upon surveying the storage facility, some artworks were found to be deteriorating, and were brought to the SUIC conservation laboratory. Offering variety in terms of material and damages, most of them aligned with the interest and complexity level required for the students. They included paintings, ceramics, textiles, and other three-dimensional objects. Starting with detailed documentation and condition reporting, the students came up with conservation plans which were then discussed before each student got started with treating their object, of course, under supervision. So far, finding the appropriate conservation materials in Bangkok has been a challenge, thus, the necessary conservation materials were brought along by resource persons from Vienna.

The immediate environment of the artwork usually indicates the reason behind many of its problems. Identification of the factors that have led to every type of deterioration in an artwork is important for choosing its course of treatment. Also, this information is necessary so that agents of deterioration can be minimised, if not removed. To achieve this, intensive training into developing a 'critical eye' for observing the surroundings took place in the SUIC stores. The focus is on the ten agents of deterioration: incorrect temperature; incorrect relative humidity; light; ultraviolet and infrared radiation; water; pollutants; fire; dissociation; pests; physical forces; and thieves and vandals, which are considered the primary threats to heritage objects. Students worked in groups, successfully identified problems and came up with a number of suggestions as to how the storage could be improved (Figure 4).

Another aspect was the investigation of immovable art works. One of the oldest temples, Wat Kampang, an example of living cultural heritage, was chosen for this exercise. Starting by understanding vernacular architecture and its association with its surroundings, the interaction of building components and structures, and their stability, were critically surveyed. Furthermore, the team investigated the stucco decorations along the façade and the lacquerwork on windows and doors. Rising damp was one of the most alarming agents of deterioration, the consequence of which was visible on already damaged wall paintings in the interior (Figure 5). The students worked on different topics in groups to find the problem areas and to work out a preventive conservation plan to tackle the sources of the problem. Investigations established that cooperation with the municipal corporation would be necessary as the causes of rising damp



Figure 4. Students investigating the condition of objects in the Silpakorn University Art Centre. © IoC. Image: Tanushree Gupta.



Figure 5. Documentation of damage to a wall painting at Wat Kampang. © IoC. Image: Tanushree Gupta.



Figure 6. Students and resource persons in Bangkok. © IoC. Image: Tanushree Gupta.

need to be addressed with the cooperation of local engineering departments.

This opportunity was taken to make visits to cultural heritage sites in the city, including the conservation laboratories of the National Museum of Thailand and the Queen Sirikit Museum of Textiles. The students were engrossed; no wonder many of them chose to continue with related topics for their masters theses. For wider outreach, a one-day symposium was organised in hybrid mode where students presented all the work they had undertaken thus far. The wider participation and intense discussions vouched for the success of this event, and thereby of the study programme. The international nature of this module brought together a true multicultural exchange which definitely made Bangkok a melting pot for the conservation of cultural heritage (Figure 6).

The motivation of the students is reflected in their choice of topics for their master's theses, which ranged from remedial conservation of single Thai objects to designing a preventive conservation plan for historical buildings, namely a temple with living culture. Two theses are being carried out in collaboration with the Ruam Samai Museum in Chiang Mai where students worked on planning a new storage space, as well as selecting a suitable lighting system. Drawing on experience from the international project in Nepal, one thesis is dedicated to the conservation of wall paintings in Bhaktapur. Nine papers, based on the master's theses, have been published by the SUIC (2023).

Conclusion

Using resources efficiently has been the motto of CHCM, and has made it a perfect example of sustainable academic collaboration. The online meeting platforms enabled an international group of students to be brought together, as well as enabling experts from different parts of the world to share their knowledge. Students in countries with limited access to the internet could either move to Vienna, and use the facilities at the University to join the lectures, or the lectures could be moved from online to hybrid mode. Travel necessary for the practical training was minimised with a dense teaching schedule. The study programme could thus deliver a snapshot of how conservation is approached in Europe and Asia. Whereas matching up with different time zones was not always easy, the advantages definitely outnumbered the disadvantages. The faculty of IoC conducted special workshops for students of SUIC to ensure quality in practical training. One such workshop was conducted in April 2022 in Thailand on painting conservation (Gupta, Marinovic, and Krist 2023).

CHCM, as an international study programme, does force travel expenses upon students during on-site study phases; however, the on-site experience of learning in/through two contrasting environments goes a long way in strengthening the technical skills of emerging young professionals, and also of the local teams involved. To avoid the transportation of conservation materials, both universities are continually looking for local suppliers.

Sustainability in the conservation of cultural heritage needs a review of how education and training are imparted. It is time we joined forces and utilised our resources more efficiently and effectively. Collaboration is the key to a successful future. Challenges faced by collections in different regions of the world are influenced by local parameters. Thus, it is more efficient that institutions come forward and collaborate to learn from each other, rather than stay in isolation and start from scratch.

Traditional knowledge of local cultures and customs, as well as of methods and materials, plays a vital role in introducing sustainable approaches in both preventive and remedial conservation. However, to make sure that ethics and standards in conservation are not compromised in the process, critical thinking based on scientific reasoning is indispensable. This concept has been applied in practice through various modules built into the curriculum, which also considers aspects of transcultural communication and collaboration, presentation techniques and media, project and site management, as well as legislation and the workings of UNESCO.

The master's programme in *Cultural Heritage Conservation and Management* has made a successful completion of its first intake of students, and is now looking forward to the next.

Note

1. CHCM is headed by Prof. Gabriela Krist of IoC (https://konservierung-restaurierung.uni-ak.ac.at/en/study/joint-master/programme/) and Prof. Sompid Kattiyapikul of SUIC (https://suic.su.ac.th/programmes/cultural-heritage-conservation-and-management).

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the ASEAN-European Academic University Network, Project number: ASEA 2021-2022/Angewandte/1, ASEAN-European Academic University Network, Project number: ASEA 2022-2023/Angewandte/1.

ORCID

Tanushree Gupta http://orcid.org/0000-0001-8355-1921
Gabriela Krist http://orcid.org/0000-0002-4782-6438

References

Berger, A., M. Klinkert, and P. Pawar. 2023. "Zwischen Asien und Europa: Transkulturell restaurieren und kooperieren." *Restauro* May 15. Accessed October 8, 2023. https://www.restauro.de/zwischen-asien-und-europa-transkulturell-restaurieren-und-kooperieren/.

die Angewandte. 2023. "Cultural Heritage Conservation and Management (International Joint Master Programme)." Accessed October 8, 2023. https://www.youtube.com/watch?v=Z-FY5PHBjr0.

Gupta, T., F. Marinovic, and G. Krist. 2023. "Austria and Thailand! Conservation Mode On!" *News in Conservation* 91: 56–58. Accessed October 8, 2023. https://www.iiconservation.org/system/files/publications/journal/2022/b2022_4.pdf.

Hietz, M., M. Haselberger, and G. Krist. 2022. "Joint Masters Programme *Cultural Heritage Conservation and Management*: Update." *ÖRV Journal* 15: 70.

SUIC. 2023. *SUIC's 7th International Conference Proceedings: The Megatrends Shaping Art, Business and Technology*. Bangkok: Silpakorn University.

University of Applied Arts Vienna. 2023. "Cultural Heritage Conservation and Management: Curriculum for the Joint Masters Programme." Accessed October 8, 2023. https://studien.homepage.uni-ak.ac.at/curricula/572_2020U_MA.pdf.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S153–S160
https://doi.org/10.1080/00393630.2024.2373565

ORIGINAL RESEARCH OR TREATMENT PAPER

Salvaging Art Collections in the Face of Natural Disasters: Challenges and Outcomes

Salvamento de Colecciones de Arte Frente a Desastres Naturales: Desafíos y Resultados

Suati Rojas Gutierrez[1], Adam Godijn[1] and Bianca Gonçalves[2]

[1]Department of Fine and Decorative Arts, International Conservation Services, Sydney, Australia; [2]Atelier CurArte, Rotterdam, Netherlands

ABSTRACT

A case study describes the impact on a collection of the extreme floods in eastern Australia in February 2022, and the salvaging of the Lismore Regional Art Gallery art collection. Despite predetermined protocols and preparedness efforts, the gallery suffered unprecedented flooding, requiring coordinated solutions to support emergency recovery. The project included relocating and stabilising around 1400 artworks, divided between the permanent collection and temporary exhibitions. Coordinated collaboration with stakeholders was needed to determine which artworks were salvageable; initial assessments indicated 60%. However, after further assessment this was reduced to 40% of all artworks able to be returned to a condition suitable for storage and display. The paper focuses on the assessment criteria used to prioritise artworks for salvage and conservation: insurance value, condition post-flooding, the views of living artists on display of treated works, and sentimental and community importance. It also outlines the conservation processes for flood-damaged paintings on canvas, works on paper, and photographgraphs, highlighting challenges and outcomes.

Un estudio de caso describe el impacto en una colección de las inundaciones extremas en el este de Australia en febrero de 2022 a si como también en el rescate de la colección de arte de la Galería de Arte Regional de Lismore. A pesar de los protocolos predeterminados y los esfuerzos de preparación, la galería sufrió inundaciones sin precedentes, lo que requirió soluciones coordinadas para apoyar la recuperación de emergencia. El proyecto incluyó la reubicación y estabilización de alrededor de 1.400 obras de arte, divididas entre la colección permanente y las exposiciones temporales. En evaluaciones iniciales en colaboración coordinada con las partes interesadas se determinó que 60% podia salvarse. Las evaluaciones iniciales indicaron un 60%. Sin embargo, después de una evaluación adicional, esto se redujo al 40% de todas las obras de arte que podían devolverse a una condición adecuada para su almacenamiento y exhibición. El artículo se centra en los criterios de evaluación utilizados para priorizar el rescate y conservación de las obras de arte: valor del seguro, condición posterior a la inundación, opiniones de artistas vivos en exhibición de obras tratadas e importancia sentimental y comunitaria. También describe los procesos de conservación de pinturas sobre lienzo, obras en papel y fotografías dañadas por las inundaciones, destacando los desafíos y los resultados.

ARTICLE HISTORY
Received October 2023
Accepted May 2024

KEYWORDS
Flood; natural disaster; flood-damaged paintings; flood-damaged works on paper; flood-damaged photographgraphs

Inundación; desastre natural; Pinturas dañadas por las inundaciones. as sobre papel dañadas por las inundaciones; fotografías dañadas por las inundaciones

Introduction

Australia is a continent known for its extreme climate. However, in recent years there has been a series of climate and weather events which have been more severe in intensity than in recorded history. These events, including the 2017–2019 drought, the catastrophic 2019–2020 bushfires and, most recently, the 2022 flood events of eastern New South Wales (NSW), have resulted in widespread damage to communities, the environment, and cultural heritage. Current modelling by the Bureau of Meteorology and the Commonwealth Scientific and Industrial Research Organisation (CSIRO 2022) suggests that such events are only likely to continue, but to increase in frequency, severity, and cost to communities as climate change worsens due to human activity.

In February and March 2022, eastern Australia experienced catastrophic floods. The city of Lismore with a population of c.27,000 (Australian Bureau of Statistics n.d.), nestled between the rainforest and the sea in northern NSW and situated at the convergence of two river catchments, was one of the worst affected cities. This event brought record-breaking rainfall, resulting in unprecedented flood levels, causing extensive damage and making it one of Australia's costliest floods (Satherley and May n.d.). During this event, the Lismore Regional Gallery (LRG) collection suffered severe damage to its premises and collection, despite efforts to protect it.

CONTACT Suati Rojas Gutierrez s.rojas@icsconservation.com 53 Victoria Avenue, Chatswood, 2067 Australia.
© The International Institute for Conservation of Historic and Artistic Works 2024

This paper focuses on the high-level post-flood conservation challenges. It does not go into specific details of individual treatments. The paper considers:

- triage criteria used in the immediate aftermath of the flood;
- subsequent experience of dealing with a unique collection damaged by water;
- the need for a swift response and concerted effort by public and private organisations to increase the percentage of salvageable artworks;
- some high-level treatment solutions for the unique and dominant issues encountered with works on paper and paintings.

While the LRG collection included works on paper, painting and objects, this paper will primarily discuss the treatment of works on paper and paintings. While there were many objects treated, this portion of the collection required a very different set of treatments and had distinct ensuing challenges.

Understanding the context

On 26 February 2022, Lismore experienced unprecedented rainfall, leading to its most severe floods in history. Over three days, a staggering 775 mm of rain caused the Wilson River to surge to an unprecedented 14.4 m above normal levels, surpassing the 2017 high of 12.1 m. The disaster marked Lismore's second major flood in five years (Satherley and May n.d.). The speed with which the water inundated houses and the central business district (CBD) left little time for residents to evacuate and for people to be rescued. People moved to their rooftops to escape from the water, and civilians created their own rescue groups in tiny boats. Despite efforts to rescue people during the event, ten lives were lost in the flood.

The Lismore flood caused significant damage to over 2600 homes, with over 2000 subsequently deemed uninhabitable (White and Rennie 2023). It caused severe damage to the art collection of the LRG, which was totally inundated by flood waters. This event ranks among the most devastating natural disasters in modern Australian history. According to the Insurance Council of Australia (2022) it was the third most costly, reaching an estimated 4.8 billion AUD in insured losses, while non-insured losses are still unquantified.

The flood event

The LRG was established in 1953. It is one of the oldest galleries in the Northern Rivers region in NSW, and a major cultural centre for the regional community. It housed a collection with a diverse range of 1400 artworks and artefacts, including paintings, photographgraphs, sculpture, ceramics, ethnographic materials, textiles, as well as the remarkable Hannah Cabinet – an intricate wooden masterpiece meticulously crafted by local master artisan Geoff Hannah over a span of six years.

In light of previous flooding incidents in Lismore, the LRG had developed a disaster management and flood plan. According to this plan, the ground level of the building was designated for temporary exhibitions, community events, and the Gallery shop and café. This arrangement allowed staff to quickly disassemble and relocate items to the first level in the event of a flood warning, typically provided with a minimum of three hours' notice. The permanent collection and art storage were strategically placed on the first level, which had not experienced water levels that high before in recorded history.

On 26 February, when Lismore residents received the initial flood warning, the director, LRG staff and volunteers promptly implemented their emergency plan, relocating all the artworks that were currently on display on the ground level to the first floor to safeguard the collection. However, what had not been anticipated was that the water levels would surge an additional 2.3 m, inundating the first level and the art storage area. The rising waters also triggered an electrical short circuit within the art storage area, resulting in a fire which burned until the water levels rose high enough to extinguish the flames (Figure 1).

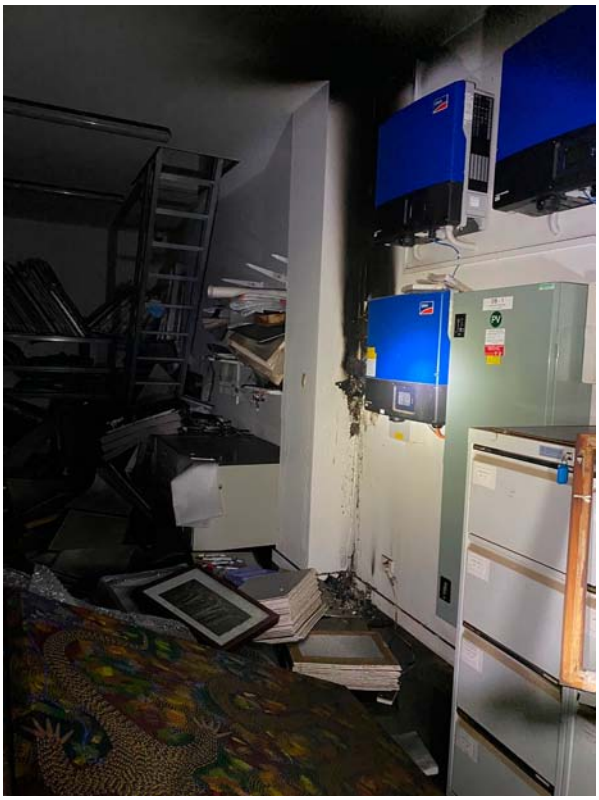


Figure 1. Evidence of fire caused by a short circuit triggered by flood water in the storage area.

The water surged rapidly and receded just as swiftly, leaving the building flood-free after 36 h.

Crisis response recovery

The day after the flood event, as soon as the building was declared safe to enter, it was discovered that the entire interior of the building was covered in muddy deposits and contaminated flood water including sewage, oil and other debris. A tragic scene was revealed of dismantled frames and stretchers, framed artworks with glazing still inundated with water, and thick layers of mud and soot on top of surfaces (Figure 2).

Urgently, a clean-up team was created, including staff members and local residents. In total, more than 350 volunteers joined during the following days to clean up and remove debris and unsalvageable materials.

The LRG was offered immediate support and assistance from the private conservation practice International Conservation Services (ICS) by sending two conservators specialising in paper and disaster recovery to plan the response and salvage measures. However, this turned out to be a challenging task given the level of mud on all surfaces and the lack of clean spaces to create a workspace to assess the artworks. There was no power, running water, food, access to basic amenities, or basic packing materials.

At that stage, the main concern was how to move the artworks out of the mud into a safe space, given the environmental conditions in the building. The temperature was 35°C with 80–90% RH, causing rapid mould growth on the artworks. A plan was devised to move the entire collection into a controlled environment where the artworks could be stabilised and properly assessed in Brisbane, 206 km to the north.

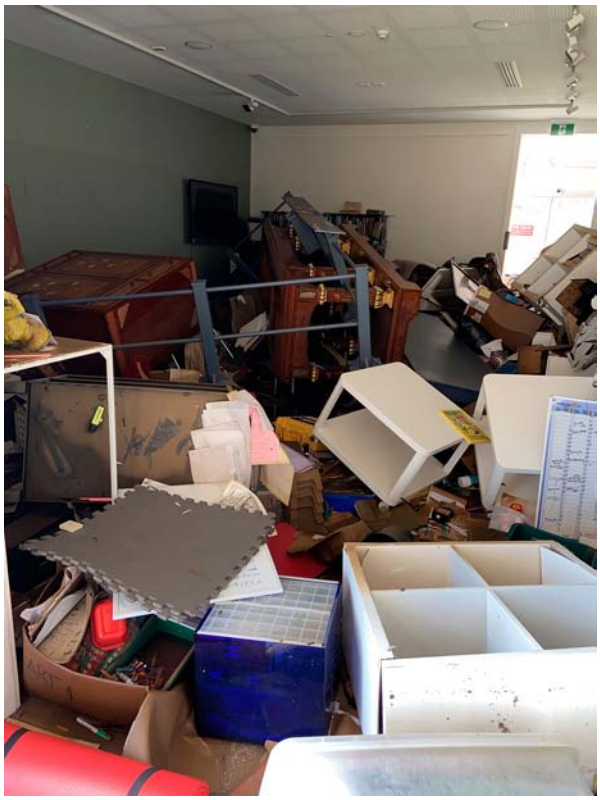


Figure 2. Damage and debris on the first level of the Gallery following flood event.

Transporting the LRG collection to Brisbane presented significant logistical challenges, including the sourcing of lifting equipment, climate-controlled trucks to safely transport the collection, and obtaining refrigerated containers at a time of exceptionally high demand. Finding cleaning and packing materials within a 200 km radius of Lismore also posed a great challenge as these had already been requisitioned.

The collection was relocated in climate-controlled trucks to Brisbane where it was placed into four 12 m long refrigerated containers maintained at 4°C to minimise mould growth. While freezing the collection was considered to stop mould and bacterial action, the idea was ultimately discarded due to concerns about potential damage to certain artworks, given their advanced state of deterioration and material composition. Moving the collection into cold storage as soon as practically possible proved to be a key process in the salvage operation, significantly slowing the mould and bacterial growth and resulting in a far greater percentage of the collection being saved.

Collection assessment

With the collection now removed from the flood zone and stabilised, the next phase required a comprehensive assessment of every artwork.

The process presented numerous challenges, the first one being identification. This could not take place in Lismore due to the need to prioritise stabilisation and mould prevention. Consequently, the registration of each artwork was deferred until after its relocation to Brisbane. The conservators were given five days to go through approximately 1400 items, which equated to an average of less than two minutes to assess each artwork. This tight deadline was determined by the budget allowed by the insurer. This initial phase served as a scoping exercise, offering insights into the extent of damage to the collection and helping to estimate the time and costs required for recovery. A framework was devised which encompassed three primary aspects (Figure 3).

To execute this systematic process efficiently, collaboration was key. A simple workflow strategy was designed. International Art Services (IAS), a company that specialises in the movement and storage of fine art, was tasked to move the artworks out of the refrigerated containers, for the administration assistants and conservators to quickly document the condition of each piece through photography, and to

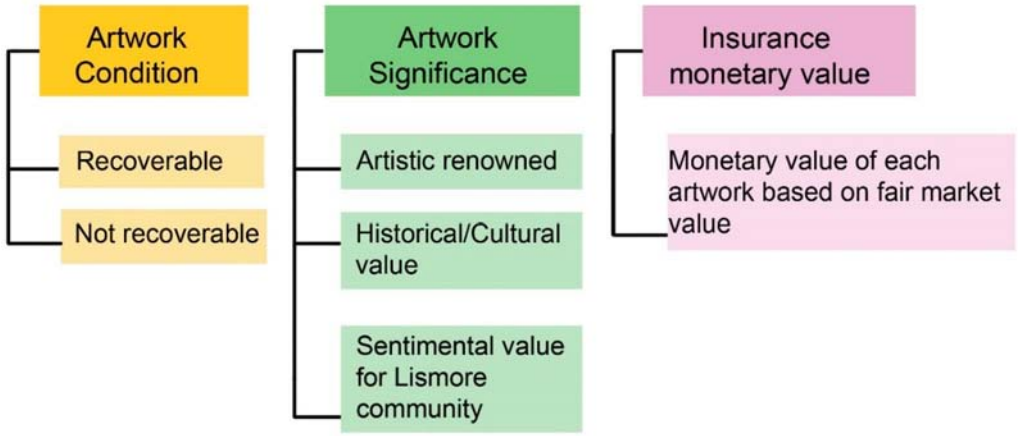


Figure 3. Values framework for assessment of the LRG collection.

assess the artworks. Simultaneously, curator Kezia Geddes undertook identification and registration, a task made challenging by missing labels, or artworks unrecognisable due to their poor condition. This was aided by LRG's database that included the entire collection, with photographic records (Figure 4).

The assessment in Brisbane revealed the extent of the damage. Large portions of the collection were fully covered in both thick layers of mud and thick soot. Many artworks were only recognisable thanks to the label on the *verso*. The smell was pungent, and many artworks were already in an advanced state of biodegradation, with surfaces covered in active mould. Paper artworks, ethnographic materials, bark paintings, and some cotton canvases were particularly affected by mould (Figure 5).

Extreme warping had already occurred to the auxiliary boards and strainers, resulting in shrunken and deformed canvases. Frames were heavily damaged by the water and the soot. Unframing was undertaken as a preventive measure, as the framing materials were damp, and hinges were failing, causing artworks to deform and mould to grow inside the window mounts. Paint surfaces were exhibiting advanced *craquelure*, blistering, and flaking media, especially on artworks with heavy impasto and acrylic-based media. Paper and photographic artworks had suffered the most due to absorbing the flood waters. Photographs printed on gelatine had either completely vanished, or were adhered to each other, or flaking.

During the assessment, the team had to quickly gauge the full extent of the damage, ascertain the treatments required for each artwork and evaluate the potential costs in comparison to the insurance value. This was problematic in that current market values were not up to date. Therefore, when the treatment costs exceeded the artwork's value, the options

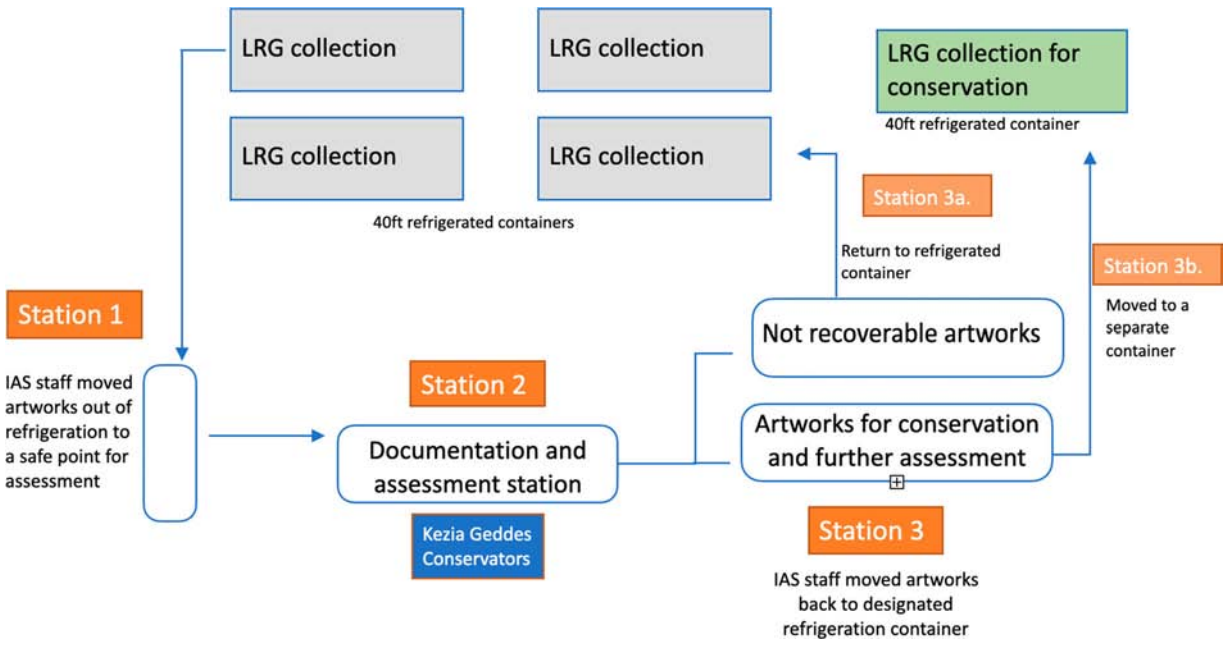


Figure 4. Workflow of initial assessment process in Brisbane.



Figure 5. (a) Initial assessment of the collection after disaster: Painting with acrylic media covered in a thick layer of soot and mud. (b) Active mould on a bark painting with ochre pigments.

were limited, as a comprehensive conservation treatment would not be feasible.

An optimistic approach was taken at this early stage. Anything with a chance of recovery, and anything significant, was kept for the next stage. The difficult decision to dispose of artworks which were definitively non-recoverable was reached collaboratively. Some of the artworks with a low monetary value, but a high significance to the community, were retained in order to undertake minimal treatment such as mould triage to stabilise them and preserve them for possible future conservation. The curator's participation during the assessment was critical, given her deep knowledge of each artwork's provenance and her grasp of its significance within the collection.

This demonstrated how important it is for conservators to understand the intangible cultural significance behind individual artworks. It is never merely a case of assessing an artwork as being either recoverable, potentially recoverable or definitely irrecoverable. Nor was an artwork included for treatment based solely on how its physical condition was presented.

Table 1 shows the classification of the total collection at the conclusion of the initial condition assessment. The contents of the initial four 12 m long

Table 1. Results of the first assessment.

Artworks	Possible recovery	Not recoverable
Paintings, ceramics, mixed media objects	200	100
Paper and photographs	516	470
Exhibition items (not part of the collection)	7	48
Textiles	11	11
Total	734	629

containers were sorted and reduced to one. These artworks were maintained at 4°C, and transported to Sydney, 9.5 h' drive south from Brisbane. The artworks deemed irrecoverable jointly by LRG and ICS and not significant to the collection were deaccessioned.

From Brisbane to Sydney's Registrar General's building (RGB)

CREATE NSW, the NSW Government's lead body for creative industries, secured a suitable space capable of accommodating the collection of affected artworks at RGB, a heritage structure located in the Macquarie Street East precinct of Sydney. While the temporary set-up had a 12-month time limit due to upcoming renovations, it provided an environment for initial drying and mould triage in a climate-controlled basement, and a clean space to undertake further assessment and conservation treatments for the collection. Adaptations were made to create a functional conservation studio.

Challenges and collaborations: salvaging the LRG collection in Sydney

Extrinsic factors to the collection and the disaster also influenced what could be conserved. The insured value of artworks posed dilemmas given each artwork was insured according to market value. On some occasions, the artworks' values had not been updated to reflect their current market value. This restricted what could be salvaged as part of the insurance claim even though recovery to an acceptable condition was feasible through treatment. If the artwork was considered significant to the collection, other solutions needed to be found.

Where artworks were considered unrecoverable or uneconomic to treat, typically a payout of the full value to the owner of the artwork would be made and ownership of the artwork would be transferred to the insurance company. LRG wished to retain full ownership of the collection to have full control of the fate of the artworks, and an agreement was made with the insurance company to ensure this.

This opportunity led to collaborative efforts with public institutions including the Art Gallery of New South Wales (AGNSW), which undertook the treatment of an additional 62 artworks that fell outside the scope of the insurance claim.

Where permanent alterations to artworks occurred, the curator felt an ethical obligation to contact living artists. The range of responses was complex. Decisions around conservation and/or retention of art involved nuanced discussions on the likely results after conservation and perceived intrinsic value of art to the community.

Notable artists saw their artworks undergo significant alterations, but only a few artists agreed to exhibit some of their pieces after the flood due to the changes which had occurred. One artist embraced some subtle changes to his artwork as something adding to the history of the work, whilst other paintings by the same artist with significant aesthetic alterations, changing the paintings' original concept, were not accepted.

Adapting treatments to challenges

Artworks arrived in staggered deliveries and were relocated to the climate-controlled basement which had high-efficiency particulate absorbing (HEPA)-filtered fans and dehumidifiers installed, to air-dry slowly. All of the paintings on auxiliary boards needed to be dried under weights as a preventive measure to control the shrinking and lifting of the media. After the artworks had dried, the team conducted a mould triage process that included dry surface cleaning with soft brush, HEPA-filtered vacuum and sponge. The artworks were then relocated to the ground floor of the RGB for further assessment and conservation treatment.

Paintings

The treatments for paintings focused on the structural stabilisation and cleaning of paint and auxiliary supports. A common issue was the pronounced shrinking of canvases, some of which had reduced their original size by 3–10 cm as a result of the warping timber strainers. Most of the original strainers needed to be replaced with new stretchers. The first step for this meant re-stretching canvases onto a temporary modular stretcher. This sought to restore the artwork's dimensions. In some cases only a few centimetres could be recovered. Some minor changes to the original size had to be accepted as more invasive stretching could have caused further deterioration to the fibres, and cracks and flaking to the media. Humidification chambers were also used to slowly reverse the warping of the affected auxiliary boards and stretchers that could not be replaced.

Other issues that were encountered included drying cracks and the lifting and blistering of paint. There were also issues with changes to colour due to ingrained mud, soot and the chemical reactions that occurred as a result of the fire and flood water. In both instances, innovative solutions were implemented to treat these issues. For example, in regard to the lifting and blistering of paint, rigid agarose gels were used to soften and flatten the affected paint instead of the standard practice of



Figure 6. (a) Details of agarose rigid gel application to reduce blister deformations in oil-based paint. (b) Varnish removal by gently softening and detaching from oil paint using low-tack tape.

heat applications. This proved to be very effective. Similarly, when the paint was too sensitive for aqueous cleaning, rigid agarose gels were again applied to reduce water penetration to the support and to afford greater control of the cleaning agent (Figure 6(a)).

Another issue that was encountered was the blanching of varnish layers and the bonding of varnish to the paint. In the majority of the cases, the paint was friable and extremely sensitive. In cases where the paint and varnish had bonded it became impossible to remove the varnish via swab, scalpel, solvents or gels. Again, innovative treatment methods were implemented with the varnish layer gently reactivated by applying solvent on Evolon® fabric for short periods of time, between 10 and 30 s. The varnish layer was then gently lifted using low tack adhesive tape (Figure 6 (b)). This unorthodox method proved to be very effective, with minimal effects to the paint surface.

Works on paper

Following the flood, the majority of works on paper were covered in biofilm, mud and oil residues. Extensive mould growth and staining from mud were present in 80% of the artworks in the collection. Severe creases, deformations and shrinking of the fibres created challenges for treatments. In some instances, bleeding and smudging of media had permanently transformed the artwork's appearance. The damage incurred made washing extremely difficult. Again, uncommon methods were implemented to treat the affected works on paper. Some of the treatments included:

- Use of surfactant Ecosurf® H9 in a poultice with sodium bicarbonate to remove difficult stains from organic matter. This method proved successful in the removal of mud stains, oil and biofilm residues which allowed penetration of water to the paper support during washing. This method was based on unpublished research by Australian conservators Briony Pemberton and Freya Merrell.
- The use of tension drying for severely creased artworks. This became a very important method for flattening the works on paper. In some cases, this had to be repeated multiple times to achieve results.
- Mould stains were reduced using a 0.5% diethylenetriamine penta-acetic acid solution.
- Mud residue was removed by warm water immersion washing. This combined with gentle brushing of the paper surface while the artwork was submerged led to generally positive outcomes, however, not all the stains could be removed with this method.
- Photographs on gelatine and paper coated with plastic film suffered severe cockling but this could be considerably reduced with controlled heat on a conservation hot table.

These issues underscore the complexity of conserving flood-affected collections and the benefits of being flexible and innovative in conservation approaches. Interestingly several permanent alterations to the artworks, which could not be reversed, had to be embraced as integral elements of their historical narrative.

Conclusion

Natural disasters in Australia and the Lismore flood event of 2022 in particular serve as a stark reminder of the immediate impacts of climate change on cultural heritage. The event itself, despite extensive disaster preparedness by the LRG, was on a greater scale than had ever been envisaged, and totally immersed the collection. This in turn required an unprecedented response to salvage as much of the collection as possible. So, the first lesson from this case study is that disaster preparedness planning in institutions such as LRG which is situated in a flood-prone area needs a major rethink. Since the event, the NSW government and the Australian Institute for the Conservation of Cultural Material have together published resources for emergency response and guidelines for salvaging water-damaged collections for museums and galleries (NSW Government 2024).

Disaster planning in the face of climate change requires adaptable methodologies, which will allow institutions to have flexible frameworks for responding to natural disasters. In the case of LRG, the plan needs to prepare for a situation which is substantially worse than the previous record flood height and more extreme in both its speed of arrival and intensity, reflecting the trend amongst general climate change weather events. However, the only way to fully mitigate future flooding and damage to the collection would be the complete relocation of the gallery to a safer site away from flood-prone areas. Given this, as the LRG is still not considered safe from further damaging weather events, all the conserved artworks are now being temporarily stored at the more recently built institution, Home of the Arts, located on the Gold Coast in Queensland, Australia. The date of their return to Lismore is, at the time of writing, unknown.

Having stabilised the collection for assessment, the process of assessing can be a challenging one. A big lesson from the Lismore project has been the complexity of developing selection criteria, which need to include condition, feasibility of return to displayable condition, insured value, emotional attachment and personal relationships with artworks, the views of living artists, and the local community. Similarly, another learning opportunity has been the importance of cultural institutions maintaining and/or updating regularly their collection inventory with monetary value (market price), as well as the historic and cultural

Table 2. Number of artworks recovered after conservation treatments.

Description	Number of artworks recovered
Paintings, ceramics, mixed media objects	198
Paper and photographs (Including those reprinted)	635
Exhibition items (not part of the collection)	7
Textiles	9
Total	849

value of each piece of the collection. It is also essential to acknowledge the potential for fallibility or bias in such scenarios. Ideally, a comprehensive assessment of significance (Jernæs 2021) for all artworks would be carried out, ensuring that each piece receives the attention it deserves.

One factor that contributed to the recovery of a high percentage of the artworks was their immediate refrigeration and relocation into a climate-controlled environment. This considerably mitigated mould growth and bacterial activity.

Finally, having selected those artworks which could be conserved, the project provided the opportunity to develop a range of specialised techniques to treat the paintings and works on paper. Some techniques briefly mentioned in the paper could be of value when dealing with flood-immersed artworks.

This paper has been written from the perspective of the conservator. Whilst the treatment of the LRG collection and the development of particular techniques to achieve this were the work of conservators, reaching decisions on which artworks to treat and the extent of treatment were very much collaborative processes working closely with LRG staff. An event such as the Lismore flood underscores the importance of consulting artists, curators and collections management teams for preserving art, as well as understanding community values. Conservators play a pivotal role in protecting and recovering a community's heritage, with post-disaster decisions guided by empathy and support, balancing the artwork's cultural significance with its monetary value.

Table 2 shows how many artworks, including reprinted photographgraphs, the conservation team was able to save and return to temporary storage. Appendix 1 gives additional resources for emergency response and disaster recovery.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Australian Bureau of Statistics. n.d. *Lismore (NSW) 2021 Census all Persons Quick Stats*. Accessed 1 October 2023. https://abs.gov.au/census/find-census-data/quickstats/2021/UCL112012.

CSIRO. *State of the Climate* 2022. Accessed 1 October 2023. https://www.csiro.au/-/media/OnA/Files/SOTC22/22-00220_OA_REPORT_StateoftheClimate2022_WEB_221115.pdf.

Insurance Council of Australia. 2022. 2022 *Flood Now Third Costliest Natural Disaster Ever*. Accessed 6 October 2023. https://insurancecouncil.com.au/resource/2022-flood-now-third-costliest-natural-disaster-ever/.

Jernæs, N. K. 2021. "A Roadmap for Making a Salvage Plan. Valuing and Prioritising Heritage Objects." *International Journal of Disaster Risk Reduction* 59: 102266. https://doi.org/10.1016/j.ijdrr.2021.102266

NSW Government. 2024. *Salvaging and Conservation Advice for Flood Damaged Collections*. Accessed 20 March 2024. https://www.nsw.gov.au/arts-and-culture/engage-nsw-arts-and-culture/resource-hub/advice-flood-damage.

Satherley, T., and D. May. n.d. *Natural Disasters and Climate Risk*. Accessed 3 October 2023. https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/BriefingBook47p/NaturalDisastersClimateRisk.

White, L. and E. Rennie. 2023. *In Harm's Way*. Accessed 3 October 2023. https://www.abc.net.au/news/2023-02-27/have-lessons-been-learned-from-2022-lismore-flood-disaster/101863278.

Appendix 1. Additional emergency planning and response to flood events references

AICCM. 2022. *FLOOD*. https://aiccm.org.au/disaster/flood/.

AICCM. 2023. *2024 Disaster Preparedness Calendar*. https://aiccm.org.au/disaster/disaster-preparedness-calendar/.

Dorge, V. and S. L. Jones. 2004. *Creación de un Plan de Emergencia: Guía para Museos y Otras Instituciones Culturales*. Los Angeles: Getty Conservation Institute. https://www.getty.edu/conservation/publications_resources/pdf_publications/pdf/emergency_sp.pdf.

ICCROM. 2018. *First Aid to Cultural Heritage in Times of Crisis*. Accessed March 2024. https://www.iccrom.org/sites/default/files/2018-10/fac_handbook_print_oct-2018_final.pdf.

ICMS and ICOM. 2010. *Manual de Procedimiento de Emergencia*. Edited by W. Hekman. https://icms.mini.icom.museum/wp-content/uploads/sites/57/2018/12/Spanish.pdf.

Söderlund Consulting Pty Ltd. 2000. *Guidelines for Small Museums Writing a Disaster Preparedness Plan*. Canberra: Heritage Collections Council. https://blueshieldaustralia.org.au/wp-content/uploads/2018/03/CAN-Be-Prepared.pdf.

UNESCO and ICCROM. 2016. Endangered Heritage: Emergency Evacuation of Heritage collections. https://www.iccrom.org/sites/default/files/Endangered-Heritage_0.pdf.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S161–S168
https://doi.org/10.1080/00393630.2024.2375151

ORIGINAL RESEARCH OR TREATMENT PAPER

OPEN ACCESS Check for updates

Hygrothermal Performance of Enclosures in a Storage Room and Energy Efficiency in Environmental Control

Comportamiento Higrotérmico de Cerramientos en un Almacén y Eficiencia Energética en el Control Ambiental

Bo Han[1], Fan Wang [1], Julie Bon[2], Linda MacMillan[2] and Nick Taylor[1]

[1]School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University, Edinburgh, UK; [2]National Library of Scotland, Edinburgh, UK

ABSTRACT

This study aims to provide energy-efficient strategies for collections care in the face of financial and environmental challenges. Focusing on paper-based enclosures in storage rooms, the research proposes strategies to enhance energy efficiency by relaxing tight environmental controls. The five-stage process began with a standard test of hygrothermal properties and buffering capacity of the enclosures. In the second stage, a computer model was developed using the first stage results. This model was used in a series of specially designed tests simulating the transient heat, air, and moisture transfer between the room and enclosure to determine an acceptable room environment in which the enclosure conditions could meet collections care standards. The modelling results were used, in the third stage, to develop an AI model that predicted the enclosure conditions using room temperature and relative humidity (RH) inputs. In the final stage, a model for energy consumption of air-conditioning system operations was developed to predict across various control accuracies. Results indicate that the tight maintenance of room RH levels can be relaxed from 47–53% to 33–65%, with a corresponding reduction in energy consumption of approximately 16–18%. This relaxation, while maintaining enclosure conditions in line with conservation standards, was demonstrated through a simulation case at the National Library of Scotland. This study underscores the broader applicability of the developed procedure, asserting its relevance for cultural institutions seeking energy-saving potential through customized enclosure models.

Este estudio tiene como objetivo proporcionar estrategias energéticamente eficientes para el cuidado de las colecciones frente a los desafíos financieros y ambientales. Centrándose en los recintos de papel en las salas de almacenamiento, la investigación propone estrategias para mejorar la eficiencia energética al relajar los estrictos controles ambientales. El proceso de cinco etapas comenzó con una prueba estándar de las propiedades higrotérmicas y la capacidad amortiguadora de los recintos. En la segunda etapa, se desarrolló un modelo informático utilizando los resultados de la primera etapa. Este modelo se utilizó en una serie de pruebas especialmente diseñadas para simular la transferencia transitoria de calor, aire y humedad entre la habitación y el recinto para determinar un entorno ambiental aceptable en el que las condiciones del recinto pudieran cumplir con los estándares de cuidado de las colecciones. Los resultados del modelado se utilizaron, en la tercera etapa, para desarrollar un modelo de IA que predijo las condiciones del recinto utilizando entradas de temperatura ambiente y humedad relativa (RH). En la etapa final, se desarrolló un modelo para el consumo de energía de las operaciones del sistema de aire acondicionado para predecir varias precisiones de control. Los resultados indican que el estricto mantenimiento de los niveles de humedad relativa de la habitación se puede relajar del 47 al 53% al 33 al 65%, con una reducción correspondiente en el consumo de energía de aproximadamente el 16 al 18%. Esta relajación, mantienendo condiciones del recinto de acuerdo con los estándares de conservación, se demostró mediante un caso de simulación en la Biblioteca Nacional de Escocia. Este estudio subraya la aplicabilidad más amplia del procedimiento desarrollado, afirmando su relevancia para las instituciones culturales que buscan potencial de ahorro de energía a través de modelos de cerramiento personalizados.

ARTICLE HISTORY
Received October 2023
Accepted June 2024

KEYWORDS
Energy efficiency; storage enclosure; environmental control; preventive conservation

Eficiencia energética; recinto de almacenamiento; control ambiental; conservación preventiva

CONTACT Fan Wang fan.wang@hw.ac.uk School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University, Edinburgh EH14 4AS, UK; Julie Bon j.bon@nls.uk National Library of Scotland, Edinburgh EH1 1EW, UK

© 2024 Crown Copyright. Reproduced with the permission of the Controller of [His Majesty's Stationery Office/King's Printer for Scotland] and [Collections Care & Estates]
This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (http://creativecommons.org/licenses/by-nc-nd/4.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

Introduction

Throughout Europe, numerous heritage collections are housed within historic buildings with significant cultural value (Bülow, Colston, and Watt 2002). Preserving these collections, while enhancing operational energy efficiency, poses a considerable challenge. Implementing changes to the construction of existing historic buildings is often a complex undertaking. Alongside this, collections care professionals are challenged to safeguard cultural heritage without risking the natural environment. Passive environmental control emerges as a viable option to effectively mitigate carbon emissions while preserving stored heritage collections (Bohm et al. 2001). National Library of Scotland is working to achieve the Scottish Government's Net Zero strategy 2045 (Net Zero Scotland 2019).

The studies reviewed show the potential for energy saving through passive environmental control. The buffering effect of six common storage enclosures (cardboard and plastic polypropylene boxes, mobile rack of shelves, some drawers with tight sealing or non-sealing) is found to be associated with reduced environmental fluctuations inside the enclosures, especially regarding the relative humidity (RH) in an *in situ* test (Rojas, Cabrera, and Corona 2020). The buffering effect, due to the 'box in box' configuration, is recommended to relax the tight environmental control in a theoretical study (Perino 2018). Relaxing the control band from 48–52% RH to 40–60% RH was predicted to yield a saving of about 40% of annual energy in a museum in a computer modelling study (Ascione et al. 2009).

These studies show that there are three separate topics: the buffering effect of the enclosure, the feasibility of relaxing the tight control, and the potential for energy saving, all with the same aim of sustainable collections care. However, there is a lack of integration to combine these three topics. An integration study, from modelling the buffering effect and hygrothermal interaction between macro-environment in the room and micro-environment in the enclosure to predicting energy consumption under various levels of control accuracy, could allow for fine-tuning of control to explore the relationship among control accuracy, micro-environmental conservation quality, and consequent energy consumption.

The enclosures in the National Library of Scotland were folded with one piece of acid-free cardboard, with full lengths overlaid on three sides when closed (Figure 1). The acid-free cardboard, with a thickness of 1.14 mm, was purposely fabricated in three layers of polypropylene and contains ground calcium carbonate and cotton pulp supplied by (Klug Conservation 2023).

In our previous experimental study (Han et al. 2024), we measured hygrothermal properties of the cardboard and buffering capacity of the enclosure, with preliminary results supporting the research presented in this paper. Measured properties include thermal diffusivity, specific heat, equilibrium moisture content, water vapour diffusion resistance coefficient, and water vapour diffusion coefficient. They were used in creating a numerical model to simulate transient heat air moisture (HAM) transfer between the micro-environment and macro-environment. Additionally, the tested enclosure was intentionally left empty to measure its actual capacity without any interference from the contents. The results provided validation data for the heat, air and moisture (HAM) model, quantified the buffering capacity of the enclosure, and demonstrating its ability to effectively mitigate the micro-environmental temperature and RH fluctuations. This finding forms the basis for relaxing the macro-environmental control. Specifically, for temperature fluctuations of 5°C within the range of 17–22°C and constant 50% RH over a period of <180 min, the micro-environmental fluctuations were 1–2°C smaller than the macro-environmental ones. Similarly, for humidity fluctuations of 10% RH within 50–60% RH and a fixed temperature of 20°C over a period of <600 min, the micro-environmental fluctuations were 2–8% RH smaller than macro-environmental ones.

Based on the outcomes of our experimental study, this study aims to improve energy efficiency by relaxing the tight macro-environmental controls while the micro-environment complies with conservation standards. There are three objectives. The first is to model the transient (HAM) transfer between the micro-environment and macro-environment, sequentially, to determine an acceptable macro-environment when the micro-environment complies with collections care standards. The second is to develop a real-time prediction model as an agent of the transient HAM simulation. Finally, the third objective is to predict energy consumption at various levels of control accuracy.

Methodology

Figure 2 illustrates a three-stage approach, detailed in an accompanying methodological framework. Leveraging findings from the previous experimental study, it provided hygrothermal properties of cardboard enclosures and buffering capacity test data for HAM model creation and validation, respectively. In the first stage, the HAM model was created by using commercial software, COMSOL Multiphysics. Sequentially, this model was used to determine an acceptable macro-environment for implementing the relaxed control. In the second stage, an artificial neural network (ANN) model was trained using data from the HAM simulation, covering various typical macro-environmental conditions. This model enabled

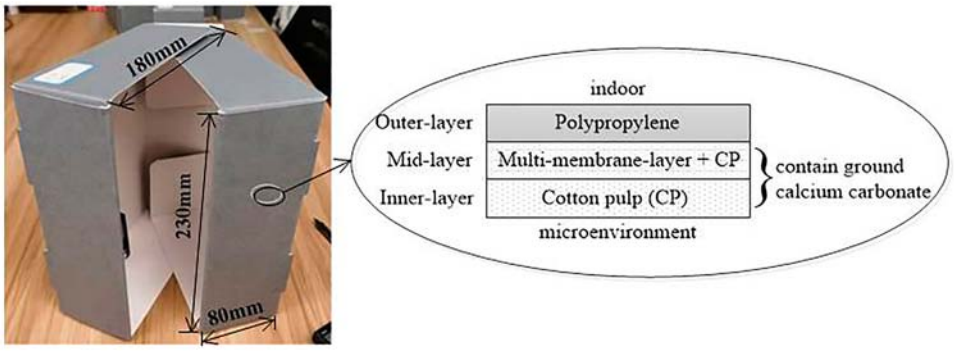


Figure 1. Enclosure sample and associated structure of its fabric.

real-time prediction of micro-environment. In the third stage, an energy consumption model was developed using the transfer-function mathematical method to describe the operational characteristics of the air-conditioning system. This model provided energy consumption predictions across various control accuracies.

HAM simulation model

Figure 3 illustrates a 2D cross-section of the enclosure in the simulation model, setting an 80 mm depth in the orthogonal direction. The thickness of cardboard is 1.14 mm. There are two 2 mm gaps. An airflow velocity of 0.2 m/s was set on the external surface of the enclosure, oriented orthogonally. This velocity aligns closely with values typically observed in on-site measurement. Natural flow through the gaps was simulated using an open boundary, with the airflow considered weakly compressive, given that air density primarily depends on temperature. The time-series macro-environmental temperature and RH were used as boundary condition surrounding the enclosure.

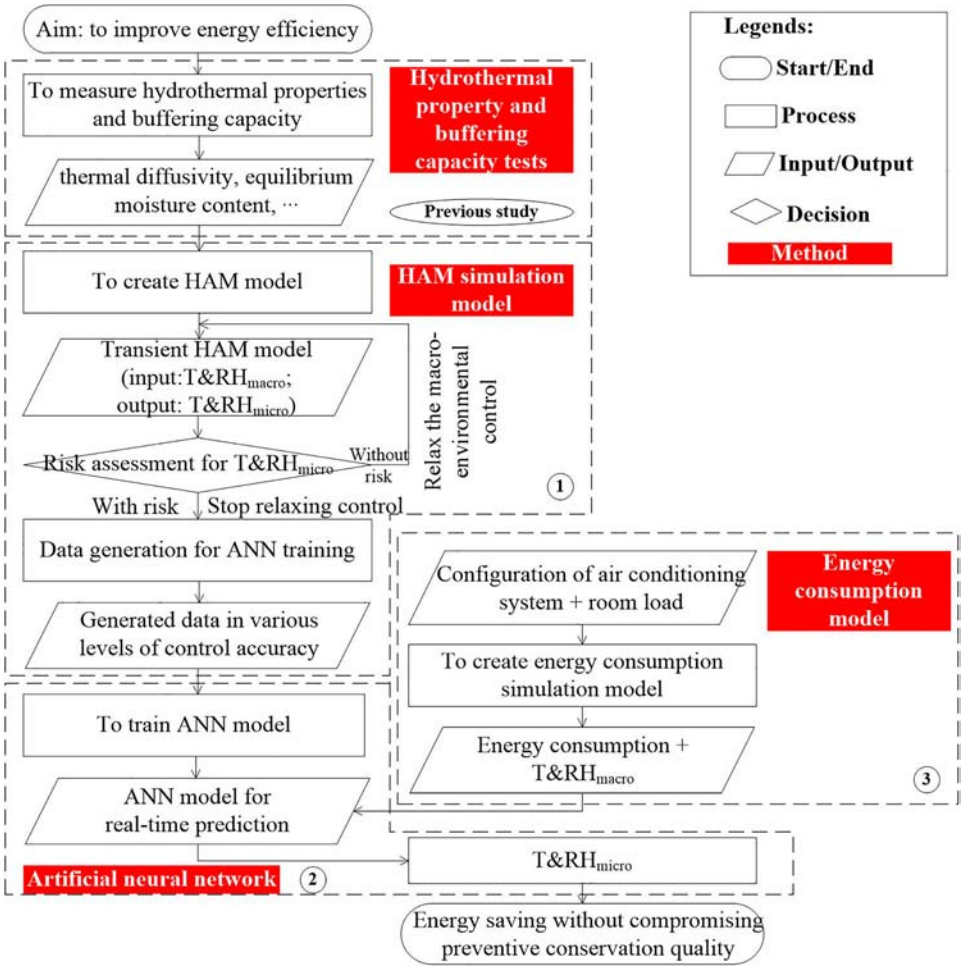


Figure 2. Methodological framework.

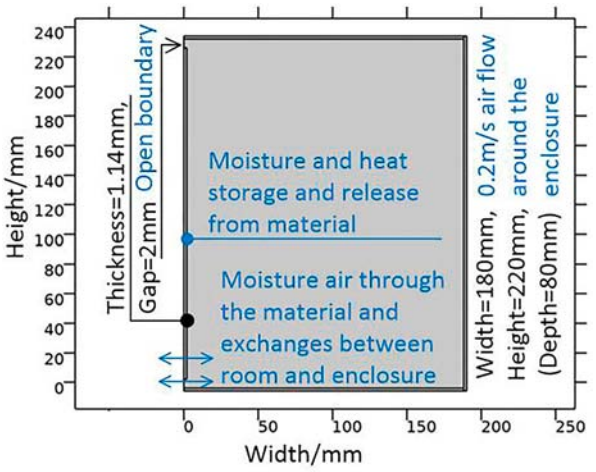


Figure 3. Diagram of HAM transfer between room and enclosure.

The HAM model describes the interdependence of heat air and moisture transfer, encompassing heat and moisture balance, heat and air convection balance, and heat and air convection balance. Table 1 displays the hygrothermal properties of the cardboard, as measured in the preceding study by Han et al. (2024). In this context, to present the equilibrium moisture content (EMC) in modelling, the associated date previously measured within 15–25°C and 33~75% RH was fitted to obtain a function, $EMC = f(T, RH)$.

The associated validation data were collected in both tight and relaxed control conditions to ensure that this model was robust enough to reproduce the HAM transfer in this research. Testo 174H temperature and humidity loggers (range: −20 to 70°C, 0–100% RH; accuracy: ±0.5°C, ±3% RH) were used to measure the micro and macro environment. The sampling interval was 15 min for both the tight and relaxed control.

The HAM simulation is highly time-consuming, typically running in hours, so it is not possible to use it in the air conditioning system with a feedback control loop operated on a scale of minutes. It is necessary to create an agent model to predict the micro-environmental temperature and RH in real time. Based on the onsite temperature and RH data collected in tight macro-environmental control, four sets of data were generated to represent four conditions in broadened control bands. Sequentially, they were fed into the HAM model for calculating the micro-environmental data. The micro-environmental and macro-environmental data were respectively used as input and output to train the agent model, ANN.

ANN

The training data is formed of a sequence of features over a set period rather than independent data points. Learning to store effective information within a time sequence is a challenge for common ANNs. Long short-term memory (LSTM) network, a type of sequence-to-sequence ANN, was designed to overcome this challenge (Hochreiter and Schmidhuber 1997). The LSTM block effectively manages memory by leveraging the input gate, forget gate, and output gate to control the flow of information, ensuring the capture and retention of relevant data in sequence (Yu et al. 2019).

Five sets of data represent the macro and micro environments, spanning from tight control to relaxed control within the qualified condition for preventive conservation. One dataset was from on-site test, representing the tight control condition, while four sets of simulation data was generated by HAM simulation, representing various levels of relaxed control conditions. Together, these five datasets form a comprehensive data package that captures crucial features of transient HAM transfer between micro and macro environments. In this data package, the input of the LSTM was macro-environmental temperature and RH, and the target output was the corresponding micro-environmental temperature and RH. The training dataset was divided into two parts; train set (the first 90% data) and test set (the remaining 10% data) (Arslan and Sekertekin 2019; Granata, Di Nunno, and de Marinis 2022). Data normalization was used in data processing to avoid distorting differences in the ranges of values (Salem et al. 2022). Table 2 shows the structure and parameters of the LSTM network. The ANN training was run on a common computer equipped with a 1.6 GHz CPU and 16GB RAM.

Energy consumption model

The energy consumption model included three parts: controller, normal HVAC components (cooling coil connected with chiller, electric heater, and electric steam humidifier), and room. This model was developed in MATLAB/Simulink. The controller used a common ON/OFF control method for obtaining quasi-continuous output. Its signal includes a series of pulses produced on a fixed period (τ) and controls the ON time (τ_{ON}) of the pulses for all components (Salsbury 2002). The mathematical model is given as Equations (1)–(2).

$$\varphi(k\tau) = \frac{\tau_{ON}}{\tau} \tag{1}$$

Table 1. Material properties.

Property	Value	Property	Value
Density	6.62×10^2 kg/m^3	Heat capacity at constant pressure	1.032×10^{-3} kJ/(kg.K)
Thermal conductivity	0.055 W/(m·K)	EMC	[EMC = $(0.01547 - 0.0006 \times T + 0.00124 \times RH) \times 6.62 \times 10^{-7}$] kg/m^3
Diffusion coefficient	1.485×10^{-10} m^2/s	Vapour resistance factors	144.48 (inward)/46.78 (outward)

Table 2. The structure and parameters of the LSTM network.

No. of layer	Name of layer	Parameters	Values
1	Input layer	Input size	2
		Minimum sequence length	1
2 & 3	LSTM layer	Number of neurons	(200, 200)
4	Dropout layer	Probability of dropping out input elements	0.1
5	Fully connected layer	Output size	2
6	Regression layer	Loss function	Mean squared error

The input to the system is given as

$$u(\tau) = \begin{cases} 1, & k\tau \le \tau < k\tau + |\varphi(k\tau)|\tau \\ 0, & \tau \ge |\varphi(k\tau)|\tau \end{cases} \quad (2)$$

where φ is the percentage of duty ratio, $u(\tau)$ is the input signal, k is the sample number. Normally, these parameters are tuned by the manufacturer.

The component and room models describe the response characteristics for the HVAC equipment and the room hygrothermal behaviour. All mathematical descriptions use transfer functions that represent a system's input-output relationship (Afram et al. 2018).

A 100m^2 inner storage room, without any external windows or doors, on an intermediate floor was used for the simulation. This storage room was a typical case representing the library's strongroom. Historical building performance information was in reference to an ARUP (2017) industrial report. The U values are 0.15, 0.75 W/m^2·K for wall and floor. Room loads were calculated based on four typical days of the dataset (hourly temperature and RH fluctuations: about ≤±2~4°C and ≤±8–21% RH) which represents the feature of four seasons for this storage room in Edinburgh. The control levels were set at ±0.5°C, ±3% RH (tight control), ±2°C, ±10% RH, and ±3°C, ±16% RH (relaxed control).

Results and discussion

Figure 4 illustrates a comparison between measured and simulated microenvironmental temperature and RH. In tight control, absolute errors are <2.5% RH and <0.5°C; in relaxed control, <2% RH and <0.2°C. Simulated trends align closely with measured data, affirming a high accuracy of the HAM model in capturing heat, air, and moisture transfer between micro- and macro-environments.

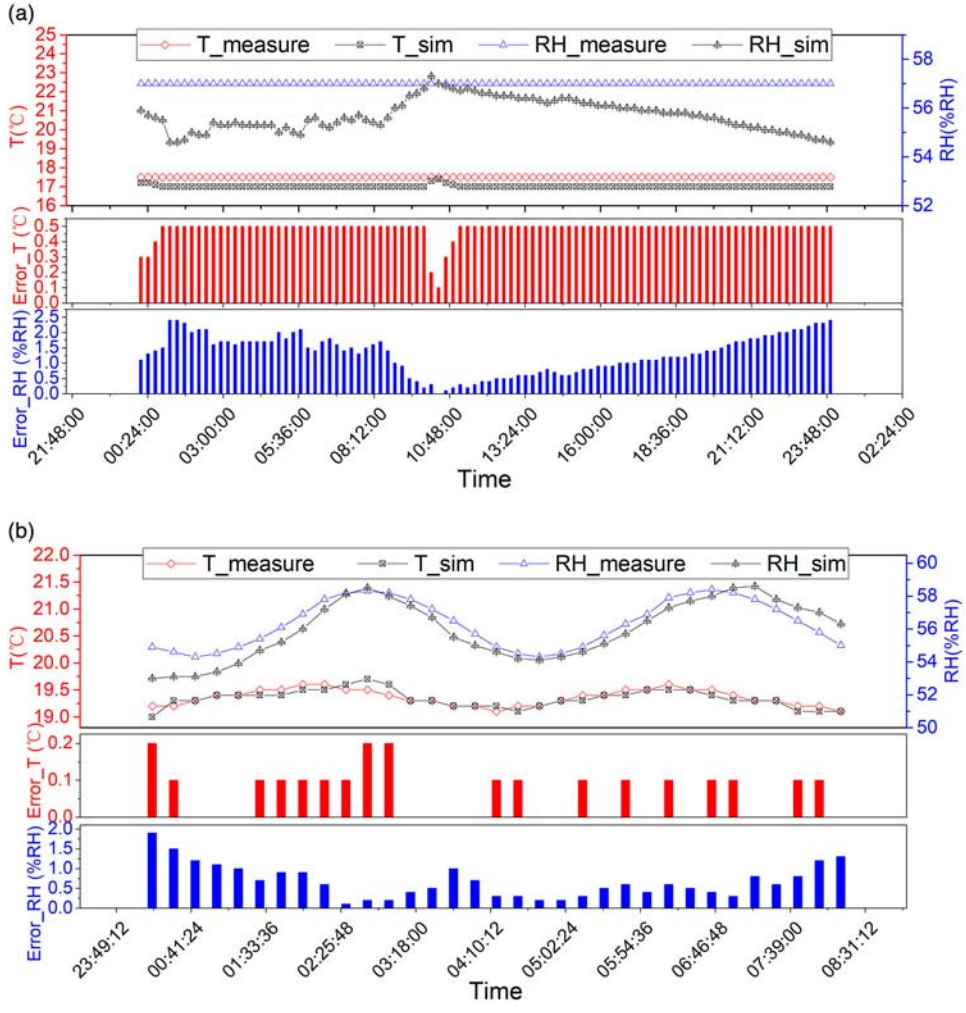


Figure 4. Comparison between measured data and simulated data in micro-environment.

Table 3. The results of relaxing the environment.

		This study	Standard
Macro	Band	33–65% RH	40–60% RH
	24 h fluctuation	±16% RH	±10% RH
Micro	Band	43–57% RH	
	24 h fluctuation	±9% RH (98% of time: <±5% RH; 2% of time: ±5–9% RH)	

In addition, as illustrated in Table 3, the macro-environmental RH can be relaxed to 33∼65% RH control band with ±16% RH fluctuation over 24 h in the most relaxed condition. Meanwhile, the micro-environmental RH can be maintained in 43–57%RH with <±9% RH fluctuation over 24 h (<±5% RH for 98% of the time). This micro-environment complies with the industrial standards outlined in BS EN 16893 (2018) and the ASHRAE Handbook (2019), which recommend a control band of 40–60% RH with a fluctuation over 24 h of ±10% RH. Therefore, this study suggests there is the potential to relax the currently tight macro-environmental controls. As the conservation sector seeks to develop sustainable environmental parameters, the results of this study demonstrate that it is possible to relax macro-environmental controls without compromising the preventive conservation quality in the micro-environment. However, the theoretical model developed here would need to be adapted and modified to fit the specific nature of different buildings, collections, and storage environments. The crucial aspect here lies in integrating the passive air-conditioning offered by the enclosure with the active air conditioning supplied by the mechanical system, aiming to enhance energy efficiency while maintaining control over the micro-environment.

Within the acceptable macro-environment, the ANN can accurately forecast the 24-hour micro-environmental temperature and RH, thereby ensuring the maintenance of a high-quality preventive conservation standard. Table 4 shows the performance results of the LSTM network. All values of R^2 (coefficients of determination) are close to 1 and the values of *MSE* (mean square error), *RMSE* (root mean square error), *MAE* (mean absolute error) and SD (standard deviation of the errors) are near 0. High precision shows in both training and testing data, which indicates the trained network has a good generalization performance without underfitting (insufficient training to capture data feature) and overfitting (overtraining to capture excessive data feature) problems. Moreover, the temperature errors are smaller than ±0.2°C and ±0.1°C while the RH errors are smaller than ±3% RH and ±2% RH in training and testing data, respectively. In addition, the prediction time was less than 5 s for daily data (96 samples with 15 min interval in 1.6 GHz CPU with 16GB RAM). Therefore, it is an accurate real-time prediction model for relaxing tight macro-environmental control.

Based on the data presented in Table 5, relaxing the control accuracy can lead to a decrease in energy consumption. In a 100 m² storage room within a historical building, equipped with a cooling chiller, electric heater, and humidifier, the macro-environmental control accuracy was relaxed from ±0.5°C and ±3% RH to ±2 °C and ±10% RH (relaxed control 1), then to ±3 °C and ±16% RH (relaxed control 2). As a result, energy savings range from 5.4 to 32.3 kWh and 5.8 to 33 kWh, with associated energy-saving ratios of 15.9–18.5% and 17.1–18.9% for these two relaxation levels, respectively. Such degree of energy saving is achievable with the common air-conditioning system operating in Edinburgh's moderate climate. Importantly, this

Table 4. Performance results of the LSTM network.

	R^2	RMSE	MSE	MAE	SD
Training data (temperature)	0.9974	0.006237	3.88E-05	0.0014	0.0409
Training data (RH)	0.9304	0.003087	9.53E-06	0.04	0.6765
Testing data (temperature)	0.9812	0.002136	4.56E-06	0.0062	0.0186
Testing data (RH)	0.9074	0.002675	7.15E-06	0.1518	0.7435

Table 5. Daily energy consumption in tight and relaxed control.

Seasons	Spring	Summer	Autumn	Winter
Hourly ambient fluctuations	≤±2°C and ±21% RH	≤±2 °C and ±16% RH	≤±3 °C and ±17% RH	≤±4 °C and ±8% RH
Tight control, SC, (±0.5 °C,±3% RH), [kWh]	109.5	36.9	34	174.4
Relaxed control 1 (±2 °C,±10% RH), [kWh]	91.3	30.3	28.6	142.2
Energy saving (percentage decrease compared to the SC), [kWh]	18.2 (16.6%)	6.6 (17.8%)	5.4 (15.9%)	32.2 (18.5%)
Gradient of energy saving potential, [kWh/°C for T, kWh/% RH for RH]	12.1 (T)/2.6 (RH)	4.4 (T)/0.9 (RH)	3.6 (T)/0.8 (RH)	21.5 (T)/4.6 (RH)
Relaxed control 2 (±3°C,±16% RH), [kWh]	89.1	28.9	28.2	141.4
Energy saving (percentage decrease compared to the SC), [kWh]	20.4 (18.6%)	7.0 (18.9%)	5.8 (17.1%)	33.0 (18.6%)
Gradient of energy saving potential, [kWh/°C for T, kWh/% RH for RH]	8.2 (T)/1.6 (RH)	2.8 (T)/0.5 (RH)	2.3 (T)/0.4 (RH)	13.2 (T)/2.5 (RH)

Note: (1) Hourly ambient fluctuations are the differences between maximum and minimum in any 1 h period. Because of building envelopes, associated indoor fluctuations are smaller than the ambient ones. (2) Gradient of energy saving potential is defined as the following equation,

$$\text{Gradient} = \frac{\text{Energy saving}}{(\text{Control accuracy}_{\text{relaxed control}} - \text{Control accuracy}_{\text{strigent control}})}.$$

relaxed control strategy is applicable across diverse system configurations, buildings, and climate zones. It unlocks opportunities for implementing highly efficient measures previously restricted by stringent environmental control demands. For instance, it would facilitate the adoption of sensible and latent heat recovery ventilation and the substitution of traditional cooling dehumidification with desiccant wheel.

In addition, gradients of energy-saving potential range from 3.6 to 21.5 kWh/°C and 0.8 to 4.6 kWh/% RH between tight control and relaxed control 1, and from 2.3 to13.2 kWh/°C and 0.4 to 2.5 kWh/%RH between tight control and relaxed control 2. It is worth noting that the energy-saving potential significantly diminishes when the control accuracy is relaxed beyond ±2 °C and ±10% RH (relaxed control 1), which is attributed to building performance and ambient fluctuations in this simulation case. Hourly ambient fluctuations typically range from ≤±2 °C and ±21% RH in spring to ≤±4 °C and ±8% RH in winter, hovering around ±2 °C and ±10% RH per hour on average. Although relaxed control 2 allows for setting of ±3 °C and ±16% RH, the macro-environmental fluctuations were generally more stable than the set values. Compared to this simulation case, greater potential for implementing the relaxing control lies in conditions characterized poor-performance buildings and large ambient fluctuations. However, when employing the relaxing control in specific scenarios, it needs tuning with passive micro-environmental control inside the enclosure with active macro-environmental control in the storage room.

Conclusions

In this paper, the hygrothermal property of the enclosure was tested for HAM model development and the temperature and RH in the micro-environment and macro-environment were collected for model validation. The model can reproduce the HAM transfer between micro-environment and macro-environment accurately. Based on the HAM simulation, an acceptable macro-environment was determined when the micro-environment complies with collections care standards. The macro-environment can be relaxed to 33–65% RH control band with ±16% RH fluctuation in 24 h in the most relaxed condition. The LSTM network was proposed to achieve real-time predictions by training input and output data from the simulation. In addition, the energy consumption model simulated the system operation in various levels of control accuracy and proved a reduction in energy consumption by approximately 16% to 18%. This promising reduction highlights the potential for relaxing control to achieve energy savings.

There are three significant benefits from this research: the acceptable macro-environment provides an opportunity to ease mechanical stress in air conditioning plant; the LSTM real-time prediction allows for micro-environmental monitoring without deploying extra sensors; and this relaxed control scheme can be used for other libraries and museums in other climate regions or using different kinds of enclosure in their storage rooms.

Furthermore, the approach is not limited to libraries. It could be applied in other institutions to develop bespoke energy-saving programmes suitable for different circumstances.

However, two limitations exist in this study. First, the buffering capacity assessment focused solely on newly made enclosures, overlooking potential changes over their lifespan. Investigating the effect in association with enclosure buffering performance degradation would be pertinent and insightful. Second, the study analysed individual boxes in isolation, neglecting the potential impact of a fully boxed storeroom. Future research could explore the buffering effect in such environments. They could be resolved in future studies.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work is a part of three-year doctoral study, funded by the Energy Technology Partnership, Scotland (ETP 173-2019).

ORCID

Fan Wang http://orcid.org/0009-0003-1464-2135

References

Afram, A., A. S. Fung, F. Janabi-Sharifi, and K. Raahemifar. 2018. "Development and Performance Comparison of Low-Order Black-Box Models for a Residential HVAC System." *Journal of Building Engineering* 15: 137–155. https://doi.org/10.1016/j.jobe.2017.11.021.

Arslan, N., and A. Sekertekin. 2019. "Application of Long Short-Term Memory Neural Network Model for the Reconstruction of MODIS Land Surface Temperature Images." *Journal of Atmospheric and Solar-Terrestrial Physics* 194: 105100. https://doi.org/10.1016/j.jastp.2019.105100.

ARUP. 2017. Museums and Galleries (U-Value Guide). Accessed November 2017. https://museumdevelopmentnorthwest.files.wordpress.com/2012/06/arup-u-values-guide_single-pg_issue-21-march-2017dble-pg-spread1-final-copy.pdf.

Ascione, F., L. Bellia, A. Capozzoli, and F. Minichiello. 2009. "Energy Saving Strategies in Air-Conditioning for Museums." *Applied Thermal Engineering* 29 (4): 676–686. https://doi.org/10.1016/j.applthermaleng.2008.03.040.

ASHRAE. 2019. *ASHRAE 2019 Handbook: Heating, Ventilating and Air-Conditioning Applications (SI)*. With contributions from V. Beltran, C. Grzywacz, J. Linden, M. Lukomski, S. Michalski, J. Taylor, and J. Tetreault, 24.1-24.43. Atlanta: ASHRAE.

Bohm, C. B., K. Zehnder, H. Domeisen, and A. Arnold. 2001. "Climate Control for the Passive Conservation of the Romanesque Painted Wooden Ceiling in the Church of Zillis (Switzerland)." *Studies in Conservation* 46 (4): 251–268. https://doi.org/10.1179/sic.2001.46.4.251.

BSI. 2018. *BS EN 16893:2018. Conservation of Cultural Heritage—Specifications for Location, Construction and Modification of Buildings or Rooms Intended for the Storage or Use of Heritage Collections*. London: British Standards Institution.

Bülow, A. E., B. J. Colston, and D. S. Watt. 2002. "Preventive Conservation of Paper-Based Collections Within Historic Buildings." *Studies in Conservation* 47 (Supp. 3): 27–31. https://doi.org/10.1179/sic.2002.47.s3.006.

Granata, F., F. Di Nunno, and G. de Marinis. 2022. "Stacked Machine Learning Algorithms and Bidirectional Long Short-Term Memory Networks for Multi-Step Ahead Streamflow Forecasting: A Comparative Study." *Journal of Hydrology* 613A: 128431. https://doi.org/10.1016/j.jhydrol.2022.128431.

Han, B., X. Li, F. Wang, J. Bon, and I. Symonds. 2024. "The Buffering Effect of a Paper-Based Storage Enclosure Made From Functional Materials for Preventive Conservation." *Indoor and Built Environment* 33 (1): 167–182. https://doi.org/10.1177/1420326X23118.

Hochreiter, S., and J. Schmidhuber. 1997. "Long Short Term Memory." *Neural Computation* 9 (8): 1735–1780. https://doi.org/10.1162/neco.1997.9.8.1735.

Klug Conservation. 2023 "Useful Knowledge No. 1 – Cotton or Chemical Wood Pulp? No. 4 – Fillers, No. 6 Polypropylene – A Material for Long-Term Archiving?" Accessed November 2023. https://www.klug-conservation.com/Useful-knowledge.

Net Zero Scotland. 2019 *About Net Zero*. Accessed 14 May 2019. https://www.netzeronation.scot/the-importance-of-net-zero.

Perino, M. 2018. "Air Tightness and RH Control in Museum Showcases: Concepts and Testing Procedures." *Journal of Cultural Heritage* 34: 277–290. https://doi.org/10.1016/j.culher.2018.01.022.

Rojas, A., F. Cabrera, and A. Corona. 2020. "Temperature and Relative Humidity in a Palaeontological Collection: The Buffering Effect of Microenvironments." *Annales de Paleontologie* 106 (4): 104206. https://doi.org/10.1016/j.annpal.2020.102446.

Salem, H., A. E. Kabeel, E. M. S. El-Said, and O. M. Elzeki. 2022. "Predictive Modelling for Solar Power-Driven Hybrid Desalination System Using Artificial Neural Network Regression with Adam Optimization." *Desalination* 522: 115–411. https://doi.org/10.1016/j.desal.2021.115411.

Salsbury, T. I. 2002. "A New Pulse Modulation Adaptive Controller (PMAC) Applied to HVAC Systems." *Control Engineering Practice* 10 (12): 1357–1370. https://doi.org/10.1016/S0967-0661(02)00099-0.

Yu, Y., X. Si, C. Hu, and J. Zhang. 2019. "A Review of Recurrent Neural Networks: LSTM Cells and Network Architectures." *Neural Computation* 31 (7): 1235–1270. https://doi.org/10.1162/neco_a_01199.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S169–S175
https://doi.org/10.1080/00393630.2024.2339768

ORIGINAL RESEARCH OR TREATMENT PAPER

Dissociation and Loss: a Challenge for Sustainable and Inclusive Conservation

Disociación y Pérdida: un Desafío para la Conservación-restauración Sostenible e Inclusive

Jane Henderson [1] and Robert Waller [2,3,4]

[1]Department Archaeology and Conservation, Cardiff University, Cardiff, UK; [2]Protect Heritage Corporation, Ottawa, Canada; [3]Art Conservation Department, Queen's University, Kingston, Canada; [4]Canadian Museum of Nature, Ottawa, Canada

ABSTRACT

The agents of deterioration (AoD) offer a structured categorization of hazards to collections: they are a basis for risk-informed preservation management. In drawing up the AoD their creators were not ignorant of wider societal issues of concern to conservators, but they envisaged them to be part of a broader institutional activity located beyond the scope of preventive conservation. Within conservation, there have been discussions about additional agents: social, cultural, or political causes of loss. Their continued exclusion from the AoD may mistakenly be interpreted as a lack of consideration of such concerns. There are reasons to limit the scope of an institution's preventive conservation system but not everyone agrees that those reasons are sufficient to justify this limitation. This paper is a discussion and disagreement by two authors. Henderson argues that dissociation should capture any loss of meaning resulting from any aspect of conservation practice, including cleaning, documentation, failure to respect beliefs, etc. She argues that dissociation from context may stop preventive conservators from identifying and respecting optimal traditional sustainable methods and techniques. Waller argues that the threat of losing context information about collection items should be managed as part of the wider cultural heritage institution's role and resolved through its engagement with the community. He acknowledges that preventive conservation can contribute to understanding and mitigating this form of loss, but advocates that primary responsibility must be situated at a higher level than the preventive conservation remit.

Los agentes de deterioro (AdD) ofrecen una categorización estructurada de los peligros para las colecciones: son una base para una gestión de la preservación informada sobre los riesgos. Al redactar la AdD, sus creadores no ignoraban cuestiones sociales más amplias que preocupaban a los conservadores-restauradores, pero las previeron como parte de una actividad institucional más amplia ubicada más allá del alcance de la conservación preventiva. Dentro de la conservación-restauración, ha habido discusiones sobre agentes adicionales; causas sociales, culturales o políticas de la pérdida. Su continua exclusión de los diez agentes puede interpretarse erróneamente como una falta de consideración de tales preocupaciones. Hay razones para limitar el alcance del mandato de conservación preventiva, pero no todos están de acuerdo en que esas razones sean suficientes para justificar esta limitación. Este artículo es una discusión y desacuerdo entre dos autores. Henderson sostiene que la disociación debe capturar cualquier pérdida de significado resultante de cualquier aspecto de la práctica de conservación-restauración, incluida la limpieza, la documentación, la falta de respeto a las creencias, etc. Sostiene que la disociación del contexto puede impedir que los conservadores preventivos identifiquen y respeten métodos y técnicas tradicionales sostenibles óptimos. Waller sostiene que la amenaza de perder información contextual sobre los elementos de la colección debe gestionarse como parte del papel más amplio de la institución del patrimonio cultural y resolverse a través de su compromiso con la comunidad. Reconoce que la conservación preventiva puede contribuir a comprender y mitigar esta forma de pérdida, pero defiende que la responsabilidad primaria debe situarse en un nivel más alto que el mandato de conservación preventiva.

ARTICLE HISTORY
Received October 2023
Accepted March 2024

KEYWORDS
Dissociation; respectful disagreement; risk; preventive conservation; loss; meaning

Disociación; desacuerdo respetuoso; riesgo; conservación preventiva; pérdida; significado

Introduction

In recent years, there is growing recognition of loss of value resulting from the separation of cultural property from the very segments of society that value it (Chipangura 2023; Cook et al. 2023; Tichmann and Abrahams 2021). These separations have been, and continue to be, from multiple causes including colonialization, financial and social exploitation, and discrimination. They resonate with a concept of dissociation centered on linking tangible information to collections. In conservation, models of collaborative international and inter-disciplinary work have increased professional

CONTACT Jane Henderson hendersonLJ@Cardiff.ac.uk Department Archaeology and Conservation, Cardiff University, John Percival Building, Cardiff CF10 3eU, UK

© The International Institute for Conservation of Historic and Artistic Works 2024

interaction among communities, within and without the authorized heritage sector (Balachandran and McHugh 2019; Wharton 2008). Inadequate past practice by many museums has resulted in collections lacking adequate and appropriate associated information. Documentation failures have led to the loss of significant elements of the intangible knowledge and meanings related to items in our collections. This leads us to ask: is the management of the loss of intangible information or association essential to conservation practice and should it be within scope of the ten agents of deterioration (AoD)? To answer this, we first examine the AoD framework to understand its origins and rationale.

Risk management for preventive conservation

The adaption of risk-informed approaches to preventive conservation was made possible by combining the concepts of a categorization of hazards, such as the 10 AoD (hereafter simply 'agents'), with categorization of types of risk based on frequency of occurrence. This provided a basis for documenting the degree of confidence that risks to cultural property could be described sufficiently comprehensively (Waller 2008; 2019). The claim to comprehensiveness depends not just on an hierarchical taxonomy for generic and specific risks but equally on clear definition of boundaries on the preservation system (Waller 2003).

The management of risks is important, but it is not the sole objective of preventive conservation. It is critical not to equate the collection risk management system remit with the preventive conservation function. Preventive conservation works within collection management systems other than preservation, specifically, collection development and collection use. Any quantification demands absolute clarity about scope: what is and what is not to be included. For example, the preservation system remit focuses on future change so must not conflate existing damage with future risk. Risk management seeks to capture potential future changes, not to describe the totality of past losses.

Introducing the 10 agents

In the 1980s, Stefan Michalski at the Canadian Conservation Institute developed a framework for preventive and remedial conservation based on a set of 9 AoDs (Michalski 1990). This, with minor modifications (CCI 2017), has become the most familiar framework for categorizing hazards that can cause changes to cultural property. They are commonly known as the agents of deterioration, growing from 9 to 10 in 1994 (Table 1). In the context of risk analysis, the term agent of change (AoC) (Strlič et al. 2013) connotes a better understanding of risks that range from continual deterioration processes, through sporadic incidents, to rare events. Each agent combined with one of three types of risks (rare events, sporadic incidents, or continual processes) leads to what is termed a 'generic risk'. Those generic risks provide a framework for describing plausible risk scenarios as clearly and concisely defined specific risks (Table 2).

Table 1. Ten agents of change (after CCI (2017)) with examples of kinds of damages caused.

Agent	Examples of damage
Physical force	Breakage, distortion
Thieves and vandals	Item lost, defaced
Fire	Total loss, soot damage
Water	Distortion, pigments running
Pests	Consumption, soiling
Pollutants	Soiling, tarnishing
Visible, ultraviolet and infrared radiation	Alteration of colors, photo-oxidation
Incorrect temperature	Accelerated chemical reactions, melting
Incorrect relative humidity	Mold growth, corrosion
Dissociation	Server corrupted, missing label

Adding dissociation

Shortly after the launch of the 9 agents, Waller (1994) introduced a 10th agent initially termed 'custodial neglect' to account for issues of loss of information and the connection of information to collections. Unfortunately, the term 'neglect' led to any factor contributing to loss in collections, including lack of staff, training, funds, etc. being identified as hazards. This ran counter to the intent of risk analysis to identify risks as closely as possible to technical, direct, causes of change, rather than secondary, or more distant factors. To better reflect the use of the 10th agent for risks that could be clearly identified, quantified, and managed, the term 'custodial neglect' was replaced by the term 'dissociation'.

Discussing dissociation

Dissociation is one of the less clearly understood agents of change. Dissociation was defined as loss of items, item-related information, or item-information associations. The boundaries of dissociation are regularly tested, and some conservators use the term to describe other forms of loss of information. Thus dissociation might now be understood either as a hazard leading to well-defined risks to accessioned (legally owned) items or a consequence of isolating items from their relevant social and cultural contexts. The remainder of this paper offers a constructive disagreement about meanings and scope of the term 'dissociation'. Constructive disagreement avoids defensive reactions, which builds trust and encourages collaboration (Geal 2018). A sustainable profession should

Table 2. Illustration of how the generic risks are further divided into specific risks.

Agent	Type of risks	Generic risk	Examples of specific risks
Physical forces	Rare (once per 100 years or less)	PF-1	PF-1-1 Earthquake causes shelf collapse leading to breakage of tea service PF-1-2 Earthquake causes tall objects to topple over and break PF-1-3 Landslide destroys and buries building crushing contents etc.
Physical forces	Sporadic (an incident every few years or decades)	PF-2	PF-2-1 A drawer of collection items is accidentally dropped resulting in breakage PF-2-2 Transportation between venues leads to shock or impact resulting in physical damage PF-2-3 Painted surface with decayed binder in transit vibrates losing some surface pigment etc.
Physical forces	Continual (on-going process) or occurrences at least once per year	PF-3	PF-3-1 Wooden floor vibrates when dancing occurs in gallery, causing canvas painting supports to vibrate against glazing PF-3-2 Gravity causes distortion in poorly supported, non-rigid, non-elastic objects PF-3-3 Retrieval of items from crowded storage situation causes surface abrasion to itemsetc.

develop such skills to facilitate respectful listening, exploration of difference, tolerance of uncertainty and disagreement. That leads to a more resilient conservation community better equipped to meet the challenges of collaborative and inter-disciplinary work.

Exploring difference: should the scope of dissociation be extended?

The following debate between the two authors examines the opportunities and dangers of extending the concept of dissociation. In the first round of exchanges, Henderson argues in favor of the affirmative statement that the term 'dissociation', as it is used in conservation, should be extended to include separation of cultural items from their original cultural context. Waller argues in opposition to that statement. Three rounds of debate explore common ground but do not reach consensus.

Henderson: extend the scope 1

Preventive conservation should expand the definition of the agent 'dissociation' to include the separation of object and meaning and this separation is a primary concern of preventive conservation. There is a necessity for clear boundaries of preventive conservation as a distinct practice within a broader collection management function. To make the case for a broader conception of dissociation, it is necessary to examine what falls within the scope of preventive conservation.

Accepted definitions of conservation (ICOM-CC 2008) embrace preventive conservation as a component of actions to preserve the physical properties and significance of cultural heritage. Conservation practice encompasses value preservation and so the function of preventive conservation is also to safeguard value from loss. An important platform for conservation decision-making has been integration of value or significance assessments, 'before heritage is subject to management, there is a process of acknowledgement … *via* value assessment' (Vargas and Alonso-Muñoyerro 2022, 184). Conservation is a process of navigating value delivery. Value may be found in tangible or intangible form but it may be necessary to 'de-privilege' the tangible aspects to illuminate the intangible (Smith 2006). The goals of a conservation intervention on an historic textile might be that it should be clean, whole, and not too faded. If the textile is a banner once carried in a protest, fought over, torn, and dropped, and is symbolic of an important social movement then its value is captured by its condition and association, a status that challenges simplistic descriptions of damage or loss. A conservator making decisions would put the future care of the object at great risk by failing to address these values. Conservators must consider whether a stain should be removed, should the banner be mounted to show it as if it was never torn, should the gallery lighting augment the aesthetic or the event? Considering how to preserve value is central to the function and scope of preventive conservation.

As part of sustainable and inclusive approaches for the care of cultural heritage, the concepts of adaptation and 'managed loss' have been explored, adding new depth to a previously sometimes casual use of words such as 'damage' and 'deterioration'. These discussions have led to some conservators reconsidering traditional approaches, to foreground ethical concerns such as inclusivity and sustainability even over physical continuity, for example in the handling of collections.

Preventive conservators have not necessarily abandoned core activities such as environmental management and pest control, but they also find themselves asking broader social questions in the course of their work. In such fertile ground seeds of doubt regarding dissociation are planted. Can a change to an object that may have been described as damage (such as reburial and decay) now be a feature of its values

and as such should a conservator facilitate this in a specific context? If failing to allow a traditional practice such as allowing an object to decay could be considered a loss in value, then knowledge of associated beliefs is necessary for appropriate future care. Thus dissociation of meaning represents past loss but also creates future risk that should be considered within the specific work roles of the conservator.

Waller: do not extend the scope 1

Henderson argues that preserving value is central to the function and scope of preventive conservation and I could not agree more. I agree that the impact of conservation measures, or their absence, both in and around cultural items can have substantial, even critical, impact on their values. In the historical context of museology, damage has been interpreted as changes in state, such as breakage, wear, soiling, and so on, leading to the loss of utility for traditional purposes such as research or exhibition. In a context that is respectful of diverse cultural values, loss of value must be interpreted in all the diverse ways that Henderson describes.

When Henderson argues that 'A conservator making decisions would put the future care of the object at great risk by failing to address these values … ' she raises an issue that I believe is well enough dealt with by current ethical codes and practitioner understandings in the field. To my mind, it signals an idea that is not really an issue, at least not for this debate. I do not believe that the definition of dissociation needs to be extended to avoid over-treatment, or inappropriate treatment of items. Sweetnam and Henderson (2022) argue, and I agree, that the need for conservation treatments to be mindful is reliant on critical self-reflection as much as institutionally-recorded information. I fear that codifying cultural, political meanings in the technical way that an agents–types–generic risk framework would require for the quantification of technically well-defined risks is a step in the wrong direction. It shifts the focus from the necessary ethical self-reflection to a technocratic operation.

Henderson: extend the scope 2

Risk management is a forward-looking system: it is not about cataloguing historic damage, whether from insect pests or looting. This approach does not diminish concerns about existing loss nor suggest there is no need to mitigate it. Dissociation of cultural context is a critically important factor causing future risk. In considering the possibility of future harm, recording the location and nature of values is critical to our operations. For some objects value is bound up in how they are kept, whether that is feeding objects and keeping them warm, or specifying access rights, or maintaining motion. These values exist across collections and capture the needs and intentions of creators, users, descendants, and cultural stakeholders. To give an example, Manu describes beliefs associated with artefacts that may inhibit conservation practice and concludes that the 'numinous qualities affected how they are preserved' (Manu, Kquofi, and Issah 2022, 233). The ability to self-reflect is predicated upon access to and awareness of relevant information. Collection organizations that hold an item without holding knowledge about how the originators intend it to be used may act in opposition to such use, for example preserving totem poles that are meant to decay. Unequal power increases the risk that future practice will continue to result in loss in value, whether that is a continuous and gradual loss, perhaps by interrupting desired decay or a sudden and significant loss such as removing a piece of graffiti art before realizing its social value and subsequently reinstating it (BBC News 2013; Jones 2015). Thus inequality of power and access are both causes and results of dissociation failures. Being unaware of diverse values whilst practicing conservation is a risk and real harm cannot be ignored because value is considered to fall outside of technocratic concerns.

Waller: do not extend the scope 2

To my mind, Henderson's argument regarding 'dissociation of cultural context contributing to future risk' is the most powerful argument in favor of including that concept within the technical definition of the agent dissociation. Still, the appropriate avenues for addressing that issue within a collection management framework are through the collection development and collection use processes. As a critical factor in considering a new acquisition, the on-going requirements for ensuring that cultural values will be retained must be identified, documented, and accepted as essential requirements for on-going care.

There has been, and continues to be, tragic loss in value of cultural property caused by separating the property from its most appropriate cultural context. Both current and future value-realizing interaction opportunities are lost. Even more tragically, meanings, the bases for future value realizations, can also be lost. So much current and future loss of value occurs through what is clearly a process of dissociation – how could I possibly believe that dissociation of items from their most appropriate cultural context should not be considered within preventive conservation's understanding of the agent dissociation? There are several reasons, all may seem at first glance to be pedantic, but are based on decades of practical experience in managing conservation, collections, and museums.

Knowledge about items held only in the minds of individuals and not captured in an institution's records is not a value at risk. That knowledge is recognized as value that should have been recorded and linked to the collection at the time of acquisition, as part of the collection documentation process. When that was not done, the value of that knowledge was lost at that time and thereafter is recognized as past damage. It must not be confused with future risk which is the focus of the collection risk management system. To think otherwise would make boundaries for quantification irreconcilably vague. Still, retaining these knowledge-related values is a legitimate concern. Preventive conservation should influence, and contribute to improving, the collection development system to avoid such losses. Nevertheless, I do not consider it to be within the scope of an institution's preservation remit when that is necessarily narrowly defined for assessing and managing risks to a collection. That scope separation must be kept clear by defining the agent dissociation as focused on future changes in state leading to loss in value.

Similar reasoning applies to loss of contextually dependent cultural values. Those values might be better maintained through improvements to the collection development and collection use systems. For example, acquiring an item might demand documenting as fully as possible the significance of cultural context during the acquisition process. Avoiding further loss of cultural context value might include providing the item for continued use within its original cultural context. Such appropriate community uses of collection items have been effectively applied (Clavir 2002). Is it best for the preventive conservation function to adopt the role of being the primary activist for promoting use of items? Or would an institution be better served by expecting curators or collection managers to adopt that role, with the support of conservation in promoting safety and preservation during use? It is understandable that preventive conservation professionals striving to achieve the broadest possible social benefit will choose the former. Still, senior museum management would likely, and in my opinion rightly, expect responsibilities to be distributed as suggested in the latter question.

Henderson: closing

We have returned to the role of conservators. In my view, a shared responsibility can also be a core responsibility. The conservators of manuscripts, or of time-based-media, or steam trains all promote use. Indeed, as I believe hanging a painting in a gallery is a form of use, I contend that conservators manage use in almost every aspect of their work without upsetting the institutional apple cart. Furthermore, I believe that use and care are simultaneous functions. Finally, I would argue that value is better represented by associations than by physical attributes and those associations live on in people even when the objects have been stripped of value by collecting institutions. Knowledge loss is never in the past while it is still alive in the people connected to those objects. It is a present and future risk when institutions fail to reconnect to this knowledge.

Waller: closing

I contend that agents should be limited to those things that are within the control of, or can be significantly influenced by, preventive conservation. My perspective is that cultural value separation, as a risk factor, is comparable to issues such as war, climate change, lack of externally perceived value, etc. These important factors affect risk to collections but are too distant from our sphere of significant influence to be instrumental in guiding choices made at the technical collection risk-management level.

We must recognize that influence on a system must be exercised in different ways at 12 levels described as 'leverage points' (Meadows 1999). Adjusting a thermostat is our lowest level leverage point, that of constants, parameters, numbers. Fostering multi-cultural values into the heritage sector's continual awareness is the highest-level leverage point: the power to transcend paradigms. Using the same risk analysis tool to address issues at those extremely different leverage points cannot lead to success.

An underlying problem in the field today is that we can fall into thinking that preventive conservation is the same as managing risks to collections. That is a necessary but not sufficient aspect of preventive conservation. Preventive conservation is broader and deeper than that simple technocratic goal. Beyond the technical level, it must work within the collection use system to optimize collection value delivery across all segments of society including culturally-defined segments (Clavir 2002; Balachandran and McHugh 2019), abilities-defined segments (Henderson and Lingle 2022), generational segments (Taylor 2013), and others. Broadening the definition of dissociation will only muddy the distinction between the highly technical goal of risk analysis and the broader societal goal of ensuring cultural property sustains and enriches all segments of humanity.

In agreement

We agree there are no simple answers and, because we cannot run independent futures with one decision or another, we will never know which might have been a better choice. We think a consensus decision is unlikely. Instead, both these approaches, and probably

many others, will be picked up based on individuals' beliefs of what is best. Our professional responsibility is, as much as possible, to avoid basing decisions on untested beliefs. Instead, we should consider how each alternative could be tested at least through thought experiments.

We can both agree that adding an agent to represent things we don't like in the world is both understandable and a testament to the success of the agents, but any such change must fit with the format to serve the technical purpose the agents serve. It is possible that an additional concept, separate from the 10 agents of change, could be considered to cover the broader sense of dissociation, something like 'separation', 'social detachment' or 'deracination'. For Waller, this is the better way forward and for Henderson expanding the term dissociation is better. We don't agree but we both respect and value our disagreement.

Closing statement

Our increasingly common broader conceptions of conservation help us to practice the respect that ethical codes have urged us towards for decades. The management of the world's resources includes the management of its cultural heritage. Careful and equitable resource extraction and its distribution and management is critical to sustainably sharing our planet. Such concerns are not limited to industry and farming. The extraction of resources, whether minerals, crops, or heritage, and their unequal distribution is not simply a feature of past colonialism, it is an on-going current and present threat to sustainable living. Many museums, especially those that claim universal museum status, are extractive and have profited from uneven distribution of resources. In some cases, it is the direct removal of cultural items, in others it is of materials of construction such as minerals, pigments, or silk, and in still others it is about wealth and the resource is to support culture. Transforming extractive industries is critical to sustainable global development and this must involve giving equal weight to the concerns of all participants regardless of their size or location (United Nations 2021, 4–5; Villanueva, Páez Cure, and Brokerhof 2023). Neither perspective offered in this paper seeks to diminish the importance of this.

By placing this discussion front and center within the conservation literature, the authors offer insight into decision-making and responsibilities for conservators. Furthermore, by modelling informed and respectful disagreement, we offer a pattern that we hope contributes to sustaining the profession. It is essential that conservators consider their interactions with others and how they contribute to three goals: their sustainable career (McDonald and Hite 2018), the sustainability of their institutions, and the sustainability of the place of their institutions in wider society.

Acknowledgement

We acknowledge that we live in places that are safe and free of war, which creates opportunities for us to disagree and yet remain friends and that this is not available to many people worldwide. We thank two reviewers and the editor for their helpful suggestions.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Jane Henderson http://orcid.org/0000-0003-3027-8452
Robert Waller http://orcid.org/0000-0002-9500-4113

References

Balachandran, S., and K. McHugh. 2019. "Respectful and Responsible Stewardship: Maintaining and Renewing the Cultural Relevance of Museum Collections." In *Preventive Conservation: Collection Storage*, edited by L. Elkin, and C. A. Norris, 3–24. New York: SPNHC; AIC; Smithsonian Institution; The George Washington University Museum Studies Program.

BBC News. 2013. "Teenage Kicks Lyrics Mural Removed from Belfast Flyover." *BBC News*, 21 June. https://www.bbc.co.uk/news/uk-northern-ireland-23000060.

CCI. 2017. *Agents of Deterioration*. https://www.canada.ca/en/conservation-institute/services/agents-deterioration.html.

Chipangura, N. 2023. "The Benin Tusk and Zulu Beadwork: Practicing Decolonial Work at Manchester Museum Through Shared Authority." *Museum Anthropology* 46 (2): 106–116. https://doi.org/10.1111/muan.12279

Clavir, M. 2002. *Preserving What Is Valued*. Vancouver: UBC Press.

Cook, R., M. Kartomi, L. Chakim, and N. Tse. 2023. "Ontology and Knowing: A Framework for Conserving a Rare Musical Instrument Within and Beyond the Archive." In *Working Towards a Sustainable Past. ICOM-CC 20th Triennial Conference Preprints*, Valencia, 18–22 September 2023, edited by J. Bridgland. Paris: ICOM. https://www.icom-cc-publications-online.org/5633/Ontology-and-knowing–A-framework-for-conserving-a-rare-musical-instrument-within-and-beyond-the-archive.

Geal, M. 2018. "Practising Constructive Disagreement." https://www.linkedin.com/pulse/practising-constructive-disagreement-mandy-geal/.

Henderson, J., and A. Lingle. 2022. "Touch Decisions: For Heritage Objects." *Journal of the American Institute for Conservation* 63 (1): 1–13. DOI: 10.1080/01971360.2023.2175983.

ICOM-CC. 2008. *Terminology for Conservation*. https://www.icom-cc.org/en/terminology-for-conservation.

Jones, B. H. 2015. "Teenage Kicks Mural Reinstated in Belfast after Outcry." *BBC News*, 16 March. https://www.bbc.co.uk/news/uk-northern-ireland-31909136.

Manu, E., S. Kquofi, and M. Issah. 2022. "The Impact of Numinosity on the Preservation of Selected Artefacts in the Manhyia Palace Museum, Ghana." *Journal of the*

Institute of Conservation 45 (3): 223–235. DOI: 10.1080/19455224.2022.2118142.

McDonald, K. S., and L. M. Hite. 2018. "Conceptualizing and Creating Sustainable Careers." *Human Resource Development Review* 17 (4): 349–372. DOI:10.1177/1534484318796318.

Meadows, D. 1999. *Leverage Points: Places to Intervene in a System*. Hartland, VT: The Sustainability Institute.

Michalski, S. 1990. "An Overall Framework for Preventive Conservation and Remedial Conservation." In *ICOM Committee for Conservation Preprints, 9th Triennial Meeting Dresden*, 2: 589–591. Paris: ICOM.

Smith, L. 2006. *Uses of Heritage*. 1st edn. London: Routledge.

Strlič, M., D. Thickett, J. Taylor, and M. Cassar. 2013. "Damage Functions in Heritage Science." *Studies in Conservation* 58 (2): 80–87. DOI:10.1179/2047058412Y.0000000073.

Sweetnam, E., and J. Henderson. 2022. "Disruptive Conservation: Challenging Conservation Orthodoxy." *Studies in Conservation* 67 (1-2): 63–71. DOI: 10.1080/00393630.2021.1947073.

Taylor, J. 2013. "Intergenerational Justice: A Useful Perspective for Heritage Conservation." In *CEROART*. https://journals.openedition.org/ceroart/3510.

Tichmann, P., and L. Abrahams. 2021. "Challenges of Re-Writing the Iziko Ethnographic Collections Archives: Some Lessons from the Khomani San/Bushmen Engagement." *Zeitschrift für Kulturwissenschaften* 15 (2): 47–60. DOI:10.14361/zfk-2021-150205.

United Nations. 2021. *Transforming Extractive Industries for Sustainable Development*. https://www.un.org/sites/un2.un.org/files/sg_policy_brief_extractives.pdf.

Vargas, Camila B., and S. M. Alonso-Muñoyerro. 2022. "About the Validity of Alois Riegl's *The Modern Cult of Monuments*." *Journal of Architectural Conservation* 28 (3): 183–196. DOI: 10.1080/13556207.2022.2045807.

Villanueva, M. C., A. I. Páez Cure, and A. W. Brokerhof. 2023. "A Climate Balancing Act: Negotiating Environmental Conditions for Loans Between Different Climate Zones." In *Working Towards a Sustainable Past. ICOM-CC 20th Triennial Conference Preprints, Valencia*, edited by J. Bridgland. Paris: ICOM. https://www.icom-cc-publications-online.org/5599/A-climate-balancing-act–Negotiating-environmental-conditions-for-loans-between-different-climate-zones.

Waller, R. 1994. "Conservation Risk Assessment: A Strategy for Managing Resources for Preventive Conservation." In *Preventive Conservation Practice, Theory and Research*, edited by A. Roy, and P. Smith, 12–16. London: IIC.

Waller, R. 2003. *Cultural Property Risk Analysis Model: Development and Application to Preventive Conservation at the Canadian Museum of Nature*. Göteborg: Göteborgs Universitet Acta.

Waller, R. 2008. "Comprehensive Risk Assessment: Applying the Cultural Property Risk Analysis Model to the Canadian Museum of Nature." In *Real Time and Deliberative Decision Making (NATO Science for Peace and Security Series C: Environmental Security)*, edited by I. Linkov, E. Ferguson, and V. S. Magar, 179–190. Dordrecht: Springer.

Waller, R. 2019. "Collection Risk Assessment." In *Preventive Conservation: Collection Storage*, edited by L. Elkin, and C. A. Norris, 59–90. New York: SPNHC; AIC; Smithsonian Institution; The George Washington University Museum Studies Program.

Wharton, G. 2008. "Dynamics of Participatory Conservation: The Kamehameha I Sculpture Project." *Journal of the American Institute for Conservation* 47 (3): 159–173. DOI:10.1179/019713608804539592.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S176–S189
https://doi.org/10.1080/00393630.2024.2375160

OPEN ACCESS Check for updates

Towards a National Heritage Climate Change Risk Assessment
Hacia una Evaluación del Riesgo de Cambio Climático del Patrimonio Nacional

Paul Lankester and Ruth Knight

Climate and Sustainability, English Heritage, Swindon, UK

ABSTRACT

Climate change is one of the greatest threats to cultural heritage. This work develops a climate change risk assessment (CCRA) methodology, assessing large portfolios of properties spread over a wide geographic area. Climate hazards, exposure and vulnerability metrics are identified, and results from two case studies presented to highlight the application of the national CCRA. How a national CCRA fits in a wider context is discussed along with improvements and further work. This method helps understand the impact of climate change across a large estate, supports investment prioritisation and climate informed decision making to increase heritage resilience.

El cambio climático es una de las mayores amenazas al patrimonio cultural. Este trabajo desarrolla una metodología de evaluación del riesgo de cambio climático (CCRA), evaluando grandes carteras de propiedades repartidas en una amplia área geográfica. Se identifican los peligros climáticos, la exposición y las métricas de vulnerabilidad, y se presentan los resultados de dos estudios de caso para resaltar la aplicación de la CCRA nacional. Se analiza cómo encaja una CCRA nacional en un contexto más amplio, junto con mejoras y trabajo adicional. Este método ayuda a comprender el impacto del cambio climático en una gran propiedad, respalda la priorización de inversiones y la toma de decisiones climáticamente informadas para aumentar la resiliencia del patrimonio.

ARTICLE HISTORY
Received 19 October 2023
Accepted 22 June 2024

KEYWORDS
Climate change impacts; adaptation; hazard; exposure; vulnerability

Impactos del cambio climático; adaptación; peligro; exposición; vulnerabilidad

Introduction

We are in a climate emergency. Climate change already impacts our heritage (Orr, Richards, and Fatorić 2021; Simpson et al. 2022) and is becoming one of the most significant risks to cultural heritage. Collection managers must be ready to adapt to increased threats to conserve our heritage.

English Heritage (EH) cares for a portfolio of over 400 historic sites and over one million historic objects. This presents a challenge, familiar to many organisations globally, of where to prioritise resource across a large estate. It isn't possible to save all heritage at threat from climate change. Therefore, it's essential to better understand the climate risk to our collective heritage (Day et al. 2019; Harkin et al. 2020; Harkin, Davies, and Hyslop 2018) to ensure investment is prioritised and climate-informed decisions are made that increase resilience.

The approach taken largely follows the risk assessment methodology set out by the Intergovernmental Panel on Climate Change (IPCC) assessment report 6 (AR6) (Ara Begum et al. 2022; Reisinger et al. 2020), whilst aligning with existing EH processes to enable the embedding of climate resilient thinking. The IPCC is the United Nations body for assessing the science related to climate change. It is critical that we start to adapt now to climate change: EH invests significantly in the estate each year and poor decisions now will be locked in for many years.

This research maps how climate *hazards* are projected to change for each site in our care. The magnitude of such changes is not always the best indicator of the significance of the projected change, it is important to consider *vulnerability*. For example, a historic house with objects on open display, that has water ingress, will be more vulnerable to an increase in precipitation than another which is dry at current levels. Moreover, the location of collections in the building is important, along with quantity and significance; this determines the *exposure* to climate impacts. Considering current control measures (the *response* to potential damage) is important. For example, a continuously staffed site, with a well-practiced emergency response would have greater adaptive capacity than a site only staffed during the day.

This introduces the four concepts of climate change risk assessments (CCRAs) as described by the IPCC (Ara Begum et al. 2022), hazard, exposure, vulnerability and response (Figure 1). Each part is important to

CONTACT Paul Lankester paul.lankester@english-heritage.org.uk Climate and Sustainability, English Heritage, The Engine House, Fire Fly Avenue, Swindon, SN2 2EH, UK

© 2024 English Heritage Trust. Published by Informa UK Limited, trading as Taylor & Francis Group
This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

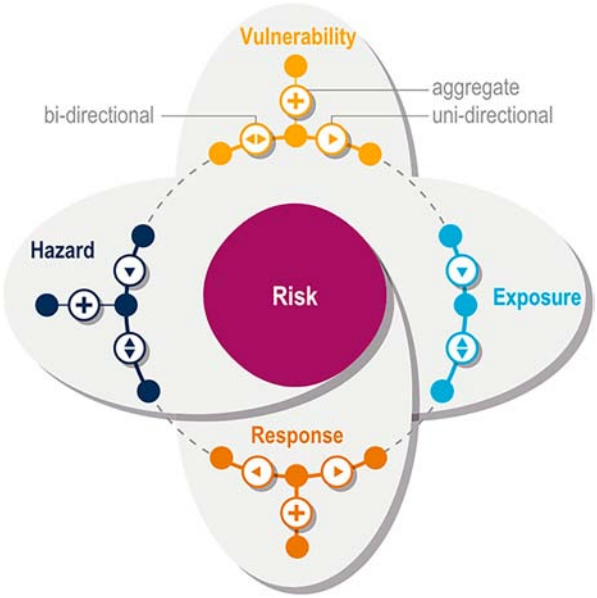


Figure 1. IPCC risk assessment framework, adapted from Ara Begum et al. (2022).

understand the risk, or opportunity, posed by climate change. This research presents a methodology to assess the impact of climate change on the EH estate, at a site-by-site level. Whilst in its initial stages, it indicates the pathway towards a CCRA for a national estate. The assessment covers five themes: buildings (assets), collections, gardens and landscapes, people, and operations.

Methods

Hazards

> The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. (IPCC 2018)

Climate hazards relevant to heritage have been identified, using existing resources (Sesana et al. 2021) such as work by Historic Environment Scotland (Harkin, Davies, and Hyslop 2018), the National Trust (2021) and reports submitted under the third round of the adaptation reporting power (DEFRA 2022), part of the UK Climate Change Act 2008. This allows DEFRA to ask certain organisations to report on the current and future predicted effects of climate change on their organisation and their proposals for adapting to climate change.

UK data sources of future climate projections were identified relating to each hazard (e.g. temperature, precipitation etc.), as well as indices of these (i.e. number of frost days, or number of days over 25°C). The aim was to source geographical data covering England to allow hazard mapping for each EH site. Hazards are well covered with useful data, although there are some gaps and areas for improvement. Some sources are available for purchase, although not used here.

Specifically, this work used a geographical information systems (GIS) approach (ArcGIS pro v.2.9.1). The boundaries of all EH sites are mapped in one layer and this is intersected with a hazard data layer which enables the production of relevant hazard data for each EH site (see example in Figure 2). Some datasets do not extend to all parts of the country; in this instance the nearest data point was assigned to a site, whilst noting the distance and a *caveat*. Specific data for each hazard is described in Table 1, including additional data not currently used, but planned for the future.

Climate modelling

Climate models, projecting future changes in the climate based on different greenhouse gas emission scenarios, are explained elsewhere (Murphy et al. 2018). Projections are typically 30-year average periods, e.g. 2070–99, and are compared to a baseline period. The general approach has been to consider the worst-case emission scenario, where no changes are made to reduce greenhouse gas emissions and to consider the time period furthest into the current century, with a mid-century option where available. This emissions scenario is referred to by the IPCC as RCP8.5, standing for representative concentration pathway which relates to a driver of climate change, radiative forcing – the amount of energy entering the earth's atmosphere compared to the energy that leaves. In this instance the value was calculated as 8.5 W/m^2 in the year 2100. Where RCP8.5 is not available, + 2°C and +4°C future scenarios are used. Sometimes this is easier to interpret with regards to management decisions; the Climate Change Committee has recommended preparing for a + 2°C world and planning for a + 4°C world (Climate Change Committee 2021).

Understanding the uncertainty of climate projections is critical. How each dataset provides for this is described below and how uncertainty is dealt with in this approach is discussed later.

United Kingdom Climate Projections (UKCP18)

Various UKCP18 data is available (18 refers to the most recent dataset, released in 2018). Here we use national datasets from the Meteorological Office in the UK's Climate Data Portal (Met Office n.d.) with later site-specific work using lower spatial resolution data. Datasets used here (Table 1) consist of 12 separate regional climate models, referred to as an ensemble. Regional climate models give data at a better spatial resolution, useful for site-based analysis, but these require inputs at their boundaries, which are derived from global models, in this instance Hadley Centre Global Environment Model version GC3.05, (HadGEM3).

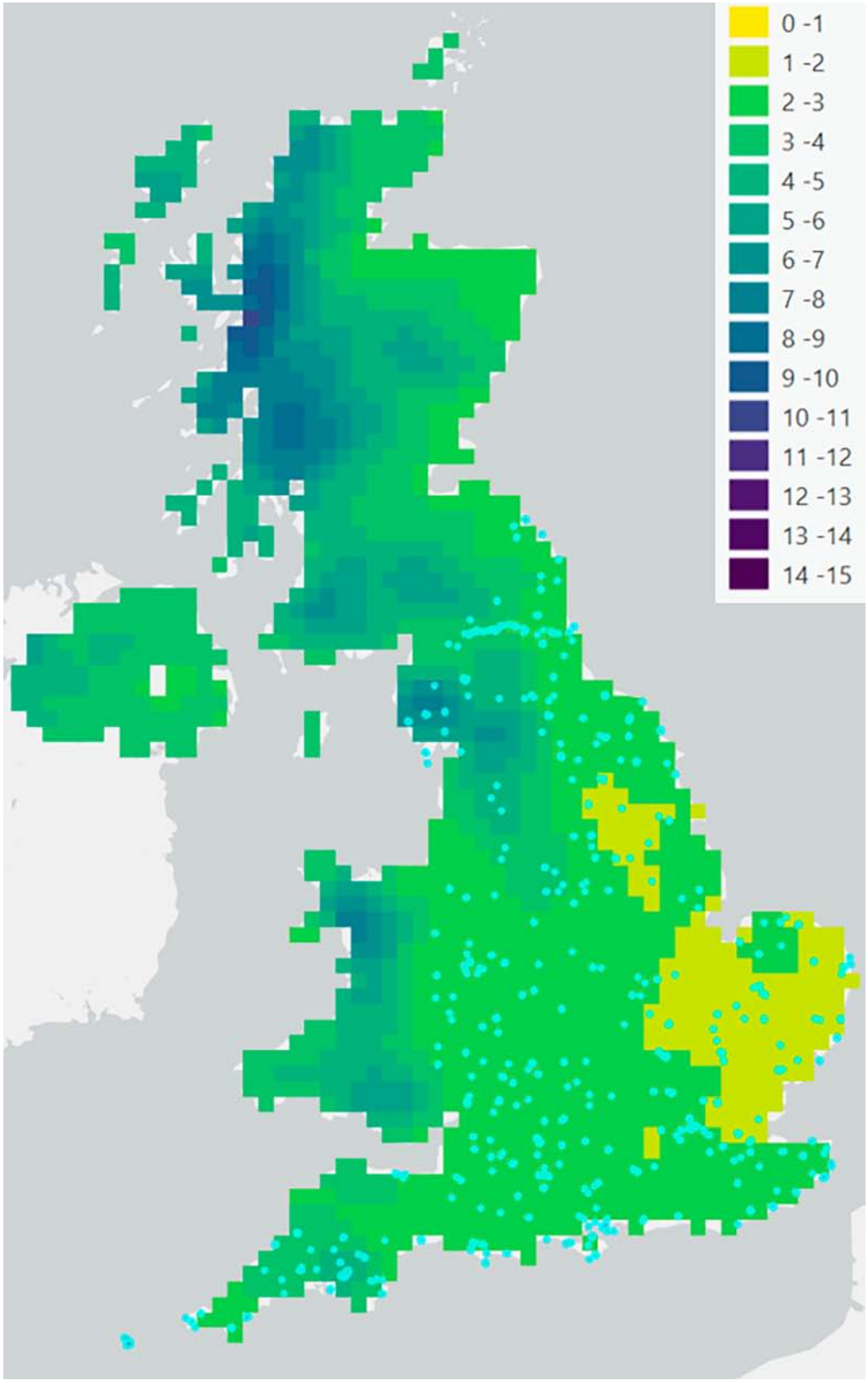


Figure 2. United Kingdom Climate Projections 2018 (UKCP18) Annual Precipitation Projections 2050–2079 overlaid with EH site boundaries marked in light blue. The median value is shown, using representative concentration pathway (RCP) 8.5, and the scale is mm/day per annum.

Data is at a spatial resolution of 12 by 12 km. There are two baseline periods 1981–2000 and 2001–2020, and two global warming levels were used, 2 and 4°C above the pre-industrial (1850–1900) period. This uses the RCP8.5 scenario to drive the model but relates to a temperature increase rather than a time period. The data at each warming level was calculated using a 21-year period, calculated by taking 10 years either side of the first year at which the global warming level is reached. The time taken by one

Table 1. Climate metrics available to map for each hazard.

Climate hazard	Metric	Description	Source	Emission Scenarios	Time horizon	Included
Temperature	mean temperature	annual averages of surface temperature [a]	UKCP18	RCP 8.5	2050–79	yes
	summer days	days per year where the maximum daily temperature is above 25°C	UKCP18	RCP 8.5	Two baselines and +1.5/2.0/2.5/3.0/4.0°C	no
	hot days	days per year where the maximum daily temperature is above 30°C	UKCP18	RCP 8.5	Two baselines and +1.5/2.0/2.5/3.0/4.0°C	no
	frost days	days per year where the minimum daily temperature is below 0°C	UKCP18	RCP 8.5	Two baselines and +1.5/2.0/2.5/3.0/4.0°C	yes
	icing days	days per year where the maximum daily temperature is below 0°C	UKCP18	RCP 8.5	Two baselines and +1.5/2.0/2.5/3.0/4.0°C	no
	growing degree days	annual sum of the number of degrees the daily average temperature is above 5.5°C each day	UKCP18	RCP 8.5	Two baselines and +1.5/2.0/2.5/3.0/4.0°C	yes
	heating degree days	annual sum of the number of degrees the daily average temperature is below 15.5°C each day	UKCP18	RCP 8.5	Two baselines and +1.5/2.0/2.5/3.0/4.0°C	yes
	cooling degree days	annual sum of the number of degrees the daily average temperature is above 22°C each day	UKCP18	RCP 8.5	Two baselines and +1.5/2.0/2.5/3.0/4.0°C	yes
	days >25°C	days per year where the average daily temperature is above 25°C	NT Hazmap	RCP 8.5	Baseline and 2060–80	yes
	days >30°C	days per year where the average daily temperature is above 30°C	NT Hazmap	RCP 8.5	Baseline and 2060–80	yes
	heat Stress (people)	days per year where shade Wet Bulb Globe Temperature (WBGT) above 25	CRI	RCP 2.6/6.0/8.5	Two baselines, each decade to 2100 and +1.0/1.5/2.0/2.5/3.0/3.5/4.0°C	yes
	Met Office heat wave	occurrence of heatwave following Met Office definition, events per year, duration (days) and % chance	CRI	RCP 2.6/6.0/8.5	Two baselines, each decade to 2100 and +1.0/1.5/2.0/2.5/3.0/3.5/4.0°C	yes
	road melt	days per year where the maximum daily temperature is above 25°C	CRI	RCP 2.6/6.0/8.5	Two baselines, each decade to 2100 and +1.0/1.5/2.0/2.5/3.0/3.5/4.0°C	yes
Precipitation	mean precipitation	monthly averages of rainfall amount (mm)	UKCP18	RCP 8.5	2040-69/2050-79/2070-99	yes
	days over 10 mm	days per year where the precipitation is above 10 mm	NT Hazmap	RCP 8.5	Baseline and 2060–80	yes
	days over 50 mm	days per year where the precipitation is above 50 mm	NT Hazmap	RCP 8.5	Baseline and 2060–80	yes
	drought severity index	calculated with 12-month rainfall deficits	UKCP18	RCP 8.5	Two baselines and +1.5/2.0/2.5/3.0/4.0°C	yes
	SPEI (drought length)	number of months with a Standardised Precipitation Evaporation Index (calculated from 6-month accumulated rainfall minus potential evaporation) less than −1.5	CRI	RCP 2.6/6.0/8.5	Two baselines, each decade to 2100 and +1.0/1.5/2.0/2.5/3.0/3.5/4.0°C	yes

(*Continued*)

Table 1. Continued.

Climate hazard	Metric	Description	Source	Emission Scenarios	Time horizon	Included
Wind	Storm damage	days per year where either, Wind speed >27 m/s, precipitation > 50 mm/h, Wind driven rain > 100 mm or snowfall > 26 mm[b]	NT Hazmap	RCP 8.5	Baseline and 2060–80	yes
Wildfire	Fire severity index – very high	days per year where the Met Office Fire severity index is above very high	CRI	RCP 2.6/6.0/8.5	Two baselines, each decade to 2100 and +1.0/1.5/2.0/2.5/3.0/3.5/4.0°C	yes
	Fire severity index – exceptional	days per year where the Met Office Fire severity index is above exceptional	CRI	RCP 2.6/6.0/8.5	Two baselines, each decade to 2100 and +1.0/1.5/2.0/2.5/3.0/3.5/4.0°C	yes
Coastal	Sea level rise	sea-level change (in cm)[c]	UKCP18	RCP2.6/4.5/8.5	each decade to 2100	yes
	Erosion	estimate of erosion extent and rate	NCERM	[d]	0-20/20-50/50-100 years	yes
Ground instability (combination of temperature and precipitation)	Shrink-Swell	potential for clay shrink-swell	BGS	RCP 8.5	2025-35/2065-75	Yes
	Slope Failure	Abrupt failure of site foundations due to weakening of underlying rock/ soil. This considers the geomorphology and future changes in Precipitation, Wind Speeds and Temperature[b]	NT Hazmap	RCP 8.5	Baseline and 2060–80	Yes
	Soil Heave	Property damage and disruption of site foundations due to uneven expansion and contraction of underlying soil. This considers the geomorphology and future changes in Precipitation and Temperature[b]	NT Hazmap	RCP 8.5	Baseline and 2060–80	Yes

Note: UKCP18: United Kingdom Climate Projections 2018. RCP: Representative Concentration Pathway. NT Hazmap: National Trust Hazard Mapping. CRI: Climate Risk Indicators. NCERM: National Coastal Erosion Risk Mapping. BGS: British Geological Society. SPEI: Standardised Precipitation Evaporation Index.

[a]others available, including monthly averages and for other epochs.

[b]raw data not available, categorised into 5 levels based on events per annum.

[c]data to 2300 available also.

[d]incorporates Sea Level Rise UKCP09 (United Kingdom Climate Projections 2009) data.

ensemble member to reach +2°C will be different to another member. To calculate specific metric values, an average is taken across the 21-year period. Data is available as the median ensemble member, lower (second lowest ranked member) and upper (second highest ranked member), indicating the range of uncertainty of plausible future outcomes (Met Office n.d.).

UK climate risk indicators

Data from UK-CRI.org (2023), developed as part of the UK climate resilience programme and covering a number of indicators – quantitative measures of an aspect of climate – for different models, resolutions, emission scenarios and time periods was used. The model, scenario and spatial scale parameters of the UKCP18 data were followed. Various time periods are available – a baseline of 1981–2010 and far future of 2071–2100 were used. Future work could consider others. The median ensemble member was selected for the national work. Site specific analysis also uses the lower and upper models (as above). Each metric is calculated as a 30-year period average.

National Trust hazard mapping

The National Trust, in collaboration with UK heritage organisations, has developed a hazard mapping tool (National Trust 2021) based on UKCP18 data and using RCP8.5. It presents current (1981–2010) and future time periods (2060–80), across a 5 km hexagonal grid. Metrics are either ranked 1–5, low to high hazard likelihood, or have raw data available. Uncertainty is currently not represented in this dataset.

British Geological Society (BGS) GeoClimate

BGS have several climate change related datasets, founded on UKCP18 data. Here GeoClimate UKCP18 Premium (Boorman, Hollis, and Lilly 1995; Harrison et al. 2018; Prudhomme et al. 2012) was used, which was created using data provided under agreement from the UK Centre for Ecology and Hydrology, a licensed product although freely accessible to some. Two time periods are available: 2030 (2025–35) and 2070 (2065–75), UKCP18 data, using RCP8.5 and the median output, as a 2.2 km square grid is overlaid with GeoSure data (1:50000 scale). The 10th and 90th percentile are available, representing wetter and drier conditions. Outputs define the susceptibility of foundations to be affected by increased clay shrink-swell, categorised into five levels, from highly unlikely to extremely likely.

Coastal erosion

Two EH reports were assessed (Hunt 2011; LUC 2020) with the national coastal erosion risk mapping (NCERM) data. NCERM provides predicted erosion rates for the short term (to 2025), medium term (to 2055) and long term (to 2105), taking into account the shoreline management policy (Environment Agency 2024).

Vulnerability

> The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. (IPCC 2018)

To understand each site's vulnerability to climate change, data was gathered from our internal accident and incident reporting system (PRIME systems) and exported to assess in Microsoft Excel for the period 2017 to May 2023. This system is used at site and data is logged as an incident type, along with information as free text. Data assessed included reports of: falling masonry, tree limb falls, external fires, flood damage, water leaks, health incidents and unexpected site closures. Assessment of the free text field used text-based search for key words relating the incidents to weather, and categorising them by type, i.e. site closures because of wind/snow/fire. Water leaks were assessed case-by-case to relate them to weather. One weakness is that this method relies on site-based staff reporting incidents.

Current risks relating to ground instability and flooding were assessed. BGS GeoSure (Lee and Diaz Doce 2018) describes the risk attributed to shrink-swell, landslides, soluble rocks, compressible ground and collapsible deposits, categorised into low, moderate or significant. BGS GeoCoast (British Geological Survey 2022) includes NCERM data and geological susceptibility data, helping understand vulnerability.

To describe current flood risk, data from the Environment Agency was assessed, including information on historically recorded floods and flood zones two (FZ2) and three (FZ3). FZ2 relates to an annual flood risk of between 1% and 0.1% chance of flooding from rivers and between a 0.5% and 0.1% chance of flooding from the sea. FZ3 relates to an annual flood risk of greater than 1% chance of flooding from rivers and greater than a 0.5% chance of flooding from the sea (Environment Agency n.d.). Groundwater flooding risk was available from BGS – susceptibility to groundwater flooding (British Geological Survey n.d.), defined as 3 categories: limited potential for groundwater flooding to occur, potential for groundwater flooding to occur below ground level, and potential for it to occur at the surface. These are based on rock type and estimated groundwater level during periods of extended intense rainfall. Surface water flooding data is available from DEFRA (n.d.), this will be incorporated at a national level in future. Future flood risk data is available at a cost but is not used here. Table 2 presents the metrics used to assess vulnerability and exposure (see below).

Table 2. Metrics used to map exposure and vulnerability.

	Metric	Assets	People	Operations	Gardens and landscapes	Collections
Exposure	Visitor numbers		x			
	Staff numbers		x			
	Volunteer numbers		x			
	Risk of income from site closure			x		
	Presence of formal gardens				x	
	Quantity of collections					x
	Significance of collections					x
	Significance of assets	x				
	Environmental designations				x	
Vulnerability	Building condition	x				
	Building sensitivities	x				
	Occurrence of external fires	x	x	x	x	x
	Falling masonry	x	x	x		
	Flood damage	x	x	x	x	x
	Water ingress (due to weather)	x	x	x		x
	Unexpected site closures			x		
	Tree/large branch falls		x	x	x	
	Current ground instability risk[a]	x	x	x	x	x
	Current flood risk[b]	x	x	x	x	x

[a]including shrink-swell, landslide, soluble rocks, compressible ground and collapsible deposits
[b]including fluvial flood risk, pluvial flood risk, ground water flood risk and historic flood occurrence

Exposure

> The presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected. (IPCC 2018)

Data collated to understand exposure across the five different themes included people at each site (visitor numbers – categorised as 1–5, site staff, and volunteer numbers) and collections (quantity and significance of objects, categorised as 1–5 and 1–3 respectively). As above designated environments were identified, and mapped, along with sites with significant gardens.

An existing metric within EH was used to help understand the exposure and vulnerability of our buildings or built assets. The sustainable conservation asset management plan (SCAMP) attributes a score to each property, based on significance, vulnerability and condition, each scored 1–5 and multiplied. A score of 125 would indicate a site of the highest significance, highest vulnerability (assessed across all aspects, not just climate change) and worst condition.

Operational exposure was considered in relation to loss of income. Monthly budget figures per site for the year 2023–24 were assessed and categorised (1–5 on a monthly basis) to indicate the impact of a closure on site income. The timing of a closure was considered – for most sites a winter closed day will have low significance, but for winter event sites a December closure can have a large impact compared to January (the annual value is an average of the monthly scores).

Results

The benefit of this method is that it rapidly gives results for an estate of significant size covering a wide geographical area. It is not practical, nor useful, to present all results but two case studies, where site-specific CCRAs have been completed, will be used to provide insight into the wider dataset, and to discuss this approach and further development. This also demonstrates how each level of assessment helps understand the impact of climate change, and how each is important in the overall goal of increasing climate resilience. Results for the two case studies are shown in Tables 3 (exposure and vulnerability) and 4 (hazard metrics).

Tintagel Castle is located on the coast in Cornwall. Half of the ruined castle is on the mainland, with the remaining part now on an island, due to coastal erosion over many centuries (Figure 3). The assessment of vulnerability identifies that high winds can be an issue, with 64 unexpected closures from 2017 to May 2023. The exposure assessment identifies that Tintagel is a significant site for income and was the second most visited site for the financial year 2022–23. Financial planning by EH already expects several closed days across the year but there are additional financial implications to high winds including accelerated deterioration driving up conservation costs. There is also significant interconnectivity here with other factors, e.g. coastal erosion limits visitor route options and warmer weather drives higher visitor numbers. Given site vulnerability to high winds, information on how this will change in the future is important. No easily accessible national datasets have been identified for this hazard but a site-specific assessment of projected future wind speeds has been completed using data available from UKCP18. Results indicate no significant changes expected in the future. However, this is still an area of current risk to EH and, as such, adaptation measures are worth considering to reduce exposure. Discussion with internal stakeholders is exploring practical measures that can be taken within the constraints of the site and its site of special scientific interest (SSSI) designation.

Table 3. Results of exposure and vulnerability metrics.

Property Name	Assets				H+S reports				People			Operations		Landscape			Ground instability - current					Flooding - current		
	Building significance	Building sensitivity	Building condition	Score	external fire occurrence	masonry fall occurrences	flood damage occurrences	water leak from weather occurrences	visitor numbers - category	volunteer nos (active YTD)	Staff nos	risk to income	site closure - category	formal gardens	environment designations	tree fall occurrences	collections present (quantity class*significance)	shrink-swell	landslides	soluble rocks	compressible ground	collapsible deposit	Historic flood occurrence	EA flood zone 2	EA flood zone 3	Groundwater flood potential (BGS)
Brodsworth Hall and Gardens	4	2	2	16	0	2	8	7	4	274	41	2.00	3	1	0	4	15	Low	Low	Low	Low	Low	0	0	0	1
Tintagel Castle	5	3	5	75	1	10	0	0	5	13	81	3.42	5	0	6	0	6	Low	Low	Low	Low	Low	0	1	1	0

Note: H + S: Health and Safety. YTD: Year to date. EA: Environment Agency. BGS: British Geological Society.

To inform these discussions, adaptation libraries are available, e.g. Climate-ADAPT (n.d.) and Adaptation Scotland (n.d.). Adaptation is defined as:

> … the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects … (IPCC 2018)

Examples of adaptation options could be coastal defences to reduce the risk of erosion, or wildfire management plans to reduce the risk of the severity of a wildfire.

Brodsworth Hall and Gardens is located near Doncaster in South Yorkshire. Built in the 1860s, the Hall has a significant historic collection and extensive Victorian pleasure gardens (Figure 4).

There have been 15 occurrences of water ingress since 2017, and survey work highlights that Brodsworth is vulnerable. Combining this with a projected increase in annual rainfall indicates the existing vulnerability could be exacerbated by climate change.

Data on current flood risk and internal health and safety reports indicate an issue with flooding in the area around the main site entrance, impacting access. Figure 5 shows one dataset relating to current flood risk. Should this increase in future it will become a more significant problem resulting in site closure and potential loss of income. This requires closer monitoring to understand the frequency/depth of flooding, informing adaptation measures to improve drainage and maintain access.

Cooling degree days (annual sum of the number of degrees the daily average temperature is above 22°C each day) are projected to increase from 30 (2000–2017 baseline period) to 135 in a + 4°C world. The Hall is grade I listed, hence introducing mechanical cooling will be challenging. However this metric can be an indicator to identify spaces likely to be uncomfortable in the future e.g. the café kitchen, and where adaption measures may be needed. Similar metrics around temperature increase can help understand opportunities arising from climate change. For example, the road melt metric (number of days with a maximum temperature greater than 25°C) can be used to consider visitor behaviour, with an expectation that visitor numbers will increase with warmer weather, potentially increasing income, before falling once temperatures reach a threshold (3Keel n.d.).

Discussion

The assessment carried out is helpful in identifying sites that may be vulnerable to changes in future environmental parameters, and in some instances the

Table 4. (a – b). Results of future hazard metrics.

	Ground instability - future						Precipitation									Coastal Risk				Temperature						
Property Name	BGS shrink/swell 2030	BGS shrink/swell 2070	NT slope failure current	NT slope failure future	NT soil heave current	NT soil heave future	NT days over 10mm rain historic	NT days over 10mm rain future	NT days over 50mm rain historic	NT days over 50mm rain future	Rainfall per annum baseline UKCP mm	Rainfall per annum 2040-69 UKCP mm	Rainfall per annum 2070-99 UKCP mm	NT storm damage current	NT storm damage future	NCERM short term with intervention (metres)	NCERM long term with intervention (metres)	Sea level rise 2100 (cm)	susceptibility (BGS)	NT days over 25 current	NT days over 25 future	UKCP annual avg .T 2050-79 °C	Frost days baseline 1981-2000 UKCP	Frost days baseline 2000-2017 UKCP	Frost days +2.0 UKCP	Frost days +4.0 UKCP
Brodsworth Hall and Gardens	1	1	1	2	1	2	17	17	0.45	0.3	717	858	837	2	2	N/A	N/A	N/A	N/A	0.96	9.7	13	45	38	23	7.9
Tintagel Castle	1	1	1	3	1	3	35	40	0.34	0.7	**1324**	**1281**	**1321**	3	3	0.68	3.4	79	low/mod	0.13	1.1	13	18	15	7.2	1.9

	Heating/Cooling demand								Growing season						Drought						Road Melt		People								Wildfire			
Property Name	HDD baseline 1981-2000 UKCP	HDD baseline 2000-2017 UKCP	HDD +2.0 UKCP	HDD +4.0 UKCP	CDD baseline 1981-2000 UKCP	CDD baseline 2000-2017 UKCP	CDD +2.0 UKCP	CDD +4.0 UKCP	GDD baseline 1981-2000 UKCP	GDD baseline 200-2017 UKCP	GDD 2.0 UKCP	GDD 4.0 UKCP	Growing season length baseline in days (CRI)	Growing season length future in days (CRI)	DSI12 baseline 1981-2000 UKCP	DSI12 baseline 2000-2017 UKCP	DSI12 2.0 UKCP	DSI12 4.0 UKCP	SPEI baseline (CRI) proportion of time in months	SPEI future (CRI) proportion of time in months	Road melt baseline in days (CRI)	Road melt future in days (CRI)	WGBT baseline in days (CRI)	WGBT future in days (CRI)	Met Office heat wave %chance baseline	Met Office heat wave %chance future	Met Office heat wave duration baseline	Met Office heat wave duration future	Met Office heat wave events baseline	Met Office heat wave events future	Fire severity index days over very high baseline	Fire severity index days over very high future	Fire severity index days over exceptional baseline	Fire severity index days over exceptional future
Brodsworth Hall and Gardens	2384	2255	1945	1561	20	30	57	135	1797	1923	2292	2816	247	333	9	8	11	14	0.07	0.41	10	92	0	16	50	100	3.9	59	0.9	6	27	103	0	1.6
Tintagel Castle	2100	1988	1680	1303	5.1	8.4	18	51	1840	1960	2315	2829	287	350	6	7	4.3	5.2	0.07	0.34	1.7	46	0	5.1	13	100	2.8	29	0.2	5	4.5	26	0	0.1

Note: BGS: British Geological Society. NT: National Trust. UKCP: United Kingdom Climate Projections. NCERM: National Coastal Erosion Risk Mapping. HDD: heating degree days. CDD: cooling degree days. GDD: growing degree days. CRI: climate risk indicators. DSI12: drought severity index (12 month). SPEI: standardised precipitation evaporation index. WGBT: wet bulb temperature.



Figure 3. Tintagel Castle © Historic England. English Heritage Trust.

level of exposure is understood, and good data exists on how hazards may change at each site.

Complexity arises when trying to combine hazard, vulnerability, and exposure together. As identified, only a small projected change in some hazards can be important for some sites, whereas other sites may be resilient to large changes. Capturing data on this across an estate of over 400 sites is a significant task.

Another consideration is how to treat each theme (buildings, collections, gardens and landscapes, people and operations). Whilst interlinked, at this stage of development each is considered separately.



Figure 4. Brodsworth Hall and Gardens. © Historic England. English Heritage Trust.

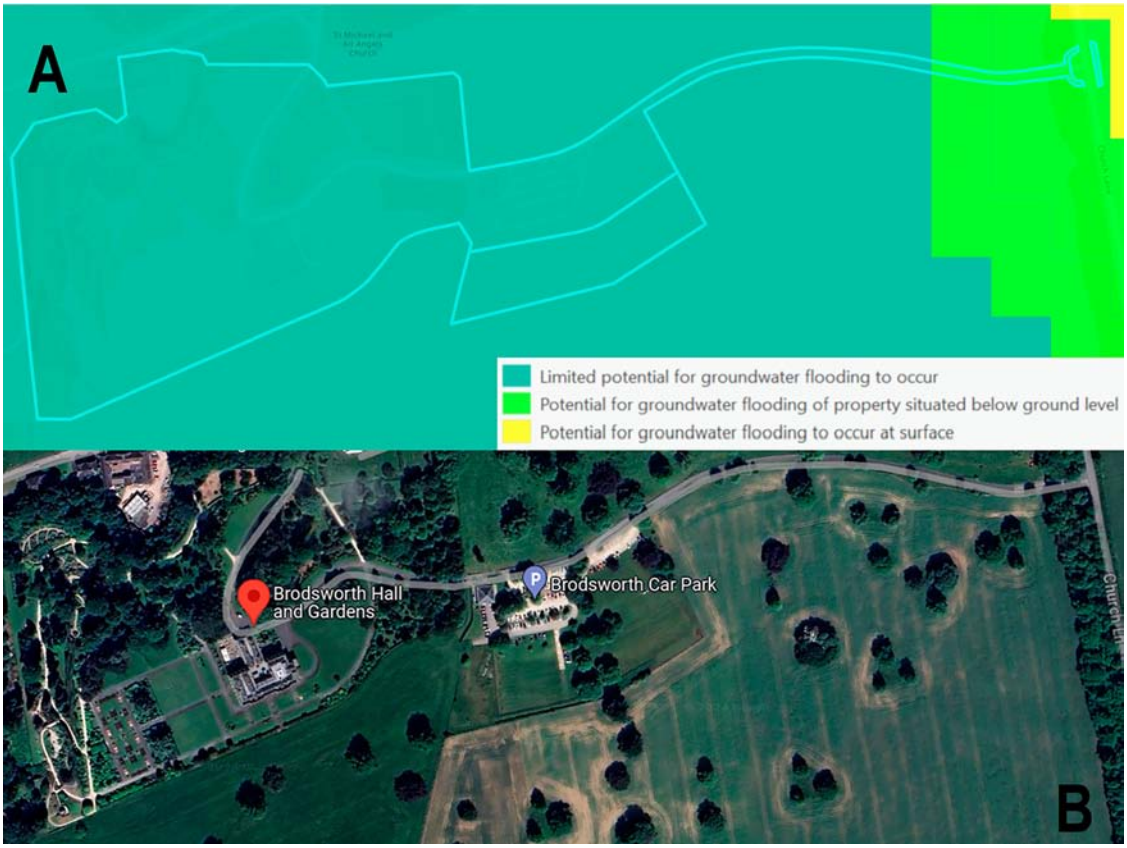


Figure 5. (a) Groundwater flooding potential for Brodsworth Hall and Gardens, with the site boundary marked. The public site entrance is located on the right of the image, along the driveway. Derived from BGS Digital Data under Licence (*2023/040*) British Geological Survey. © and Database Right UKRI. All rights reserved. (b) Satellite image of Brodsworth Hall and Gardens. Imagery © 2024 Airbus, CNES/Airbus, Getmapping plc, Infoterra Ltd &Bluesky, Maxar Technologies, The Geoinformation Group, Map data ©2024 Google.

The health and safety of people naturally is paramount. As such, changes to hazards which increase the risk of injury are very significant. The nature of a heritage organisation means that aspects with historic significance are important, arguably more so than operations. However, without the operational aspect, with the current business model, there would not be resource to fund maintenance and conservation of sites.

It is important to consider the purpose of a CCRA. For EH it is identifying high risk impacts, allowing for targeted investigation and investment in adaptation measures to make sites climate resilient. After undertaking the national CCRA it is important to undertake site-specific CCRAs and site-based insight is essential.

Further work

Many areas could be developed further. Functions relating environmental parameters to material damage could be developed as national maps, e.g. biomass accumulation on stone (Gómez-Bolea et al. 2012) and stone recession rates (Bonazza et al. 2009) and there is the potential to assess climate impacts to indoor materials (Huijbregts et al. 2013; Lankester 2013). Further hazard metrics such as wind-driven rain (Orr et al. 2018) and future flood risk could be included. There may be less obvious metrics to include, e.g. the level of investment planned for a site can be seen as a risk. As decisions now can be locked in for decades, prioritising sites with high levels of planned investment for a detailed CCRA will be important.

Other metric limitations include growing degree days, a simple indicator which doesn't consider other parameters required for growth of plants or insects. Recent soft capping research gives a good example of this (Richards et al. 2024). Since considerable resource is put into de-vegetation of monuments and land management, changes in growth and distribution of specific species could have a large impact and is another area for future exploration.

Limitations

Limitations of the data are important to consider, for example the data used to assess exposure and vulnerability from the internal health and safety system relies on staff reporting climate linked incidents which can result in inconsistencies. The system is not intended to report climate related incidents and as a result it



Figure 6. Example of a dynamic adaptation pathway for wildfire risk, developed by The National Trust (n.d.).

may be necessary to carry out a programme of engagement to highlight the use of such data for this work to encourage complete and consistent reporting. However, only by working with stakeholders who manage different aspects of each site can all the issues be understood and assessed in relation to climate change impact.

The methodology implemented here is heavily based on UK data and datasets available internally at EH, but the method is applicable more widely using similar hazard data available elsewhere and gives indicators of metrics useful to understand vulnerability and exposure.

Dynamic adaptation pathways

Naturally uncertainty associated with future climate projections is also a limitation. One way of dealing with this is the use of dynamic adaptation pathways (Haasnoot et al. 2013) (Figure 6). These provide a pathway to adaptation, highlighting available solutions to increasing climate resilience and their likely longevity. A strength is the ability to link to observed indicators at specific sites, in this example drought conditions, and identify on site tipping points at which different adaptation options may be required as well as providing a useful visual tool for engaging and planning for action with stakeholders.

Response

Response has not been included here but is covered by individual site CCRAs, and opportunities to collate national datasets will be identified and implemented in the future to develop the CCRA methodology. Response is a crucial part of the IPCC risk assessment framework which relates to actions, or lack thereof, that increase or decrease risk. For example, cyclical maintenance, or the lack thereof will affect the level of associated risk, or the speed of staff response to incidents can affect their severity. One example may be flooding: a site which is staffed at all times, with a well-prepared and practised emergency response plan has a greater ability to respond to an incident than another site that is staffed less frequently, without equipment available onsite.

Conclusion

Understanding the most significant climate risks to a complex historic estate with a wide geographical spread is essential in directing limited resources effectively. This research improves our understanding and ways of assessing the current and likely future impact of climate change, starts to identify which sites and aspects will be at greatest risk and lays the foundations for developing suitable adaptation measures to ensure these sites and EH are resilient to a changing climate.

Acknowledgements

This work was possible as a result of a Movement for Good award from the Benefact Group.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by Benefact Group.

References

3Keel. n.d. "Assessing the impact of climate change on UK tourism" 3Keel. Accessed October 5, 2023, https://www.3keel.com/climate-and-domestic-tourism/#:~:text=Data%20from%20more%20than%2085million,behaviour%20as%20weather%20patterns%20change.

Adaptation Scotland. n.d. "Adaptation Scotland" Sniffer. Accessed October 5, 2023, https://www.adaptationscotland.org.uk/.

Ara Begum, R., R. Lempert, E. Ali, T. A. Benjaminsen, T. Bernauer, W. Cramer, X. Cui, et al. 2022. "Point of Departure and Key Concepts." In *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by H. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, and B. Rama, 121–196. Cambridge: Cambridge University Press. https://doi.org/10.1017/9781009325844.003.

Bonazza, A., P. Messina, C. Sabbioni, C. M. Grossi, and P. Brimblecombe. 2009. "Mapping the Impact of Climate Change on Surface Recession of Carbonate Buildings in

Europe." *Science of the Total Environment* 407 (6): 2039–2050. https://doi.org/10.1016/j.scitotenv.2008.10.067

Boorman, D. B., J. M. Hollis. and A. Lilly. 1995. "Hydrology of Soil Types: A Hydrologically Based Classification of the Soils of the United Kingdom". Institute of Hydrology Report No. 126.

British Geological Survey. 2022. *User Guide: BGS GeoCoast V1. British Geological Survey Open Report, OR/21/001*. Nottingham: British Geological Survey. Accessed October 2023. https://www.bgs.ac.uk/download/bgs-geocoast-user-guide/.

British Geological Survey. n.d. *Susceptibility to Groundwater Flooding Explanatory Notes for Users*. Nottngham: British Geological Survey. Accessed October 2023. https://www.bgs.ac.uk/?wpdmdl=11850.

Climate-ADAPT. n.d. "Climate-ADAPT." European Environment Agency. Accessed October 5, 2023. https://climate-adapt.eea.europa.eu/.

Climate Change Committee. 2021. *Progress in Adapting to Climate Change 2021. Report to Parliament*. London: Climate Change Committee. Accessed October 2023. https://www.theccc.org.uk/wp-content/uploads/2021/06/Progress-in-adapting-to-climate-change-2021-Report-to-Parliament.pdf.

Day, J. C., S. F. Heron, A. Markham, J. Downes, J. Gibson, E. Hyslop, R. H. Jones, and A. Lyall. 2019. *Climate Risk Assessment for Heart of Neolithic Orkney World Heritage Property: An Application of the Climate Vulnerability Index*. Edinburgh: Historic Environment Scotland. Accessed May 2024. https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=c6f3e971-bd95-457c-a91d-aa77009aec69.

DEFRA. 2022. "Climate Change Adaptation Reporting: Third Round Reports." UK Government. Accessed October 2023. https://www.gov.uk/government/collections/climate-change-adaptation-reporting-third-round-reports#defra-agencies-and-public-bodies.

DEFRA. n.d. "DEFRA Risk of Flooding from Surface Water Data Download." UK Government. Accessed October 2023. https://environment.data.gov.uk/DefraDataDownload/?Mode=rofsw.

Environment Agency. 2024 "National Coastal Erosion Risk Mapping (NCERM) - National (2018 - 2021)." Environment Agency. Accessed January 2024. https://www.data.gov.uk/dataset/7564fcf7-2dd2-4878-bfb9-11c5cf971cf9/national-coastal-erosion-risk-mapping-ncerm-national-2018-2021.

Environment Agency. n.d. "Flood Zones and What They Mean." Environment Agency. Accessed October 2023. https://flood-map-for-planning.service.gov.uk/flood-zone-results-explained?zone=FZ1.

Gómez-Bolea, A., E. Llop, X. Arino, C. Saiz-Jimenez, A. Bonazza, P. Messina, and C. Sabbioni. 2012. "Mapping the Impact of Climate Change on Biomass Accumulation on Stone." *Journal of Cultural Heritage* 13 (3): 254–258. https://doi.org/10.1016/j.culher.2011.10.003.

Haasnoot, M., J. Kwakkel, W. Walker, and J. Maat. 2013. "Dynamic Adaptive Policy Pathways: A Method for Crafting Robust Decisions for a Deeply Uncertain World." *Global Environmental Change* 23 (2): 485–498. https://doi.org/10.1016/j.gloenvcha.2012.12.006

Harkin, D., M. Davies and E. Hyslop. 2018. *A Climate Change Risk Assessment of the Properties in Care of Historic Environment Scotland*. Edinburgh: Historic Environment Scotland. Accessed May 2024. https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=55d8dde6-3b68-444e-b6f2-a866011d129a.

Harkin, D., M. Davies, E. Hyslop, H. Fluck, M. Wiggins, O. Merritt, L. Barker, M. Deery, R. McNeary, and K. Westley. 2020. "Impacts of Climate Change on Cultural Heritage." *MCCIP Science Review* 2020: 616–641.

Harrison, A., J. White, M. Mansour, L. Wang, J.D. Mackay, A. Hulbert, A. G. Hughes. 2018. *User Guide for the British Geological Survey GeoClimateUKCP18: Clay Shrink-Swell Dataset. British Geological Survey Open Report, OR/20/13*. Nottingham: British Geological Survey. Accessed May 2024. https://www.bgs.ac.uk/?wpdmdl=59738.

Huijbregts, Z., M. Martens, J. Schijndel, and H. Schellen. 2013. "The use of Computer Simulation Models to Evaluate the Risks of Damage to Objects Exposed to Varying Indoor Climate Conditions in the Past, Present, and Future". In *Climate for Collections: Standards and Uncertainties*, edited by J. Ashley-Smith, A. Burmester and M. Eibl, 375–387. London: Archetype Publications.

Hunt, A. 2011. *English Heritage Coastal Estate Risk Assessment. English Heritage Research Report 68*/2011. Portsmouth: English Heritage. Accessed May 2024. https://historicengland.org.uk/research/results/reports/6005/EnglishHeritageCoastalEstateRiskAssessment.

IPCC. 2018. "Annex I: Glossary." edited by J. B. R. Matthews. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*, edited by V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield, 541–562. Cambridge and New York: Cambridge University Press.

Lankester, P. 2013. *The Impact of Climate Change on Historic Interiors*. Unpublished doctoral thesis, University of East Anglia, Norwich, UK.

Lee, K., and D. Diaz Doce. 2018. *User Guide for the British Geological Survey GeoSure Dataset: Version 8. British Geological Survey Open Report, OR/17/050*. Nottingham: British Geological Survey. Accessed May 2024. https://nora.nerc.ac.uk/id/eprint/518790/1/OR17050.pdf.

LUC. 2020. *Coastal Risk and Priority Places. Historic England Research Report 37*/2019. Portsmouth: Historic England. Accessed May 2024. https://historicengland.org.uk/research/results/reports/7915/CoastalRiskandPriorityPlaces.

Met Office. n.d. *Met Office Climate Data Portal*. Exeter: Met Office. Accessed October 2023. https://climate-themetoffice.hub.arcgis.com/.

Murphy, J. M., G. R. Harris, D. M. H. Sexton, E. J. Kendon, P. E. Bett, R. T. Clark, K. E. Eagle, et al. 2018. *UKCP18 Land Projections: Science Report*, Exeter: Met Office. Accessed May 2024. https://www.metoffice.gov.uk/pub/data/weather/uk/ukcp18/science-reports/UKCP18-Land-report.pdf.

National Trust. 2021. *National Trust Climate Hazards*. Swindon: National Trust. Accessed October 2023. https://national-trust.maps.arcgis.com/apps/webappviewer/index.html?id=a44672bb34c4491a909034d0eed76583.

National Trust. n.d. *Climate Change Adaptation Guidance — Places: Wildfire*. London: The International National Trusts Organisation. Accessed October 2023. https://www.into.org/app/uploads/2023/06/PLACES1.pdf.

Orr, S. A., J. Richards and S. Fatorić. 2021. "Climate Change and Cultural Heritage: A Systematic Literature Review (2016–2020)." *The Historic Environment: Policy & Practice* 12 (3-4): 434–477. https://doi.org/10.1080/17567505.2021.1957264

Orr, S. A., M. Young, D. Stelfox, J. Curran, and H. Viles. 2018. "Wind-driven Rain and Future Risk to Built Heritage in the United Kingdom: Novel Metrics for Characterising Rain Spells." *Science of the Total Environment* 640–641: 1098–1111. https://doi.org/10.1016/j.scitotenv.2018.05.354

Prudhomme, C., S. Dadson, D. Morris, J. Williamson, G. Goodsell, S. Crooks, L. Boolee, H. Davies, G. Buys, and T. Lafon. 2012. "Future Flows." Climate Data NERC Environmental Information Data Centre. https://doi.org/10.5285/bad1514f-119e-44a4-8e1e-442735bb9797.

Reisinger, A., M. Garschagen, K. J. Mach, M. Pathak, E. Poloczanska, M. van Aalst, A. C. Ruane, et al. 2020. *The Concept of Risk in the IPCC Sixth Assessment Report: A Summary of Cross-Working Group Discussions*. Geneva: Intergovernmental Panel on Climate Change.

Richards, J., E. Cooke, M. Coombes, J. Jones, and H. Viles. 2024. "Evaluating the Robustness of Nature-Based Solutions: Future Resilience of Sedum-Based Soft Capping as a Conservation Approach for Heritage Sites in Britain and Ireland." *Physical Geography* 45 (1): 20–38. https://doi.org/10.1080/02723646.2023.2212422.

Sesana, E., A. Gagnon, C. Ciantelli, J. Cassar, and J. Hughes. 2021. "Climate Change Impacts on Cultural Heritage: A Literature Review." *WIRES Climate Change* 12 (4): e710. https://doi.org/10.1002/wcc.710.

Simpson, N. P., S. A. Orr, S. Sabour, J. Clarke, M. Ishizawa, M. Feener, C. Ballard, et al. 2022. "ICSM CHC White Paper II: Impacts, Vulnerability, And Understanding Risks of Climate Change for Culture and Heritage: Contribution of Impacts Group II to the International CoSponsored Meeting on Culture, Heritage and Climate Change." Charenton-le-Pont and Paris: ICOMOS & ICSM CHC. Accessed May 2024. https://openarchive.icomos.org/id/eprint/2718/1/ICSM%20CHC%20White%20Paper%20II-%20Impacts%2C%20vulnerability%2C%20and%20understanding%20risks%20of%20climate%20change%20for%20culture%20and%20heritage.pdf.

UK-CRI.org. 2023. *Climate Risk Indicators*. Reading: University of Reading. Accessed October 2023. https://uk-cri.org/.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S190–S197
https://doi.org/10.1080/00393630.2024.2364997

ORIGINAL RESEARCH OR TREATMENT PAPER

Sustainable Preservation of Photographs in a Hot and Humid Climate: Dry Cabinets and Metal–Organic Framework Paper Composites

Preservación Sostenible de Fotografías en un Clima Cálido y Húmedo: Gabinetes Secos y Compuestos de Papel con Estructura Organometálica

Bertrand Lavédrine [1], Anne-Laurence Dupont[1], Pierre Tignol[1,2], Christian Serre[2], Vanessa Pimenta[2], Moisés L. Pinto[3] and Abeer Al Mohtar[3]

[1]Centre de Recherche sur la Conservation, Muséum national d'Histoire naturelle, Paris, France; [2]Institut des Matériaux Poreux de Paris, ESPCI Paris, Ecole Normale Supérieure, PSL University, Paris, France; [3]CERENA, Departamento de Engenharia Química, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal

ABSTRACT

In a project to preserve photographic archives in Southeast Asia, the authors sought to develop sustainable solutions with low environmental impact, avoiding air conditioning and using locally available materials. Dry cabinets were tested and implemented to store a glass plate negative collection that was rehoused in envelopes and boxes made locally. The project took just over a year to complete, and two years of monitoring environmental conditions have shown that relative humidity can be stabilized at low levels. However, the dry cabinets are airtight to limit the introduction of moisture and dust, preventing air exchange. In order to avoid the build-up of degradation by-products released by the stored materials, and in particular off-gassing of acetic acid from the cellulose acetate-based photographs, the use of an adsorbent is necessary. To achieve this, a cellulose-based composite with particles of a porous hybrid inorganic/ organic solid, denoted as a metal–organic framework (MOF), at a very high loading over 70% by weight and shaped as a sheet of paper, has been prepared and tested. This special paper maintains acetic acid-free air in the cabinets and also helps to reduce the energy consumption by reducing the need for cool storage. This MOF paper composite traps small carboxylic acids and was found to be an appropriate solution for maintaining clean air in the dry cabinets or any other confined space or enclosure. Additionally, it can also be designed to trap other noxious pollutants such as hydrogen sulfide or formaldehyde, by choosing other MOFs.

En un proyecto para preservar archivos fotográficos en el sudeste asiático, los autores buscaron desarrollar soluciones sostenibles con bajo impacto ambiental, evitando el aire acondicionado y utilizando materiales disponibles localmente. Se probaron e implementaron gabinetes secos para almacenar una colección de negativos en placas de vidrio que se realojó en sobres y cajas fabricados localmente. El proyecto tardó poco más de un año en completarse, y dos años de monitoreo de las condiciones ambientales han demostrado que la humedad relativa se puede estabilizar en niveles bajos. Sin embargo, los armarios secos son herméticos para limitar la introducción de humedad y polvo, impidiendo el intercambio de aire. Para evitar la acumulación de subproductos de degradación liberados por los materiales almacenados y, en particular, la liberación de gases de ácido acético de las fotografías a base de acetato de celulosa, es necesario el uso de un adsorbente. Para lograr esto, se ha desarrollado un compuesto a base de celulosa con partículas de un sólido híbrido inorgánico/orgánico poroso, denominado estructura metal-orgánica (MOF), con una carga muy alta superior al 70% en peso y con forma de hoja de papel. preparado y probado. Este papel especial mantiene el aire libre de ácido acético en los gabinetes y también ayuda a reducir el consumo de energía al reducir la necesidad de almacenamiento en frío. Este compuesto de papel MOF atrapa pequeños ácidos carboxílicos y aparece como una solución adecuada para mantener el aire limpio en gabinetes secos o cualquier otro espacio o recinto confinado. Además, también se puede diseñar para atrapar otros contaminantes nocivos como el sulfuro de hidrógeno o el formaldehído, eligiendo otros MOF.

ARTICLE HISTORY
Received September 2023
Accepted June 2024

KEYWORDS
Dry cabinet; VOCs; metal–organic framework; photographs

gabinete seco; COV; estructura metal-orgánica; fotografías

Introduction

Photographs are particularly sensitive to high relative humidity (RH), and storing them in a hot and humid climate leads to irreversible degradation ultimately leading to their total destruction. Thus, the international standards and guidelines for long- term preservation recommend to store them in a dry and cool to cold environment. In a tropical climate, adopting such conservation conditions requires the implementation

CONTACT Bertrand Lavédrine bertrand.lavedrine@mnhn.fr Centre de Recherche sur la Conservation, 36 rue Geoffroy Saint-Hilaire, 75005 Paris - France

© The International Institute for Conservation of Historic and Artistic Works 2024

of air conditioning, resulting in high cost and maintenance issues as well as a significant carbon footprint. The authors were faced with such a dilemma in a campaign for preserving a collection of silver gelatin glass plate negatives and 35 mm colour slides from the Department of Archaeology and National Museums in Yangon (Myanmar). This collection has great significance, as it holds images from important places and objects in Pagan and from across Myanmar captured during the first half of the twentieth century. Besides their artistic and aesthetic qualities, they have a high documentary value. The monuments in Pagan, dating from the eleventh to the fourteenth centuries, suffered major damage and destruction due to earthquakes in 1975 and 2016. This unique photograph collection may provide invaluable information for the restoration of the Pagan monuments. Unfortunately, these photographs have been subjected to a tropical climate for more than 70 years with the glass plate negatives exhibiting image layer degradation while the colour slides show colour fading. A preliminary survey of the glass plate negative collection indicated that the main degradation factor was the excess of moisture that promoted mould growth, and hastened the formation of silver mirroring and varnish deterioration. The priority was therefore to keep the collection in a drier environment and to rehouse it in good quality enclosures to ensure long-term preservation and provide improved access and use. The first part of this article focuses on the survey and care of the glass plate negative collection, in particular through installing commercially available dry cabinets. The second part evaluates how to extend the use of these dry cabinets to the storage of photographs on cellulose acetate supports by implementing an acetic acid adsorbent.

Implementation of a dry environment

International standards for long-term storage of glass plate negatives recommend a temperature of 18°C and an RH of 30–40% (ISO 2000). Lowering the temperature was not easily achievable in the context of this project because it requires a heating, ventilation, and air conditioning (HVAC) system with maintenance issues and high energy consumption. On the other hand, ensuring an RH level of between 30 and 40% with a low carbon footprint seemed achievable. Silica gel is often used as a passive means to control RH by placing a certain quantity in a cassette in showcases or in cabinets but in humid climates, it saturates quickly and must be regularly regenerated, which requires constant involvement. Dry cabinets are widely used to protect photographic equipment from fungi or for storing moisture-sensitive electronic components or even for entomological collections (Eureka Dry Tech 2019). Many models produced in India, China, Korea, or Taiwan are commercially available in Asia and beyond. These are simple and robust. In addition, they have the advantage of a low power consumption (a 60 L cabinet requires 5 W of power) and low maintenance requirements. They are made of metal with airtight glass doors and are available in different sizes (30–600 L). They include a small inbuilt dehumidification unit: either a Peltier cooler system, which removes moisture from the air by condensing it out on a cold surface, or an automatic regeneration desiccant unit. The desiccant, such as a zeolite, is regularly automatically reactivated with a hot air flow. The tightly closed cabinet doors ensure stable RH inside by limiting access to external moisture. This also prevents dust, dirt, insects, and rodents from entering.

Assessing dry cabinet performances

Preliminary tests were carried out at the National Museum of Natural History in Paris to evaluate the cabinet's performance. A small dry cabinet (Sirui HC-70 ®, 70 L) was acquired, set to 35% RH, and filled with paper documents (books, photo albums) that had been conditioned for a few days at 90% RH at room temperature. Temperature and humidity inside the cabinet were monitored using a datalogger during the summer in Paris with the room RH over 50% and temperature fluctuating from 25°C to 30°C. When the moist documents were introduced inside the cabinet, the RH inside rose to 70%. The unit then regularly removed a small fraction of water from the air inside the cabinet. For each drying cycle, the RH decreased by less than 1% until it reached the set value (35% RH). Each stepwise drop in RH was accompanied by a brief rise in temperature due to the operation. It took eight days before the RH within the cabinet dropped from 70% to 35%. Once the RH inside the cabinet had reached the set RH level, the buffering effect of the material inside the cabinet and the airtight insulation helped maintain the humidity level in a passive mode for a few days. When the RH inside rose over 37%RH due to air infiltration, a new series of drying cycles started, which lasted a few hours until the RH dropped to the set RH level. To maintain the RH stable inside the cabinet, a total of 2 days of operation was sufficient over the following 22 days. Following these preliminary tests, six Ruggard® electronic dry cabinets (600 L) were acquired to store the 5,500 glass plate negatives. The padding made of synthetic polyurethane foam shelf was removed and the target RH set to 40% for each cabinet. The cabinets were then filled with the glass plate negatives collection over the period from January 2020 to December 2020 (Figure 1). Over the next two years of monitoring, the RH stayed very stable (Figure 2) in all six cabinets. We noticed some short-term high RH peaks, probably due to the



Figure 1. Dry cabinets with the collection of glass plate negatives, after re-housing at the Department of Archaeology and National Museums of Myanmar in Yangon.

opening of the cabinets when working on the collection. When comparing the RH inside the cabinet to the ambient RH, the improvement is impressive (Figure 2); even during the monsoon season (June to October) when the ambient RH reached over 80%, the RH inside the cabinet remained stable around from 35 to 40%, depending on the cabinet. After one year's operation, the RH set point was fine-tuned in some cabinets to get as close as possible to 40% RH (Figure 2). Considering their limited and discontinuous power consumption requirements, a further future improvement would be to power the cabinets using photovoltaic cells.

Locally produced enclosures

Envelopes for glass plate negatives

The original paper envelopes had induced damages on the glass plate negatives and it was necessary to replace them with a suitable housing while keeping them separate as historical evidence. The use of synthetic polymer envelopes, either polyethylene or polyester, was excluded due to the risk of adhesion to the gelatin layer and biological degradation resulting from the moisture inside. Paper is water-vapor permeable, and depending on its thickness, it acts not only as an RH buffer but also as cushioning, mitigating uneven pressure between plates and eventually absorbing shocks. Paper used for photographs preservation has to be 'photo safe' (ISO 2013) so as not to promote further image degradation. Initially, attempts were made to find locally produced good quality paper such as that produced in Luang-Prabang (Laos) for the preservation of the Buddhist Archives (Jürgens 2015). Local mulberry paper used to make umbrellas in the northeast of Myanmar failed the photographic activity test (ISO 2007). Another issue with this paper was its coarse and uneven texture. There was a risk of abrasion of the photographic image layer and the irregular contact with the image may have generated a specific degradation pattern. In the end, paper enclosures had to be imported from abroad. Photo-safe four-flap envelopes were expensive (averaging $5US each) and not available in all formats so Chronos® paper sheets (79.2 cm × 121.9 cm) were bought in Europe instead. By optimizing the cutting, only 1300 sheets were needed to house the whole collection for a final average cost of less than $0.5US per envelope. Making a traditional four-flap envelope leads to the loss of 4/9 of the paper sheet after cutting. To avoid such waste, the four-flap envelopes were made by cutting two strips of paper and sliding the smaller one into two slits in the larger one (Figure 3(a)). The local team quickly mastered their making, how to place the plate inside image side up, and how to sequence the closing of the flaps carefully.

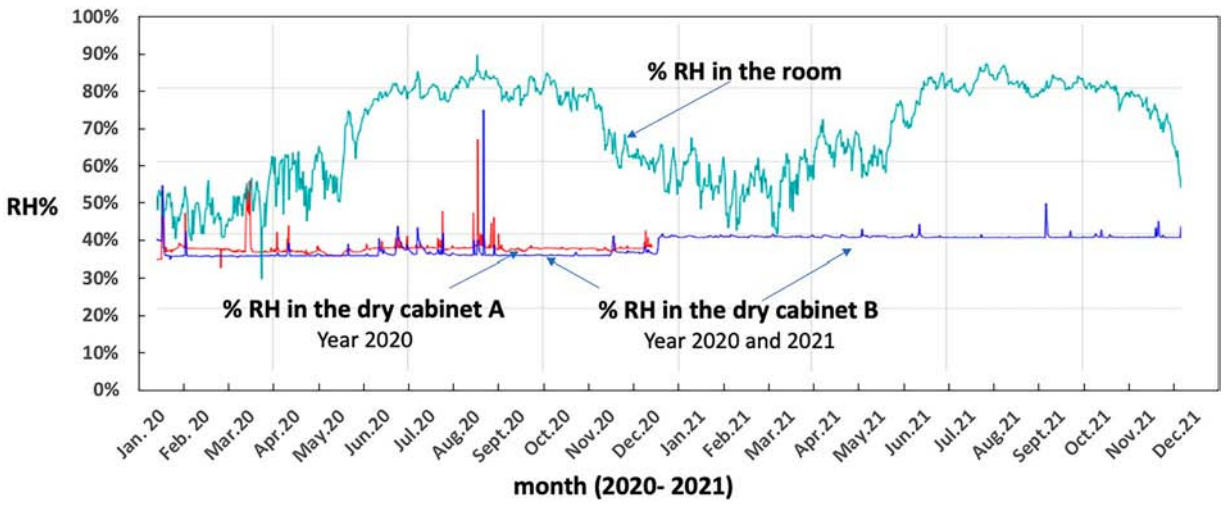


Figure 2. RH inside dry cabinets (dark blue and red for two different cabinets) and in the room (turquoise) for 2 years, beginning in 2020. The frequent peaks in RH are due to the doors being opened. In December 2020, the set point in the cabinets was slightly increased to 40% RH.



Figure 3. Local production of photographic enclosures. (Left) Four-flap envelopes made with 2 paper strips. (Right) Making boxes in the background, the old storage cabinets can be seen.

Boxes for glass plate negatives

Originally, the plates were not housed in boxes: the smaller formats (dimensions in cm: 16.5 × 21.6, 12 × 16.5, 9.5 × 10.8) were stored vertically on the shelves while the larger plates (20.3 × 25.4 and 25.4 × 20.5) were stored flat, separately. It was decided that containers would offer extra protection and allow a safe retrieval and handling of the plates. No conservation boxes were available locally. The easiest and cheapest option was to make them from locally-available 2.8 mm thick fluted polypropylene (PP) sheets. Fluted PP boxes (or E-flute corrugated PP) (Seo, Shin, and Kim 2009) are light and mechanically resistant enough for holding heavy glass plates. They absorb shocks and are cheaper than conservation-quality cardboard boxes. Furthermore, they are not sensitive to water and hence to bio- deterioration. Two types of foldable boxes were produced for less than $1.5US each: one flat box inspired by the Metropolitan Museum of Art (New York, USA) model and one vertical box. Within a few days, the team was skilled at producing these boxes (Figure 3(b)). For some boxes, hot melt polyethylene adhesive was applied with a glue gun to secure certain parts. In that case, the upper layer of the E-flute PP was scratched to let the glue penetrate into the fluted structure and reinforce cohesion. Finally, the repackaging process could start. The three smallest plate formats were housed vertically along their long edge in the 24.5 × 19.0 × 9.5 cm boxes, while the largest plates were kept flat in the 26.0 × 30.4 × 5.0 cm boxes. For preservation it would have been easier to group the plate formats according to their format, thus limiting the risks of mechanical damage that may occur if boxes contain different plate formats (i.e. due to uneven pressure and possible movement of the plates). However, re-introducing a new numbering system would be challenging and add complexity as well as a risk of dissociating negatives of different formats but belonging to the same series, so the order of the plates has been preserved in the boxes. These boxes therefore were filled with a limited number of plates (ca. 20) in various formats and when a mechanical risk was identified, for example with the proximity of two plates of very different formats, cushioning made of a fluted PP sheet was inserted between the two.

Further perspective for storage of acetate films in dry cabinets

As mentioned earlier, the collection also contained 35 mm chromogenic colour slides on cellulose triacetate supports dating from the 1960s. These colour slides showed colour fading and would have benefited from storage in the dry cabinets to slow down the degradation of the dyes and also that of the cellulose acetate base (Reilly 1993). However, it is not advised to store cellulose acetate films in airtight containers since the acetic acid released by the hydrolysis of cellulose acetate builds up and catalyzes its own degradation as well as that of the surrounding photographs (Reilly 1993; Al Mohtar et al. 2021). As a result, these cellulose acetate-based films were not stored in dry cabinets but were left in their original condition for the time being, until a means of preventing the accumulation of acetic acid could be found. The use of zeolites as adsorbents proposed by Kodak (Ram et al. 1993) is less effective, as they are very hydrophilic and absorb more moisture than acetic acid. As for activated carbon, it can release adsorbed compounds. The solution emerged from collaborative work on acetic acid capture carried out as part of the European Union-funded *Nemosine* project.

Making a metal–organic framework paper composite

We have evaluated the possibility of using metal–organic frameworks (MOFs). This new class of porous materials has been developed to selectively adsorb certain gases. They are synthesized in the laboratory by bonding metal cations to organic molecules (e.g. carboxylates), producing an ordered porous hybrid structure. The number of possible combinations of organic bonds and metal cores is very large, making it possible to obtain a wide range of structures with adjustable pore size and chemical polarity. Out of all the MOF compounds tested, the mesoporous Fe(III) tricarboxylate MOF denoted MIL-100(Fe) ('MIL' stands for 'materials of the Institute Lavoisier') was shown to be very efficient for adsorbing acetic acid at a moderate cost (Dedecker et al. 2019; Severino et al. 2023). It can be produced by a green synthesis process, at room temperature, by mixing non-toxic compounds in water (iron nitrate and trimesic acid). The MIL-100 (Fe) obtained has a porous crystalline structure with a Brunauer–Emmett–Teller (BET) surface area exceeding 1500 m^2g^{-1} (Tignol et al. 2024). When exposed to acetic acid vapors in the presence of variable humidity, MIL-100(Fe) strongly adsorbs the acetic acid on its constitutive open metal sites (Lewis acid sites) with little or no desorption. The release of the trapped gas is achieved by heating the MOF at a temperature above 150°C (Severino et al. 2023). One outstanding feature of MIL100(Fe) is that water adsorption does not compete with acetic acid adsorption, the latter being thermodynamically favoured. MOFs are synthetized as powders, and shaped to form granules or beads. However, handling beads or granules is not very practical in heritage institutions, so they have to be packed in bags or cassettes, with a risk of perforation. We have therefore investigated a shaping that produces a paper-based composite that retains the mechanical properties of the paper and the sorption properties of MOF; this should be more practical for use in galleries, libraries, archives, or museums. Such shaping ensures the structural integrity of the constituents while allowing controlled airflow and efficient purification. A paper sheet is also a well-known and universally used material, easy to store, to handle and fully customizable to fit the shape of all conservation enclosures, whether envelopes, boxes, display cases or frames. The heritage conservation community is familiar with a type of adsorbent sheets made of a cellulose mixed with 20% zeolites, which was popular in the early 2000s (MicroChamber®) (Daniel et al. 1999). Such material can be more efficient and last longer if it contains a higher loading of an appropriate adsorbent. Our aim was then to load as much MOF powder as possible into a sheet of paper. However, incorporating more than 30% fillers into a cellulosic substrate adversely hampers its mechanical properties due to the disruption of the fibre network and fibre-to-fibre bonding (Mintova and Valtchev 1996). In order to produce a sheet of paper with very high filler content while maintaining sufficient mechanical properties, bleached softwood kraft pulp fibres were mixed with microfibrillated cellulose (MFC), also called cellulose nanofibres (CNF). The CNF are made of nanometre-wide and up to several micrometres-long cellulose microfibrils (Thomas et al. 2018). In the composite, they act as a nanostructuring material. Such an entangled network of fibers and microfibrils allows satisfactory mechanical properties despite the very high MOF loading. The ultimate tensile strength (UTS), corresponding to the maximum stress that a material can endure when pulled before breaking, is around 1.5 MPa for a 75 wt % MOF paper sheet, and such a sheet can still easily be handled without breaking. The MOF paper sheets were prepared by vigorously dispersing 6.25% of softwood pulp fibers, 18.75% of NFC (Celova®, Weidmann), and 75% of MIL-100(Fe) powder in water and then filtering the suspension under vacuum on a fast filtration Whatman filter paper or a nylon fabric. Similarly, composite paper sheets loaded with as much as 90% of MIL-100(Fe) or with other porous materials other than MOFs, namely activated carbon, and zeolites, were successfully produced (Figure 4). The fibrous matt was then pressed to extract the excess of water and dried under weights and between blotting paper. Characterization and tests described below were carried out with the MOF paper loaded with 75% MIL-100(Fe). The MOF sheets exhibited a grammage of 120–140 gm^{-2} and can be used as such or after activation. Activation (8 hours at 150°C under vacuum) allows all the pores to be clean before use so to adsorb slightly higher amounts of acetic acid than the non-activated ones. The properties and morphology of the new composite were assessed using nitrogen porosimetry (Figure 5) and scanning electron microscopy (Figure 6). This MOF paper sheet exhibited equal performance to that of the native MIL-100(Fe) powder, while significantly outperforming

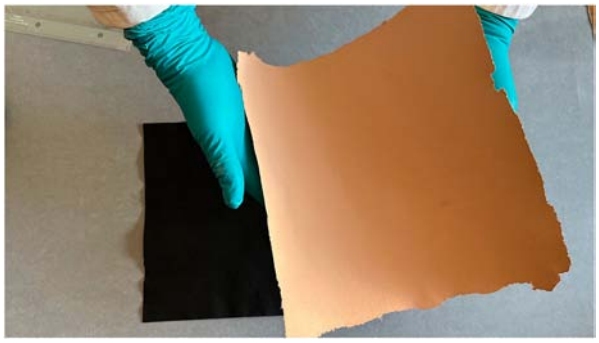


Figure 4. A 83% MIL-100 paper composite sheet. In the background, a similar composite paper loaded with activated carbon.

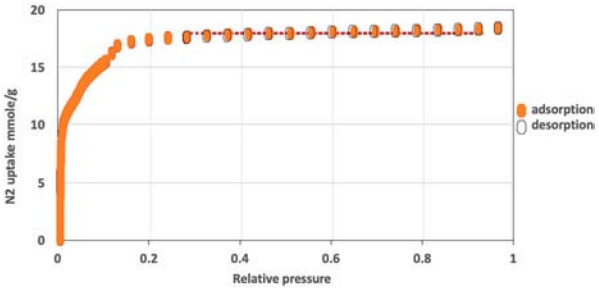


Figure 5. N_2 adsorption-desorption isotherms at 77 K for MIL-100(Fe) paper sheet.

the more traditionally shaped products such as beads or granules, even those containing 85–95 wt % MOF. Actually, the binder used for shaping them results in blocking some pores of the MOF, but this was not observed in MOF paper (Tignol et al. 2024).

Use of the MOF paper composite for photograph preservation

To ensure that the MIL-100(Fe) paper sheet could be safely placed in the vicinity or in contact with artefacts, the composite was submitted to the photographic activity test. Another compatibility test was carried out to verify that no residual volatile compounds emitted by it could have a deleterious effect on cellulosic artefacts in its vicinity. The test was done by measuring the degree of polymerization (DPv) of cellulose of Whatman no.1 test paper after artificial aging (21 days) in the same vial as the composite, and comparing to the DPv of a Whatman no.1 reference paper aged under the same conditions but without the composite (ISO 2020). The MOF paper successfully passed the two tests and *in situ* validation tests were finally carried out to verify the efficiency of MIL-100(Fe) under real acetate films storage conditions in a film archive (Al Mohtar et al. 2023). In laboratory tests, MOF paper proved as effective as MOF powder in trapping acetic acid vapours produced by an acetic acid solution. To verify this in real conditions, we selected movie films suffering from vinegar syndrome. The VOCS emitted from movie films were first assessed by connecting the film container to a proton-transfer-reaction time-of-flight mass spectrometer (PTR-ToF-MS) (Kammer et al. 2021). Acetic acid was the major compound detected, representing 81% of the VOCs off-gassing and being emitted at a rate of 779 ngs^{-1}. This test was repeated, but the off-gassing was passed through a filter holder containing a piece of MOF paper, acetic acid and more than 30 different VOCs emitted from cellulose acetate film were captured by the MOF until its saturation. An experiment carried out at the Valencia Film Archive (Spain) showed that when MOF was added to a movie film can, the concentration of acetic acid dropped rapidly from around 2.2 pm to 0.2 ppm. MIL-100(Fe) will avoid cross contamination between good condition cellulose acetate films and degraded films and will significantly extend their life span. A recently published theoretical model shows that using 0.1 kg of MIL-100(Fe) paper per kg of acetate film at 22°C for 10 years should have the same benefit as storing it in a cold room at 5°C (Al Mohtar et al. 2023). After 10 years, the composite may become saturated and should be replaced. The MIL-100 MOF powder or paper can be regenerated by immersion in purified water at room temperature. This simple procedure extracts the acetic acid trapped in the pores without affecting the mechanical stability of the sheet and allows it to be reused (Tignol et al. 2024).

Conclusion

The photograph collections of the Department of Archaeology and National Museums of Myanmar was an excellent case study for implementing an

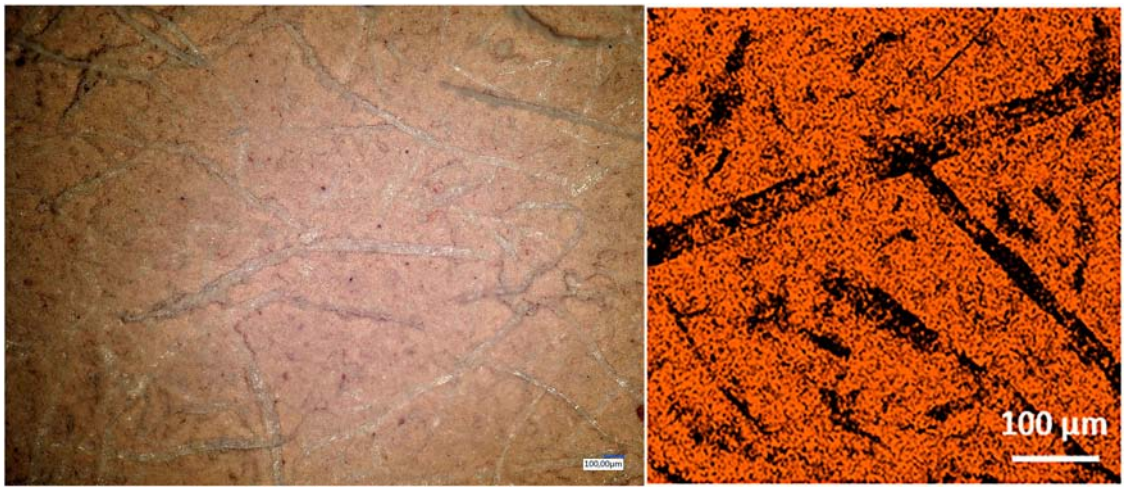


Figure 6. Optical microscopy (left) and mapping with energy-dispersive X-ray spectroscopy (right) of a 75 wt % MIL-100(Fe) paper surface. On the scanning electron micrograph (right) the softwood cellulosic fibers are shown in black and the iron (MIL-100) in brown. The fine nano-fibrillated cellulose fibers are not perceptible at this magnification.

innovative conservation strategy. As it was not possible to apply the standardized recommendations, compromises had to be made that relied on local materials and resources, collection assessment, and the training and commitment of local staff. The implementation of dry cabinets has proven to be very efficient for maintaining a stable RH level. Inside the cabinets, the RH is stabilized at an average 40% RH with low standard deviation (maximum of 5%), whereas outside the cabinets it fluctuates from about 40% to over 80% during the monsoon. This preservation solution was quick to implement and had multiple benefits. It has allowed a radical and lasting improvement in the conservation of the photograph collection, without having to resort to the traditional approach using heavy-duty solutions, such as HVAC, which would probably not have been as successful anyhow, given the political and epidemiological situation that arose shortly after the start of the project. To extend the use of such dry cabinets to the storage of the cellulose acetate films, the addition of a new type of porous sorbent was investigated and the iron carboxylate MOF denoted MIL-100(Fe) proved to be capable capturing selectively traces of acetic acid. It opens up the possibility of conserving acetate films or other materials that emit carboxylic acids all together at room temperature expanding the life expectancy of cellulose acetate films and avoiding the risk of cross contamination. Al Mohtar et al. (2023) calculated that this might also results in an average reduction of the carbon footprint related to acetate films preservation of about 50% in the current European Union (EU) energy mix policy, and by about 40% considering the 2030 EU energy mix (where a transition towards renewable energy is expected). The ability to shape adsorbents into highly charged paper sheets allows to foresee a wide range of possibilities, enabling specific pollutants to be targeted just by choosing the most appropriate adsorbent or adsorbents blend. In addition to MIL-100(Fe) for capturing carboxylic acids, other MOFs are suitable for the efficient capture or conversion of various indoor museum pollutants. For example, Sadovnik (2021) uses the microporous Al pyrazole dicarboxylate Al-3,5 PDA to capture selectively traces of formaldehyde in the presence of humidity without any release before 50°C. Martínez-Ahumada et al. (2021) also proposed the use of different MOFs to trap or convert SO_2, H_2S, NH_3, NOx, while Sun et al. (2021) report a manganese-based MOF for high-performance catalytic ozone removal. It shall therefore be possible to produce a whole range of paper sheets loaded with a high loading of specific MOF powders to individually target specific pollutants. Then, depending on the air quality to be achieved or the sensitivity of the objects to be preserved, the collections manager might assemble different MOF-loaded sheets. This is expected to be highly valuable in preserving collections as well as improving air quality for human health. As mentioned, the sheets might be used as passive sorbents in envelopes, boxes, cabinets, display cases. They could also be used for air dehumidification or in cooling systems in HVAC units (Feng et al. 2018) as they require less energy (<80°C) to be dried compared to the traditional mineral porous compounds. The proposed approaches therefore represent promising solutions for effective and more sustainable heritage preservation, while making a significant contribution to reducing the carbon footprint in the cultural heritage sector.

Materials

Celova®, Weidmann, https://weidmannfibertechnology.com/

Chronos® paper 100% pure, acid-free alpha-cellulose with an alkaline buffer, pH 8.5, and no optical brighteners. It passed the photographic activity test: 90g/m2. https://secan.fr/produit/blanc-naturel-ph-85/

Ruggard® electronic dry cabinet. https://www.ruggard.com/product/11837/Ruggard-EDC_600L-Electronic-Dry-Cabinet-(Black,%20600L)

Sirui® HC-70 Dry Cabinet https://sirui.in/product-category/dry-cabinets-dehumidifiers/

Acknowledgements

The project was carried out within the framework of an international collaboration between the UNESCO offices in Thailand and Myanmar, the Department of Archaeology of Myanmar and the Centre de Recherche sur la Conservation in France. The management team included Andrew Henderson and Misako Ito (UNESCO Thailand), Naing Naing Aye (UNESCO Myanmar), and Daw Nyo Nyo Than (Yangon Department of Archaeology). We would like to thank the following people for their support: Daw Ohnmar Aung, Director of the Department of Archaeology and National Museum, Yangon Branch Office, Ms Chaw Su Su Hlaing Department of Archaeology and National Museum, Yangon Branch Office, Ms Min Jeong Kim, Head of the UNESCO Myanmar Project Office and U. Kyaw Oo Lwin, Director-General of the Department of Archaeology and National Museums, for their support; Christine Bastard, at the National Museum of Natural History, Paris, for cutting paper strips; Martin Jürgens, at the Rijksmuseum, Amsterdam, for his work in Luang Prabang; Nora Kennedy and Georgia Southworth, at the Metropolitan Museum of Art, New York, for their model of a foldable box; Connie McCabe, at the National Gallery of Art, Washington, for our inspiring discussion; Kamonwan Petchot, at UNESCO, Bangkok, and Seng Hkawn, UNESCO, Myanmar, for the logistics; Pierre Pichard, at EFEO, for providing information on Pagan; Sabrina Paris and Léon Vilmont, at the CRC, Paris, for analysing paper fibres; Tram Vo, Los Angeles, for ensuring preservation training; and the Republic of Korea, through the National Archives of Korea, for its generous funding.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The work on MOFs has received funding from the EU Horizon 2020 research and innovation program under grant agreement no. 760801\NEMOSINE.

ORCID

Bertrand Lavédrine http://orcid.org/0000-0002-9710-3895

References

Al Mohtar, A., S. Nunes, J. Silva, A. M. Ramos, J. Lopes, and M. L. Pinto. 2021. "First-Principles Model to Evaluate Quantitatively the Long-Life Behavior of Cellulose Acetate Polymers." *ACS Omega* 6 (12): 8028–8037.

Al Mohtar, A., M. I. Severino, P. Tignol, L. Ranza, A. Neves, F. Nouar, V. Pimenta, et al. 2023. "Iron(III) Based Metal-Organic Frameworks in Movie Film Preservation: Fundamental Aspects and Application." [Preprint]. SSRN. https://doi.org/10.2139/ssrn.4530955.

Daniel, F., V. Hatzigeorgiou, S. Copy, and F. Flieder. 1999. "Étude de l'Efficacité d'un Nouveau Produit d'Archivage: le MicroChamber." In *Les Documents Graphiques et Photographiques: Analyse et Conservation. Travaux du CRCDG, 1994–1998*, 25–50. Paris: Direction des Archives de France.

Dedecker, K., E. Dumas, B. Lavédrine, N. Steunou, and C. Serre. 2019. "Metal-Organic Frameworks for the Capture of Volatile Organic Compounds and Toxic Chemicals." In *Metal-Organic Frameworks (MOFs) for Environmental Applications*, edited by S. K. Ghosh, 141–178. New York: Elsevier. https://doi.org/10.1016/B978-0-12-814633-0.00007-7

Eureka Dry Tech. 2019. "Entomology Dry Cabinet Storage for Butterfly Specimens." Accessed 26 August 2019. https://eurekadrytech.com/blog/eureka-dry-cabinet-storage-butterfly-specimen.

Feng, X., M. Qin, S. Cui, and C. Rode. 2018. "Metal-Organic Framework MIL-100(Fe) as a Novel Moisture Buffer Material for Energy-Efficient Indoor Humidity Control." *Building and Environment* 145: 234–242. https://doi.org/10.1016/j.buildenv.2018.09.027.

ISO. 2000. *Imaging Materials – Imaging Materials — Processed Photographic Plates — Storage Practices (ISO Standard No. 18918)*. Geneva: International Organization for Standardization. www.iso.org/standard/60377.html.

ISO. 2007. *Imaging Materials – Processed Imaging Materials – Photographic Activity Test for Enclosure Materials (ISO Standard No. 18916)*. Geneva: International Organization for Standardization. www.iso.org/standard/31940.html.

ISO. 2013. *Imaging Materials – Processed Imaging Materials – Albums, Framing and Storage Materials (ISO Standard No. 18902)*. Geneva: International Organization for Standardization. www.iso.org/standard/60377.html.

ISO. 2020. *Information and Documentation — Papers and Boards Used for Conservation — Measurement of Impact of Volatiles on Cellulose in Paper. (ISO Standard No. 3404)*. Geneva: International Organization for Standardization. www.iso.org/standard/75439.html.

Jürgens, M. C. 2015. "The Buddhist Archive of Photography: Archival Organization, Digitization and Conservation in the Context of Research Projects of the British Library (2006–2014)." In *The Lao Sangha and Modernity: Research at the Buddhist Archives of Luang Prabang, 2005 to 2015*, edited by V. Grabowsky, H. G. Berger, K. Boulyaphonh, and B. Sengsoulin, 267–290. New York: Anantha Publishing.

Kammer, J., F. Truong, C. Boissard, A. Soulié, A. Dupont, L. Simon, V. Gros, and B. Lavédrine. 2021. "Quantitative and Qualitative Assessment of VOCs Emitted From Cellulose Acetate Movie Films by PTR-ToF-MS." *Journal of Cultural Heritage* 47: 50–58. https://doi.org/10.1016/j.culher.2020.09.004.

Martínez-Ahumada, E., M. L. Díaz-Ramírez, M. D. J. Velásquez-Hernández, V. Jancik, and I. A. Ibarra. 2021. "Capture of Toxic Gases in MOFs: SO2, H2S, NH3 and NOx." *Chemical Science* 12: 20. https://doi.org/10.1039/D1SC01609A.

Mintova, S., and V. Valtchev. 1996. "Deposition of Zeolite A on Vegetal Fibers." *Zeolites* 16 (1): 31–34. https://doi.org/10.1016/0144-2449(95)00078-X.

Ram, T. A., J. P. Pytlak, H. D. Heuer, D. F. Kopperl, and D. Carroll. 1993. "Molecular Sieves – An Aid to Film Preservation." *Presented at the 135th SMPTE Conference and Equipment Exhibit, Los Angeles CA*, November 1993.

Reilly, J. M. 1993. *IPI Storage Guide for Acetate Film*. Rochester, NY: Image Permanence Institute, Rochester Institute of Technology.

Sadovnik, N. 2021. *Elimination du formaldéhyde par adsorbants recyclables de type MOFs. Chimie organique, version 1*. Normandie Université.

Seo, Y. B., J.-S. Shin, and H.-J. Kim. 2009. "Development of a Conservation Fluted Box for Storage of Document Archives." *Journal of Korea Technical Association of the Pulp and Paper Industry* 41 (5): 38–43.

Severino, M. I., A. Al Mohtar, C. Vieira Soares, C. Freitas, N. Sadovnik, S. Nandi, G. Mouchaham, et al. 2023. "MOFs with Open Metal(III) Sites for the Environmental Capture of Polar Volatile Organic Compounds." *Angewandte Chemie International Edition* 62 (6): e202211583. https://doi.org/10.1002/anie.202211583.

Sun, Z., Y. Si, S. Zhao, Q. Wang, and S. Zang. 2021. "«Ozone Decomposition by a Manganese-Organic Framework over the Entire Humidity Range." *Journal of the American Chemical Society* 143 (13): 5150–5157. https://doi.org/10.1021/jacs.1c01027.

Thomas, B., M. C. Raj, J. Joy, A. Moores, A. G, L. Drisko, and C. Sanchez. 2018. "Nanocellulose, a Versatile Green Platform: From Biosources to Materials and Their Applications." *Chemical Reviews* 118 (24): 11575–11625. https://doi.org/10.1021/acs.chemrev.7b00627.

Tignol, P., V. Pimenta, A. Dupont, S. Carvalho, F. Nouar, M. Pinto, C. Serre, and B. Lavédrine. 2024. "A Versatile Shaping Method of Very-High Loading Porous Solids Paper Adsorbent Composites". *Small Methods*, 8 (3): 2301343. https://doi.org/10.1002/smtd.202301343.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S198–S207
https://doi.org/10.1080/00393630.2024.2336801

ORIGINAL RESEARCH OR TREATMENT PAPER

OPEN ACCESS Check for updates

From Lima to Canton and Beyond: Mobile and Digital Research Infrastructure for Closing the Gap Between Resource-rich and Resource-poor Organisations

De Lima a Cantón y más allá: Infraestructura de Investigación Móvil y Digital para Cerrar la Brecha entre Organizaciones con y sin recursos científico-técnicos propios

Haida Liang [1], Luke Butler[1], Sotiria Kogou[1], Marcus Burke [2], Lynn Lee[3], Lucia Pereira Pardo [4*], Lora Angelova [4], Fenella France[5] and Blythe McCarthy [6]

[1]ISAAC Lab, School of Science and Technology, Nottingham Trent University, Nottingham, UK; [2]Hispanic Society Museum and Library, New York, USA; [3]The Getty Conservation Institute, Los Angeles, CA, USA; [4]Collection Care Department, The National Archives, London, UK; [5]Preservation Research and Testing Division, Library of Congress, Washington, DC, USA; [6]Department of Conservation and Scientific Research, Freer Gallery of Art and Arthur M. Sackler Gallery, National Museum of Asian Art, Smithsonian Institution, Washington, DC, USA

ABSTRACT

Access to research infrastructure for heritage science is the best way of narrowing the collections knowledge gap between resource-rich and resource-poor cultural institutions. Here we demonstrate a novel workflow that streamlines the use of a mobile laboratory for data collection (MOLAB) followed by a digital platform for data processing, analysis and interpretation (DIGILAB). The data collection and processing are taken care of by heritage science specialists, while the data analysis and interpretation can be performed collaboratively with conservators and curators. MOLAB with specialist personnel and mobile scientific instruments can sometimes be aided by in-house fixed laboratory (FIXLAB) equipment and personnel from resource-rich institutions to assist the resource-poor institutions if their collection can be hosted by the resource-rich institutions for analysis. The aim is to widen participation in the adoption of heritage science and material analysis in the understanding and conservation of collections, while ensuring high-quality, efficient and reliable data acquisition, processing, analysis and interpretation. The approach taken in this project combines access to various research infrastructure platforms to achieve extra benefit through adding further expert-assisted data analysis and interpretation capabilities, enabled by a new digital platform for data processing and visualisation.

El acceso a la infraestructura de investigación para las ciencias del patrimonio es la mejor manera de reducir la brecha de conocimiento sobre colecciones entre las instituciones culturales con y sin recursos científico-técnicos propios. Aquí demostramos un flujo de trabajo novedoso que agiliza el uso de un laboratorio móvil para la recopilación de datos (MOLAB) seguido de una plataforma digital para el procesamiento, análisis e interpretación de datos (DIGILAB). Generalmente, especialistas en ciencias del patrimonio llevan a cabo la recopilación y el procesamiento de datos, mientras que el análisis y la interpretación de los datos se suele realizar en colaboración con curadores y con conservadores-restauradores. MOLAB, con personal especializado e instrumentos científicos móviles, en ocasiones puede apoyarse en equipos de laboratorio fijo interno (FIXLAB) y personal de instituciones con recursos científico-técnicos para ayudar a las instituciones sin estos recursos, alojando temporalmente objetos de su colección para ser analizados. El objetivo es ampliar la participación en la adopción de la ciencia del patrimonio y el análisis de materiales en la comprensión y conservación-restauración de las colecciones, garantizando al mismo tiempo una adquisición, procesamiento, análisis e interpretación de datos de alta calidad, eficientes y confiables. El enfoque adoptado en este proyecto combina el acceso a varias plataformas de infraestructura de investigación para lograr un mayor beneficio, mediante la inclusión de capacidades adicionales de análisis e interpretación de datos asistidas por expertos, gracias a una nueva plataforma digital para el procesamiento y visualización de datos.

ARTICLE HISTORY
Received November 2023
Accepted March 2024

KEYWORDS
Material analysis; research infrastructure for heritage science; mobile laboratory; MOLAB; FIXLAB; DIGILAB; MAPSI; GUISI

PALABRAS CLAVE
Análisis de materiales; infraestructura de investigación para las ciencias del patrimonio; laboratorio móvil; MOLAB; FIXLAB; DIGILAB; MAPSI; GUISI

CONTACT Haida Liang haida.liang@NTU.AC.UK ISAAC Lab, School of Science and Technology, Nottingham Trent University, Nottingham NG11 8NS, UK
*Present address: Instituto de Ciencias del Patrimonio (INCIPIT), Consejo Superior de Investigaciones Científicas (CSIC), Edificio Fontán, Bloque 4, Cidade da Cultura Monte Gaiás s/n, 15707 Santiago de Compostela, Spain

© 2024 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group
This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

Introduction

In a current UK-US collaboration *From Lima to Canton and Beyond: an AI-aided Heritage Materials Research Platform for Studying Globalisation through Art*, we explore the concept of using modern research infrastructure for heritage science to close the gap between organisations that are resource-rich and those that are resource-poor. Characterisation of heritage materials is integral to the conservation process. However, high-quality, efficient and reliable material analysis requires access to specialist equipment and skilled personnel, both of which can be expensive. The concept of taking specialist personnel and mobile scientific instruments to the objects or sites for *in situ* non-invasive analysis of the materials was born out of the logistic difficulties of moving museum objects into an external scientific laboratory, and the impossibility of moving a monument, along with increasing demand arising from conservation ethics for non-invasive analysis. The term 'MOLAB' was first coined in a European Commission funded Eu-ARTECH integrated infrastructure initiative in 2004 by the University of Perugia, Italy (Brunetti et al. 2007). It is now a well-known concept in the European Research Infrastructure for Heritage Science (E-RIHS https://www.e-rihs.eu/), which is divided into four operational platforms: mobile laboratories (MOLAB); fixed laboratories (FIXLAB); archives (ARCHLAB); and digital laboratories (DIGILAB). For the FIXLAB platform, samples or objects are brought to large immovable specialist instrumentation such as synchrotron facilities to be analysed. ARCHLAB provides access at a museum or a research institution for physical reference materials and past unpublished scientific analysis results and conservation records of heritage assets to be consulted in person. DIGILAB is a relatively new platform compared to the other three, and it has been conceptualised to be a data service that acts as a searchable data repository, as well as a software platform that enables specialist data analysis and visualisation. These four platforms offer not just the latest scientific instruments and data services, but also skilled personnel and expertise.

The advancement in non-invasive imaging and material analysis techniques used by heritage scientists and conservators to characterise the composition of heritage assets, has created increasingly large datasets that require expert processing and interpretation. This creates a barrier to access and use by non-experts. Here we demonstrate a novel workflow that streamlines the data collection by Nottingham Trent University (NTU) Imaging and Sensing for Archaeology, Art History and Conservation (ISAAC) MOLAB (https://www.isaac-lab.com/isaac-mobile-lab) and any cultural institution's in-house fixed laboratory facility (FIXLAB) followed by an ISAAC DIGILAB platform (https://www.isaac-lab.com/isaac-digilab) for data processing, analysis, visualisation and interpretation. The data collection and processing are taken care of by heritage science specialists, while the data analysis and interpretation can be performed collaboratively by heritage science specialists, conservators and curators.

The objects of interest discussed here are a large corpus of watercolours from ethnographic drawings to maps and botanical drawings, made by local artists in north-western Latin America, or Asia, for export to Europe and North America.

Inspired by the Enlightenment, from the late eighteenth century, European colonial powers such as Britain and Spain were collecting information from around the world. Maps and charts were commissioned, as well as scientific drawings of flora and fauna, and local artists were often employed to draw and paint these. Several Spanish scientific expeditions, such as the Royal Botanical Expedition to the Viceroyalty of New Granada (today Ecuador, Colombia, and Venezuela), led by José Celestino Mutis from 1783 to 1816 among others, hired local artists such as Francisco Javier Cortés (born Quito 1775, died Lima 1839), professor of drawing for the School of Medicine in Lima, to provide the illustrations (Bleichmar 2017). Botanical paintings following European conventions of scientific drawings were also commissioned from Chinese export artists in Canton (today Guangzhou, China) by the Royal Horticultural Society (RHS) and the Royal Botanical Gardens (RBG) at Kew, London, and were painted on Whatman papers sent from London (Bailey 2019; Kogou et al. 2015). Similarly, during this period, the East India Company was actively employing Chinese and Indian artists to draw flora and fauna in South East Asia and India respectively (Dalrymple 2020). These cultural encounters have often resulted in hybrid artistic practices.

In Latin America, local artistic traditions, such as the ethnographic oil paintings produced in Mexico from the late seventeenth century – including the well-known *Castas* series depicting racial mixtures, regional produce, and local costumes – set the stage for depictions of ethnic types and costumes to be included in some of these scientific volumes. Interest in ethnography would explode into a general interest in the nineteenth century. This led to the production of export paintings depicting the daily lives of local citizens (Majluf 2006; Majluf and Burke 2008).

By about 1818, in the context of the coming of Peruvian independence, watercolours of Peruvian subjects were documented in Lima. The earliest are associated with Cortés, soon to be joined by his presumed pupil, Francisco (Pancho) Fierro in the 1820s. By the 1830s, watercolours by Fierro, his followers, and imitators, became widespread, and were eventually produced in their thousands, with the phenomenon

tapering off around 1850–1860 (Ades 1989; Majluf 2006). Similar ethnographic drawings are found in Colombia and Ecuador (Driver and Jones 2009).

In the meantime, trade in Chinese export paintings depicting the daily life of locals in Canton flourished in the late eighteenth to the nineteenth century (Clunas 1984). By the 1820s, Chinese export watercolours were painted not only on European and Chinese papers and occasionally silk, but also on pith, a plant material mistakenly called rice paper initially (Nesbitt, Prosser, and Williams 2010). Pith was cheap and it absorbs watercolour readily, creating a relief texture with a velvety visual depth. Its translucency reminds one of silk. Costume paintings of Peruvian types on pith are also found in albums with provenances and artistic styles suggesting that they were copied from Peruvian originals in studios in Canton, where pith was a typical support (Figure 1) (Anderson 2011; Majluf 2006; Majluf and Burke 2008).

These works produced in north-western South America and in Canton from 1780 to 1850 are connected to a complex web of social, political, artistic, geographic, economic, and technological phenomena, all of which affected the motives for their creation, the materials from which they were made, the means of their dispersal and preservation, and the lives of the people who made, sold, bought, and collected them. The subject is made more complex by the wide array of early republican Latin American society depicted, the numerous ethnic origins of the subjects, the extraordinary international nature of the clientele, and the wide dispersal of the works.

This project focuses on a large group of works with ethnographic as well as selected scientific and geographic subjects (e.g. maps and botanical drawings), primarily watercolours made for export to Europe or North America by local artists in north-western Latin America, or Asia. These are now found in widely dispersed public collections in the USA and UK. Given the large corpus of Chinese export watercolours on paper from the RHS and the Victoria and Albert Museum (V&A) that had already been studied 10 years ago by NTU, the V&A and the RHS (Kogou et al. 2015), and the recent publication of scientific studies of pigments by the National Museum of Asian Art (NMAA) found in more than 200 Chinese paintings from the past c.1000 years (McCarthy and Giaccai 2021), it is now possible to compare artists' materials used for export paintings and those for domestic consumption. The project is intended to reveal details of global trade and information exchange networks among the Americas, Asia and Europe c.1780–1850. Pigments, dyes and paper are commodities that have been traded extensively throughout history; their identity and the way they are used are often traceable to their geographic and cultural origins. This period also saw the synthesis of new pigments, especially in Europe, making it easier to date an object using these pigments.

The cultural institutions whose collections have been studied so far are, in London, UK: The National Archives (TNA); RBG; RHS; Royal Geographical Society (RGS); V&A; and in the USA: The Hispanic Society of America (HSA), New York; Museum of International Folk Art (MOIFA), Santa Fe, New Mexico; Lilly Library, Indiana University, Bloomington, IN; Library of Congress (LOC), Washington D.C.; Getty Research Institute (GRI), Los Angeles, CA; National Museum of Asian Art (NMAA), Smithsonian Institution, Washington D.C.; and Yale University Art Gallery (YUAG), New Haven, CT. The range of institutions with varying resources and circumstances, the large numbers of collections studied, and the interdisciplinary nature of the project offer a perfect test bed for how modern cultural heritage research infrastructure for heritage science can be used in a variety of ways to narrow the gap in knowledge and scholarship on collections in resource-rich and resource-poor organisations.

Method and workflow

While within the framework of E-RIHS pilot project IPERION HS (https://www.iperionhs.eu/catalogue-of-services/), the three platforms (ARCHLAB, FIXLAB and MOLAB) were accessed independently and rarely used in combination, here we demonstrate how the combined use of all four platforms can bring extra benefits.

The novel workflow starts with scanning all works of interest with a reflectance spectral imaging system in the visible to near infrared (VIS/NIR), e.g. the PRISMS system that collects images in 10 spectral bands between 400 and 850 nm in evenly spaced intervals and scans automatically at high resolution using a motorised pan-tilt stage operational from distances up to tens of metres (Kogou et al. 2015; Liang et al. 2014; Liang, Keita, and Vajzovic 2007) which is often used in ISAAC MOLAB (Figure 2). This is then followed by ISAAC DIGILAB processing of the spectral image cubes using a machine learning algorithm to group all pixels with similar spectra into clusters (Kogou et al. 2020a). These spectral cluster maps correspond to material distribution maps which can be used to guide and optimise the next stage of MOLAB analysis with complementary spectroscopies, e.g. Raman, X-ray fluorescence (XRF), external reflection Fourier transform infrared (FTIR) and UV-visible-shortwave infrared (UV/VIS/SWIR; 350–2500 nm) reflectance at the same points (e.g. one point per cluster). This improves efficiency while ensuring a more thorough complementary analysis. Raman spectroscopy offers sharp spectral lines corresponding to molecular vibrations that are specific to the crystalline structure;



Figure 1. (a) Pancho Fierro (1830–1860), *Tapada* dressing (putting on the skirt and veil), watercolour on paper, 128 × 100 mm. Inv. no. LA1752, Hispanic Society of America. (b) *Costume of the People of Peru*, copy on pith attributed to the studio of Tingqua in Canton, of Peruvian original attr. Fierro based on subject matter and style, LOT 4456, no. 18, 280 × 180 mm, Inv. no. 00651678, Library of Congress.

FTIR provides spectral absorption bands characteristic of vibrational modes of chemical bonds; UV/VIS/SWIR reflectance spectroscopy complements PRISMS spectral imaging with higher spectral resolution for the identification of red organic dyes (e.g. madder or scale insect dyes such as lac and cochineal) and an extended spectral range to the SWIR range (1000–2500 nm), which is sensitive to vibrational overtones that are devoid of the spectral distortions typically encountered in external reflection FTIR; while portable XRF identifies the elements with atomic number $Z > 13$ and is generally invariant to chemical degradation of a material.

The DIGILAB platform also comes with visualisation software to assist with logging the measurements and allowing interdisciplinary collaboration on the analysis and interpretation. The original ISAAC DIGILAB concept was developed in another UK-US collaboration project *AI for DIGILAB: A new concept in digital infrastructure for heritage materials research*, where users who have collected their own spectral imaging data can upload it to ISAAC DIGILAB to have it processed and returned to the user who can then view the results using the graphical user interface for the visualisation and analysis of spectral imaging data (GUISI) visualisation tool (https://www.isaac-lab.com/using-guisi) (Figure 3). However, we soon realised that those who need this tool most are the ones who do not know how to operate and calibrate a spectral imaging system correctly to produce quality data. This experience indicated a need to provide both MOLAB and DIGILAB services in tandem, to be effective for resource-poor institutions.

The workflow was also modified as we collected data from different organisations in the US and the UK, which resulted in a more pragmatic workflow as shown in Figure 4. While VIS/NIR reflectance spectral imaging system is collecting data from a group of artworks, XRF point analysis of another group of artworks can be carried out in parallel based on visual observation to select points of analysis. Once the VIS/NIR reflectance spectral imaging data have been collected, they are processed using the ISAAC DIGILAB spectral clustering tool to produce cluster maps that are approximately equivalent to material maps (Kogou, Shahtahmassebi et al. 2020a). This is only approximate because even though a VIS/NIR reflectance spectrum is mostly unique to a given material or material mixture, there are cases where this is not true, when elemental analysis with XRF offers a way of further distinguishing the materials. For example, cadmium red made of cadmium sulfoselenide (CdS/CdSe), a modern substitute with its similar colour and opacity for toxic vermilion, mercury sulphide (HgS), is found to be indistinguishable in VIS/NIR reflectance spectra from vermilion (Li et al. 2019). Therefore, XRF analysis not purely guided by VIS/NIR reflectance spectral imaging cluster maps may offer an advantage

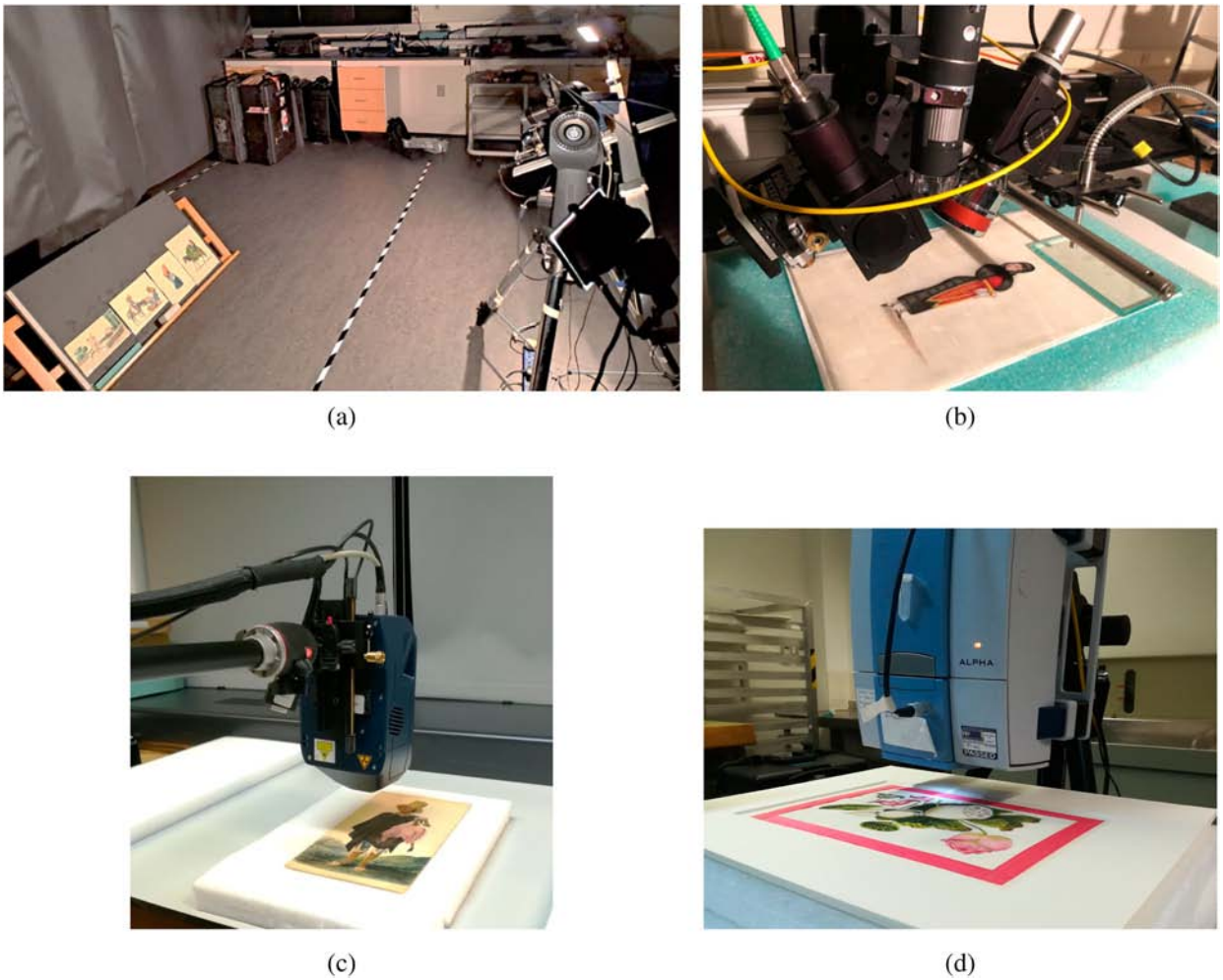


Figure 2. MOLAB in operation during the project. (a) The PRISMS reflectance spectral imaging system at YUAG. (b) Hybrid system for Raman spectroscopy including spatially offset mode of operation, a microscopic imaging device to record the position for measurement and fibre optic reflectance spectroscopy in the range 350–2500 nm at 3–5 nm spectral resolution on a platform that moves with precision motorised linear stages, analysing a pith painting of a Peruvian subject in the Lilly Library collection. (c) XRF point analysis of the Joseph Brown collection from the RGS. (d) External reflection FTIR point analysis of the RBG collection of Chinese export paintings on pith.

beyond it being efficient to run XRF in parallel to spectral imaging. Once the cluster maps have been produced, we can complete the XRF analysis on clusters where no XRF data had been collected to ensure thorough analysis.

In addition, during the current data collection campaigns involving around 10 cultural institutions, we realised that the digital tools developed have mainly been focussed on the data processing and post processing stages, and that an additional tool was needed for semi-automated live marking/annotation of images of the artworks to both record during measurements and display multimodal complementary data analysis results and their interpretations in large-scale interdisciplinary research. The digital platform can then traverse easily from data collection, interdisciplinary collaboration to the public dissemination of results, which includes the use of clearly defined database infrastructures and easy-to-use software. Therefore, a new tool needs to be added to the digital platform. The marking application for specialist information (MAPSI) tool is being developed primarily for marking and tracking measurements taken over many items within a collection. It will allow for the building and managing of complex databases (held on the cloud) using different complementary scientific techniques, data formats and curatorial information, providing freedom to its users without the need for building complex databases manually. It will act as a e-logbook and a virtual space for collaboration, and will ensure that metadata and paradata are well described, so that users from different institutions can easily understand findings produced by others. MAPSI can also be used with previously collected data so that databases can be built around previous studies.

Case studies

During the project, ISAAC MOLAB visited a diverse group of some 10 cultural institutions ranging through university libraries and museums, national libraries and archives, and national museums, to

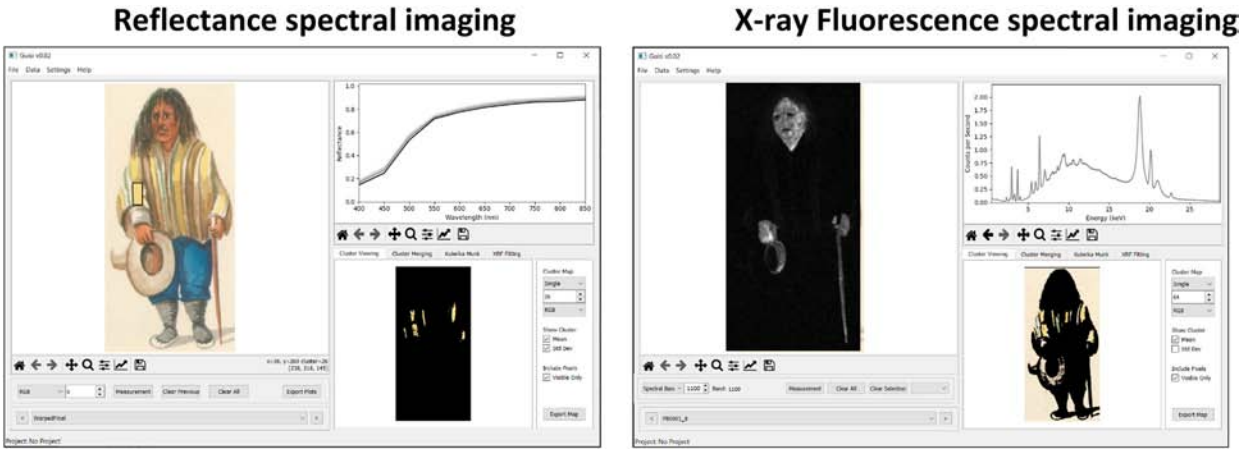


Figure 3. GUISI visualisation tool analysing PRISMS reflectance spectral imaging data (left) and Bruker M6 Jetstream MA-XRF spectral imaging data (right) for *Peru type* #481, c.1860, Getty Research Institute, inv. no. P840001. Left: GUISI gives the average spectrum of a region marked by the user (black bordered box in the main panel) in the spectral panel (top right panel; solid black curve), a single reflectance spectral cluster map showing the true colour of each pixel that belongs to the cluster (bottom right panel) and the corresponding mean cluster spectrum (top right panel; grey curve with shading indicating one standard deviation). Right: GUISI shows the image of channel 1100 for mercury (Hg) map in the main panel, a single XRF cluster map showing the true colour of each pixel that belongs to the cluster (bottom right panel) and the corresponding mean cluster spectrum (top right panel).

learned societies. Some of these have their own laboratories and skilled scientists (GCI, LOC NMAA, TNA); while others have the equipment, but no or a limited number of skilled personnel (MOIFA); and in some cases they have neither instruments nor skilled personnel (RGS, HSA). ISAAC MOLAB typically consists of unique instruments developed in-house, adapted commercial instruments and off-the-shelf commercial instruments. The MOLAB offered the possibility of access to equipment and personnel, but typically, owing to budget and time constraints, data collection had to be performed intensively in less than a week, which required high-efficiency operation. Furthermore, resource-poor organisations do not have scientists to analyse the data, therefore MOLAB alone is not enough. A DIGILAB-assisted MOLAB operation resolves both problems. Spectral imaging provides a more thorough analysis than the more common point-based fibre optic reflectance spectroscopy analysis, but requires more sophisticated tools for data processing, analysis and interpretation. This applies to in-house material analysis by scientists in museums using FIXLAB facilities, and to MOLAB data capture where intense operation over a week is the norm.

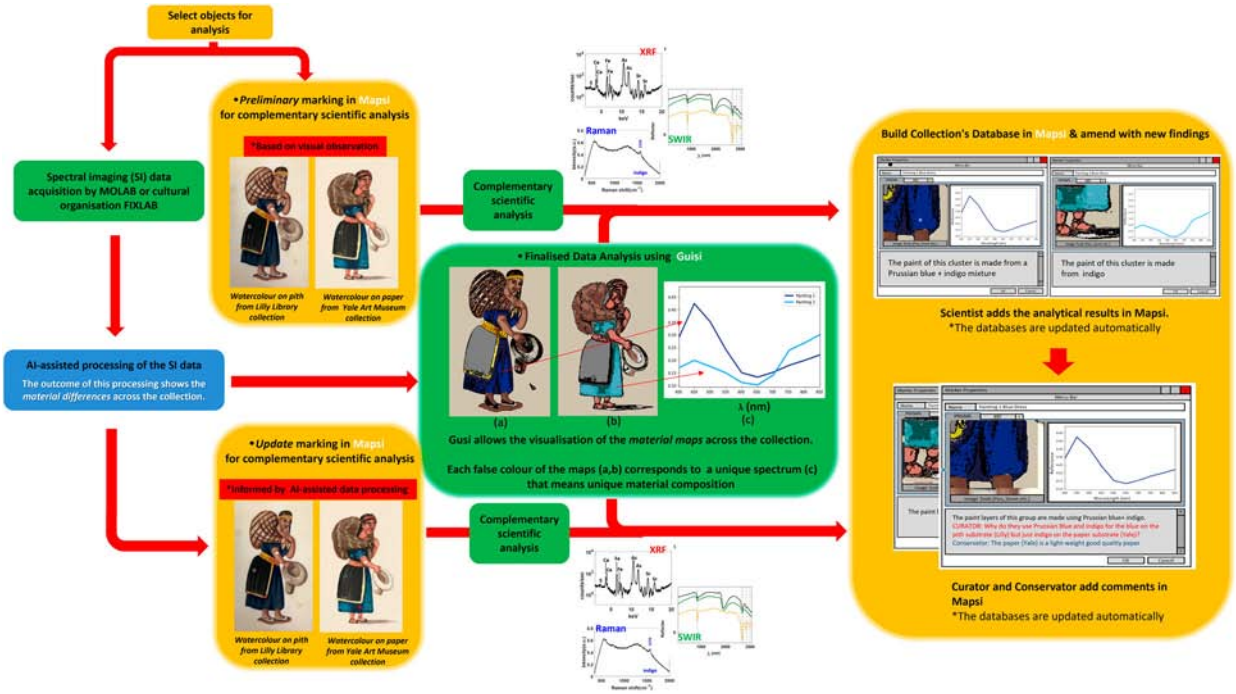


Figure 4. The novel workflow from data collection to data processing and interpretation, allowing for data collection by different groups and interdisciplinary collaboration for interpretation.

Case study 1: resource-rich institutions

The GRI collection of Peruvian watercolours attributed to Fierro (Anderson 2011) was analysed. ISAAC MOLAB with two members of staff brought the PRISMS spectral imaging system (Figure 2a) to scan the collection, while GCI colleagues used their bench-top Renishaw inVia Raman microscope, Bruker ARTAX micro-XRF system for point analysis and the Bruker M6 Jetstream XRF scanner for 4 of the paintings (Figure 3) (Kogou, Lee et al. 2020), Keyence VHX-6000 digital microscope and ASD FieldSpec reflectance spectrometer. Except for the last two instruments which are mobile, the others can only be used in a FIXLAB context. Unlike MOLAB which was conducted in a couple of days including assembling and packing the instrument, the FIXLAB data collection was conducted over a longer period, with fewer time constraints.

At the LOC, a collection of watercolours of Peruvian subjects on pith produced in Canton but copied from originals attributed to Fierro, and three collections of watercolours of Chinese subjects on pith from Canton export studios, was analysed along with a collection of watercolours commissioned by American missionaries of Iranian subjects by local artists in Qajar. ISAAC MOLAB with two members of staff brought the Raman-UV/VIS/SWIR reflectance spectroscopy hybrid system to the LOC, which allowed the two other members of ISAAC MOLAB to use the other instruments at the NMAA down the road, thus shortening the time spent in one city. LOC colleagues used their MegaVision spectral imaging system, Bruker ARTAX micro-XRF system, ASD FieldSpec reflectance spectrometer and Bruker Alpha FTIR system as FIXLAB to analyse their in-house collections. The workflow was followed with LOC FIXLAB and ISAAC MOLAB supported by ISAAC DIGILAB data processing to guide the point analysis for efficiency.

Case study 2: resource-poor institution

Lilly Library, Indiana University, had limited heritage science resources and ISAAC MOLAB brought a suite of instruments as shown in Figure 2. The Lilly Library provided three separate rooms, one for spectral imaging, one for Raman-UV/VIS/SWIR reflectance spectroscopy hybrid and one for XRF, where the first two rooms were darkened, and the third one was a large space with controlled access for X-ray safety. The conservators assisted with support structure for the artworks and handling of the watercolours for analysis. The collection at Lilly Library included both Peruvian originals on paper and copies on pith made in Canton. The workflow was followed with MOLAB data collection supported by ISAAC DIGILAB data analysis and visualisation. The optical microscope at the Lilly Library was used to collect microscopic images of the pith paintings. The co-location of Prussian blue and indigo for blues on the pith paintings from Canton seemed strange and consultation with NMAA colleagues on their knowledge of Chinese paintings of the same period through their past analysis (e.g. McCarthy and Giaccai 2021) shed light on the interpretation, though further research and analysis of other collections is required to reach a conclusion. Thus, in this case, MOLAB, DIGILAB, FIXLAB and ARCHLAB were all mobilised.

Case study 3: resource-poor institution with access to local mobile instruments

MOIFA's collection of watercolours of Peruvian subjects on pith made in Canton were analysed. MOIFA was in a rather unusual situation of having access to a newly-acquired suite of mobile instruments from the Museums of New Mexico Conservation Unit of Museum Resources Division, but without specialists to operate all the instruments. The local mobile instruments included a portable XRF, Keyence microscope and a FTIR spectrometer, which meant that ISAAC MOLAB had fewer instruments to bring on a trip that included a number of connecting flights for materials analysis, and had room to take a relatively compact optical coherence tomography (OCT) system (Kogou et al. 2015; Read et al. 2021) to examine the layers and cell structure of the pith paintings. This provided interesting evidence for reverse painting on the back of the pith substrate, similar to the technique used for painting on silk (Figure 5). The advantage of OCT detection of paint layers on the back of the substrate is that there was no need to unmount the paintings from their frames. Two members of ISAAC lab with PRISMS and an OCT and one colleague from GCI went to MOIFA to collect the data. MOLAB and skilled personnel using local instruments completed the data collection and allowed the information on reverse painting technique to be acquired.

Case study 4: resource-poor institution assisted by MOLAB and a resource-rich institution

ISAAC MOLAB brought all the instruments in Figure 2 and an in-house developed 810 nm OCT system (Cheung, Spring, and Liang 2015) to TNA with four members of staff. TNA was just setting up a laboratory and had acquired portable XRF, portable FTIR, and a bench-top Raman instrument which could also be used as FIXLAB equipment if necessary. It had two large laboratory spaces to house the MOLAB equipment over a couple of weeks. While within the UK it is relatively easy to transport a significant number of instruments with a van, it is still time-consuming to set up the instruments including testing, dismantling and careful repacking of the instruments at the end

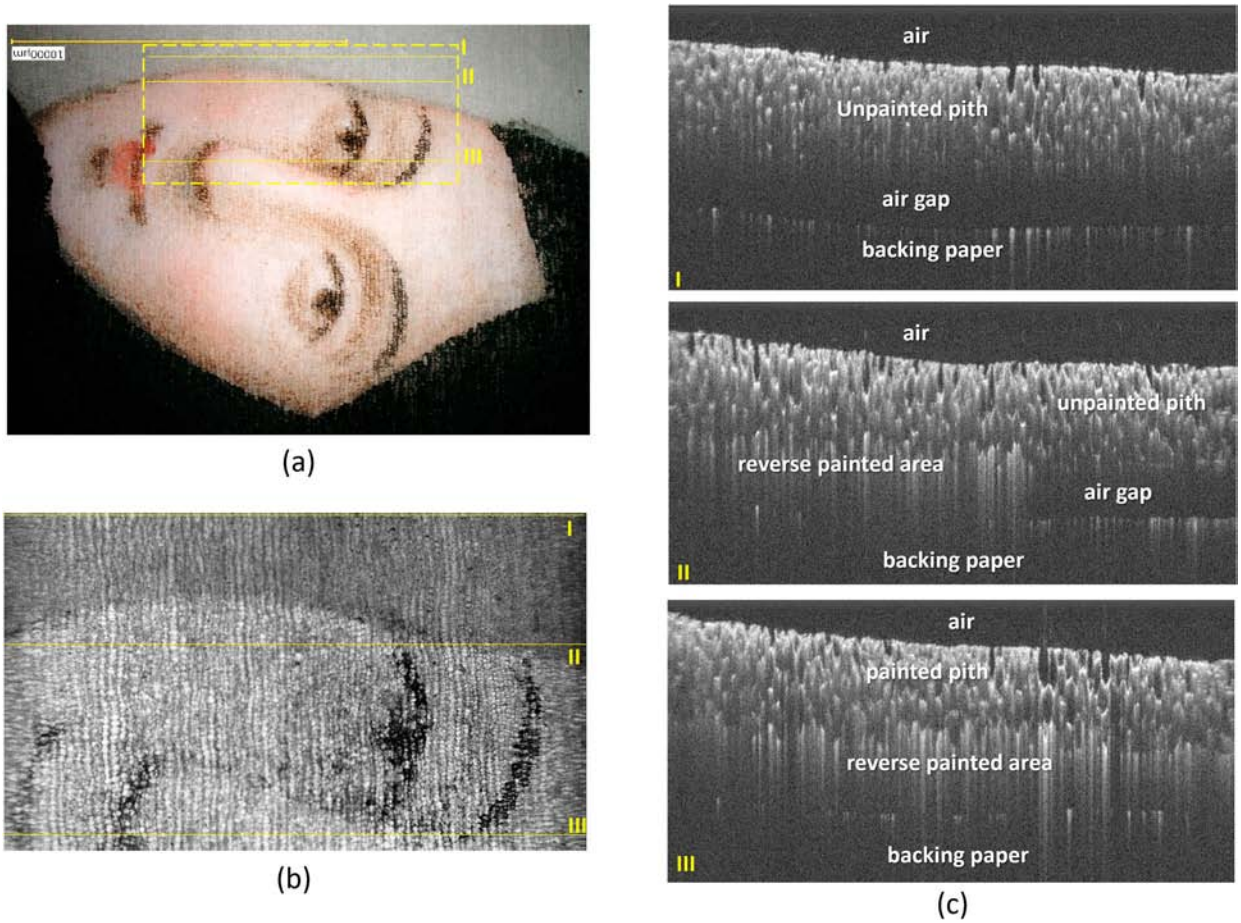


Figure 5. (a) Detail (width ~13 mm) from painting A2003-28-2, MOIFA collection. The yellow rectangle indicates the area that was scanned with the 930 nm OCT system. (b) *En-face* image of the area that was scanned using OCT (averaged slices in depth). (c) OCT virtual cross-section images of the areas that are indicated with the yellow horizontal lines in (b). Image scales 0.9 mm in height and 10 mm in width.

of data collection. The smaller institutions in the same city also struggled to find enough space for uninterrupted data collection. The RGS does not have any heritage science resources and the collection of watercolours of Colombia subjects by an English trader and local artists was brought over to TNA to be analysed following the same workflow. Similarly, to save time, the collections from RBG at nearby Kew, which consists of various botanical subjects from Canton, Penang, Hong Kong and India, were also brought over to TNA. This work prompted TNA to establish frameworks and contracts around hosting collection items from other cultural organisations onsite, as well as hosting researchers and their instruments. The framework put in place can also be used in the future for other projects and can be used as an example to be copied by other institutions wishing to host external collections and heritage science analysis.

Conclusions

The large number of cultural organisations that hold the relevant artworks for this project are separated geographically across the Atlantic, with a diverse range of digital and heritage science resources. This provided a perfect test bed for how modern heritage science research infrastructure such as MOLAB and DIGILAB in combination can narrow the gap in scholarship on collections in resource-rich and resource-poor organisations. In some cases, all four platforms, MOLAB, FIXLAB, DIGILAB and ARCHLAB were mobilised in this large interdisciplinary collaboration.

The large number of collections and items involved makes the research challenging in terms of the volume of data that needs to be collected and analysed, which naturally called for a novel approach and workflow involving new computational and visualisation tools, some of which have been developed and used for data processing, while others are still in development.

The artworks were selected based on art historical research, and research questions related to the global circulation of the watercolours, the artist materials and techniques. So far nearly 400 water colour paintings have been analysed with spectral imaging collected for each painting with a total of over 4000 XRF, Raman, UV/VIS/SWIR reflectance and FTIR spectra collected. Some interesting preliminary results have already emerged which shows that there are clear differences in the artists' materials and how they were used to create colours, from different

geographic locations and cultural origins from Lima to Canton and beyond. For example, chrome yellow is typically used for yellow and often mixed with Prussian blue for green in Peruvian watercolours (Kogou, Lee et al. 2020), while gamboge is often used for yellow and mixed with indigo for green in watercolours from Canton (Kogou et al. 2015). Detailed results and their interpretation will be given in forthcoming publications.

The interdisciplinary nature of the project naturally involves curators, conservators, heritage scientists and educators, which allows the virtual collaboration tool to be tested by a broad range of researchers likely to be engaged with the museum collections. A large corpus of relevant works is held in collections in UK and US cultural institutions and a cost-effective way of bringing these collections together is through digital scholarship and virtual exhibitions.

Acknowledgements

We would like to acknowledge: Natalia Majluf for advising on connections between the collections studied; Felix Driver for bringing to our attention the Joseph Brown collection at the RGS; Catherine Souch and Alasdair Macleod, RGS, for facilitating access to the collection; Darlene Sadlier for making connections with the Lilly Library; Erika Dowell, Doug Sanders, Joel Silver and Jim Canary of the Lilly Library for facilitating analysis; Barbara Anderson for making connections with MOIFA; Amy Groleau, Khristaan Villela of MOIFA and Mark MacKenzie of Museums of New Mexico, for facilitating analysis at MOIFA; Mark Nesbitt, Lynn Parker, and Fiona Ainsworth for facilitating selection of items from RBG to be analysed; Idurre Alonso, GRI, for facilitating the selection of items from the GRI collection; Douglas MacLennan, Nathan Daly, Catherine Patterson and Karen Trentelman of GRI for collaboration on data collection and discussion; Theresa Fairbanks Harris, of YUAG, for facilitating the selection of items and data collection; Marcie Wiggins for facilitating data collection and Aniko Bezur for enabling the YUAG collections to be analysed in the IPCH laboratories; Matthew Clarke for facilitating the selection of items and analysis at the NMAA; Meghan Wilson, Amanda Satorius, and Cynthia Ryan, Library of Congress, for collaboration on data collection; Barbara Bair and Sara Duke, Library of Congress, for selecting the items to be analysed; Marika Spring, Marta Melchiorre and Catherine Higgitt, National Gallery London; and Aniko Bezur and Marcin Wiggins of Yale IPCH for their contribution in shaping the ISAAC DigiLab in the first UK-US collaboration project *AI for DIGILAB: A new concept in digital infrastructure for heritage materials research*.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the UK Arts and Humanities Research Council (AHRC) under grant AH/V009745/1 and AH/T013184/1, and the US National Endowment for the Humanities (NEH) under grant HC-278118-21.

ORCID

Haida Liang http://orcid.org/0000-0001-9496-406X
Marcus Burke http://orcid.org/0009-0003-1241-0410
Lucia Pereira Pardo http://orcid.org/0000-0002-4708-2467
Lora Angelova http://orcid.org/0000-0003-2496-9310
Blythe Mccarthy http://orcid.org/0000-0002-6427-3484

References

Ades, D. 1989. *Art in Latin America*. 1st ed. London: South Bank Centre.

Anderson, B. 2011. *From Lima to Canton and Back, Nineteenth-Century Chinese Watercolors for Peru, El Palacio*, 45–50. https://www.yumpu.com/en/document/view/51020413/from-lima-to-canton-and-back-nineteenth-century-watercolors-for-.

Bailey, K. 2019. *John Reeves: Pioneering Collector of Chinese Plants and Botanical Art*. 1st ed. New York: ACC Art Books.

Bleichmar, D. 2017. *Visual Voyages: Images of Latin American Nature from Columbus to Darwin*. New Haven: Yale University Press. https://yalebooks.yale.edu/book/9780300224023/visual-voyages.

Brunetti, B. G., M. Matteini, C. Miliani, L. Pezzati, and D. Pinna. 2007. "MOLAB, a Mobile Laboratory for *In situ* Non-Invasive Studies in Arts and Archaeology." In *Lasers in the Conservation of Artworks*, edited by J. Nimmrichter, W. Kautek, and M. Schreiner, Springer Proceedings in Physics, 116, 453–460. Berlin: Springer. https://doi.org/10.1007/978-3-540-72310-7_54

Cheung, C. S., M. Spring, and H. Liang. 2015. "Ultra-High Resolution Fourier Domain Optical Coherence Tomography for Old Master Paintings." *Optics Express* 23 (8): 10145–10157. https://doi.org/10.1364/OE.23.010145.

Clunas, C. 1984. *Chinese Export Watercolours*. London: Victoria and Albert Museum.

Dalrymple, W. 2020. *Forgotten Masters: Indian Painting for the East India Company*. London: Bloomsbury.

Driver, F., and L. Jones. 2009. *Hidden Histories of Exploration: Researching the RGS-IBG Collections*. London: Royal Holloway, University of London, in association with Royal Geographical Society.

Kogou, S., L. Lee, G. Shahtahmassebi, and H. Liang. 2020. "A New Approach to the Interpretation of XRF Spectral Imaging Data Using Neural Networks." *X-ray Spectrometry* 50 (4): 310–319. https://doi.org/10.1002/xrs.3188.

Kogou, S., A. Lucian, S. Bellesia, L. Burgio, K. Bailey, C. Brooks, and H. Liang. 2015. "A Holistic Multimodal Approach to the Non-Invasive Analysis of Watercolour Paintings." *Applied Physics A* 121 (3): 999–1014. https://doi.org/10.1007/s00339-015-9425-4.

Kogou, S., G. Shahtahmassebi, A. Lucian, H. Liang, B. Shui, W. Zhang, B. Su, and S. Van Schaik. 2020. "From Remote Sensing and Machine Learning to the History of the Silk Road: Large Scale Material Identification on Wall Paintings." *Scientific Report* 10: 19312. https://doi.org/10.1038/S41598-020-76457-9.

Li, Y., C. S. Cheung, S. Kogou, F. Liggins, and H. Liang. 2019. "Standoff Raman Spectroscopy for Architectural Interiors from 3–15 m Distances." *Optics Express* 27 (22): 31338–31347. https://doi.org/10.1364/OE.27.031338.

Liang, H., K. Keita, and T. Vajzovic. 2007. "PRISMS: A Portable Multispectral Imaging System for Remote *in Situ* Examination of Wall Paintings." *Optics for Arts, Architecture,*

and Archaeology 6618: 661815. https://doi.org/10.1117/12.726034.

Liang, H., A. Lucian, R. Lange, C. Cheung, and B. Su. 2014. "Remote Spectral Imaging with Simultaneous Extraction of 3D Topography for Historical Wall Paintings." *Journal of Photogrammetry and Remote Sensing* 95: 13–22. https://doi.org/10.1016/j.isprsjprs.2014.05.011.

Majluf, N. 2006. *Reproducing Nations: Types and Costumes in Asia and Latin America c. 1800 to 1860*. New York: Americas Society.

Majluf, N., and M. B. Burke, eds. 2008. *Tipos del Perú : la Lima criolla de Pancho Fierro*. Madrid/New York: Ediciones El Viso/Hispanic Society of America.

McCarthy, B., and J. Giaccai. 2021. *Scientific Studies of Pigments in Chinese Paintings*. London: Archetype Publications.

Nesbitt, M., R. Prosser, and I. Williams. 2010. "Rice-paper Plant *Tetrapanax papyrifer*." *Curtis's Botanical Magazine* 27 (1): 71–92. https://doi.org/10.1111/j.1467-8748.2010.01647.x.

Read, M., C. S. Cheung, H. Liang, A. Meek, and C. Korenberg. 2021. "A Non-Invasive Investigation of Egyptian Faience Using Long Wavelength Optical Coherence Tomography (OCT) at 2 μm." *Studies in Conservation* 67: 168–175. https://doi.org/10.1080/00393630.2020.1871208.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S208–S217
https://doi.org/10.1080/00393630.2024.2336794

ORIGINAL RESEARCH OR TREATMENT PAPER

OPEN ACCESS Check for updates

Making It Last: Training Conservators in Sustainable Solutions for Treating Outdoor Painted Sculpture

Haciendo que Dure: Capacitar a Conservadores-restauradores en Soluciones Sostenibles para el Tratamiento de Esculturas Pintadas al Aire Libre

Rosa Lowinger[1], Abigail Mack[2], Ellen Moody[3], Flavia Perugini[3], Rachel Rivenc[4] and Stavroula Golfomitsou[3]

[1]RLA Conservation, Los Angeles, USA; [2]Mack Art Conservation, New York, USA; [3]Getty Conservation Institute, Los Angeles, CA, USA; [4]Getty Research Institute, Conservation and Preservation, Los Angeles, USA

ABSTRACT

Outdoor painted sculptures (OPSs) are a regular feature of public spaces and private collections throughout the world. Their painted finishes can appear deceptively simple, but their esthetic is a subtle combination of color, texture, and reflectance, making them challenging to care for and repair. OPSs are exposed to direct sunlight, rain, wind, pollutants, human interactions, and biological debris from plants and animals. Conservation of these artworks is a matter of preserving an artist's esthetic intent, rather than the original paint system, which will inevitably need to be replaced. This paper discusses the development of the Getty Conservation Institute workshop *Treatment Strategies for OPS*, to develop skills in this specialized area of conservation. The full repainting of an artwork is expensive, laborious, logistically challenging, and includes the use of chemicals and processes with significant carbon footprints: improving the economic and environmental sustainability of these treatments has become imperative. The workshop teaches participants strategies that help stave off full repainting, such as working with specialized painters for lasting localized repairs, removing graffiti without altering the sculpture's finish, and creating regular maintenance programs that help prevent deterioration.

Las esculturas pintadas al aire libre (EPAL) son una característica habitual de los espacios públicos y colecciones privadas de todo el mundo. Sus acabados pintados pueden parecer engañosamente simples, pero su estética es una combinación sutil de color, textura y reflectancia, lo que los hace difíciles de cuidar y reparar. Las EPAL están expuestas a la luz solar directa, la lluvia, el viento, los contaminantes, las interacciones humanas y los desechos biológicos de plantas y animales. La conservación-restauración de estas obras de arte es una cuestión de preservar la intención estética del artista, más que el sistema de pintura original, que inevitablemente deberá ser reemplazado. Este artículo analiza el desarrollo del taller del del Getty Conservation Institute sobre *Estrategias de tratamiento para EPAL*, para desarrollar habilidades en esta área especializada de conservación-restauración. El repinte completo de una obra de arte es costoso, laborioso, desafiante desde el punto de vista logístico e incluye el uso de productos químicos y procesos con importantes huellas de carbono: mejorar la sostenibilidad económica y ambiental de estos tratamientos se ha vuelto imperativo. El taller enseña a los participantes estrategias que ayudan a evitar el repintado completo, como trabajar con pintores especializados para reparaciones localizadas duraderas, eliminar graffiti sin alterar el acabado de la escultura y crear programas de mantenimiento regulares que ayuden a prevenir el deterioro.

ARTICLE HISTORY
Received October 2023
Accepted March 2024

KEYWORDS
Outdoor sculpture; coating; stakeholders; workshop; education

PALABRAS CLAVES
Escultura al aire libre; revestimiento; partes interesadas; taller; educación;

Introduction

Outdoor painted sculptures (OPS) are modern and contemporary works found in public and private collections around the world. An increased investment in public art over the last few decades has led to a rise of painted outdoor sculpture in public spaces. Composed of structural forms made of metal, concrete, fiberglass, or modern composite materials that are coated with one or more polymer films, these artworks are often monumental, site specific, and made by a team consisting of fabricators, engineers, installers and industrial painters. Frequently abstract in design, OPS are, by definition, sited in locations where they are exposed to uncontrolled, and sometimes harsh, environmental conditions. As a result, they are highly prone to rapid deterioration and a wide range of paint coating failures.

CONTACT Ellen Moody emoody@getty.edu 1200 Getty Center Drive, Los Angeles, CA 90049

© 2024 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group
This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (http://creativecommons.org/licenses/by-nc-nd/4.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

Painted outdoor sculptures became prominent in the 1960s. Owing to their intended display location, painted outdoor sculptures will reach a point where their surfaces are so altered that removal of the original finish and a full repainting is required (Figure 1). There has been an ongoing critical need for understanding the proper approach to undertaking this kind of treatment. Conserving an OPS is a matter of sustaining an esthetic rather than original materials. This is achieved by periodically stripping and repainting works – an approach that can appear to run counter to traditional conservation ethics, but is necessary to maintain the desired paint color and sheen in the outdoor environment. Moreover, such treatments are costly, labor intensive, and involve the use of chemical strippers, solvents, and catalyzed paints – materials whose removal and application can produce wasteful by-products and potentially pose health and safety risks. A key goal of sustainability in outdoor sculpture conservation is ensuring that treatments are rigorously performed so that they do not have to recur more than absolutely necessary.

For all of these reasons, conserving painted outdoor sculptures is a unique area of practice that straddles art and architectural conservation and requires understanding of industrial processes as well as the meticulous esthetics of modern and contemporary art. Yet, there is little available training for conservators on the treatment of OPS. Graduate-level programs rarely include this topic in their curricula and its mastery is only achieved with extensive understanding of industrial materials and uses – not something that can be delivered in a conservation training program. As a result, there is a dearth of clarity about the role of conservators in the ongoing maintenance and treatment of such works, and few established protocols for sustaining the unique esthetics of OPS while creating pathways toward resilience that can be implemented safely and affordably by conservators around the world.

To fill this need, the Getty Conservation Institute (GCI) has been conducting research, symposia and workshops on the care, conservation, and maintenance of OPS for over a decade. Beginning with a June 2012 meeting held at the Metropolitan Museum of Art, and continuing with a 2014 publication titled *Conserving Outdoor Painted Sculpture* (Beerkens and Learner 2014), weeklong training courses at the Getty Center in Los Angeles in 2018 and at the Kröller Müller Museum in Otterlo, Netherlands, in 2023, the GCI has been aiming to codify recommended practices for treating OPS, with the goal of making this work informed and sustainable. This paper describes how the GCI's workshop, entitled *Treatment Strategies for OPS* has partnered with paint specialists, artists, their foundations, and conservators in the US and Europe who are leaders in this field to achieve this goal. Our intention is to expand our efforts to include professionals from all over the world.

OPS: background

In the first half of the twentieth century, the vast majority of outdoor sculptures was representational and was made primarily of bronze and stone. This began to change in the early 1960s, when the US



Figure 1. J. J. Belion, *Homage to Simon Rodia* 1965. Before (above) and after treatment (below) of painted concrete sculpture located at California State University Long Beach, CA. Image: RLA Conservation.

President John F. Kennedy convened an ad hoc committee on Federal Office Space that aimed to increase the government's immediate and long-term need for new buildings. Included in the documents for the committee were *Guiding Principles for Federal Architecture* that encouraged the 'finest contemporary American architectural thought' for designs of these new federal structures and accompanying artworks. The result was the creation of seminal monumental artworks for federal US buildings by the likes of Claes Oldenburg, Alexander Calder, Tony Smith, Ellsworth Kelly, Louise Nevelson, and Alexander Liberman (US Admin 1963). By the early 1970s, the General Service Administration's Art in Architecture Program and the National Endowment for the Arts mandated that a percentage of construction costs for new buildings (usually between 0.5 and 2%) be set aside for commissions by living artists (Sims 2010). This was a game-changing direction in public outdoor sculpture and led to a plethora of new commissions of modern monumental works for parks and public spaces with corporations and universities quickly joining in.

The rise in demand for large-scale outdoor sculpture was mirrored by the rise of fabrication studios. Though traditional outdoor sculptures in bronze and stone were often fabricated by artists in conjunction with foundries and quarries, the new abstract monumental works required a set of skills which tended to come from non-art industries like metal working, bridge and ship building, and construction. In 1965, Long Beach State College, now California State University Long Beach, organized an international sculpture symposium that partnered artists with these industrial firms to create works that deliberately exploited the possibilities of pairing technology and science with artmaking (Rivenc et al. 2018). While this combination resulted in a suite of artworks for the university's campus whose scale and materials were not before possible, artists like Robert Murray complained that the collaboration was, at times, strained, because industrial shops were not accustomed to having artists in their workplaces: 'There were a few (adjustments) I had to give up on because a foreman or shop steward didn't want me on the floor' (Murray 2015).

The collaboration between industry and artists changed radically in 1966, when Donald Lippincott founded Lippincott LLC in North Haven, Connecticut, as a bespoke creative environment where 'sculptors could have large-scale works fabricated in a manner that was sensitive to their specific needs and methods while bringing to bear the full range of professional manufacturing capability required' (Lippincott 2018). Shortly thereafter, in 1969, Peter Carlson opened a facility in Sun Valley, CA to facilitate the monumental works, many of them painted, of Ellsworth Kelly, Robert Rauschenberg, Claes Oldenburg, and later Jeff Koons. In the five decades that have ensued, fabrication studios have popped up all over the world. Most painted outdoor sculptures are made in such facilities where artists provide drawings or maquettes and the works are made by welders, metalworkers, industrial painters, and other technicians. These new types of businesses provide artists with 'a sympathetic environment and technical expertise that enabled [them] to achieve a scale of which they had only dreamt before' (Davies 2010). The resulting 'quiet collaboration' between artist and fabricator changed the field of art production worldwide and allowed for industrial processes to become the norm rather than the exception in the creation of monumental outdoor sculpture (Williams and Lowinger 1995).

Despite rigorous fabrication, within a few years of installation, many of these new monumental works have required conservation. Donald's brother, Alfred Lippincott, recalls problems of water pooling inside of steel sculptures, causing rust to bleed through welds, and paints fading much faster than expected. The sizes of the artworks turned treatments into logistical nightmares requiring street closures, scaffolding, and cranes. As Lippincott recalled, 'We started providing maintenance manuals, but they'd get filed in a drawer and no one would look at them again'. Without maintenance, works deteriorated rapidly, exacerbating the need for sustainable conservation processes. Early repair efforts tended to be done by fabricators, building and grounds staff, outsourced to autobody shops, or local tradespeople. While a small group of conservators and allied tradespeople stepped up to take care of the works, the conservation community, trained for preservation and repair of interior museum artworks, was woefully unprepared to address outdoor sculpture. While artists in the US were at the forefront of this class of art production, an international body of OPS has since emerged all over the world.

How OPS are made

OPS typically begin with a drawing or maquette conceived by an artist. For works that are made by fabricators, this design is then typically transformed into a technical drawing or specification that is used in much the same way as architectural plans are used for constructing buildings. The physical artwork itself consists of a substrate and surface coatings, the latter known as the 'paint stack'. The substrate defines the shape, size, and sculptural quality of the work. The paint stack protects the substrate from deterioration, and determines the color, surface texture and reflectance of the surface.

OPS substrates can be made of many different paintable surfaces, but the most common ones in current use are carbon steel, stainless steel, aluminum, resin, fiberglass, bronze, concrete, and, occasionally, wood.

An artist's choice of substrate is determined by numerous considerations, most important among them being the size and shape of the sculpture they wish to create. Aluminum, for example, is a desirable material because it can 'be rolled out much flatter than a plate of steel or stainless steel … which allow [ed] for flatness in different shapes', as Alfred Lippincott stated about George Sugarman's sculptures (2014). Steel, an alloy of iron and carbon, known for its strength, is often selected for very large sculptures or those requiring a substructure to support their shape. Stainless steel, which has chromium added to the iron/carbon mix, is desirable for its corrosion resistance; but it is roughly 30% more expensive than the mild or carbon steel, as the non-stainless varieties are known, and it is also trickier to weld, because certain alloys can crack or warp during fabrication.

New materials are always being adapted from industrial uses for sculpture, and nowadays fabrication methods include 3D printing and water-jet cutting of forms alongside methods such as welding, casting, rolling, and bending. Some works employ a combination of substrates to achieve varying shapes and structural needs, as seen in Roy Lichtenstein's *Mermaid* 1979, which uses both concrete and mild steel within a single structure (Figure 2). In caring for OPS, maintaining the integrity of the substrate is a matter of making sure it remains properly coated by the paint stack, and is sited to prevent structural damage.

The paint stack of an OPS is a system of industrially manufactured layers, consisting of one or more primers and a top coat that provides the color and surface appearance of the work. Some systems also use a clear coat as a final top layer. Layers are applied by spraying, rolling, or brushing. Application influences the texture: the smoothest finishes can only be achieved by spraying. The application



Figure 2. Roy Lichtenstein, *Mermaid* 1979, mixed media (painted concrete and mild steel), located in the City of Miami Beach, FL. Image: RLA Conservation.

method and resulting finish may or may not be an important part of the artist's concept, so this is a crucial detail to investigate in the planning stages of a treatment. The top coats on Roy Lichtenstein's outdoor sculptures, for example, were painted by hand, however, today his Foundation recommends their repainting be done by spray (Wolfe 2023). Paints and clear coats can also vary in reflectance from matte, to glossy, eggshell, and satin. Some contemporary artists like Yayoi Kusama, Huma Bhaba, and Yinka Shonibare, will also layer textures, reflectance, and colors to achieve multi-colored patterns. In addition to the esthetic function, the role of the paint stack is protective: it shields the substrate from weathering, and is ultimately sacrificial.

The challenges of conserving OPS, and decision-making

Top coats have built-in limited lifespans that can range from between 5 and 20 years depending on the durability of the chosen paint stack. Conserving an artwork's esthetic eventually requires repainting. The repainting of OPS typically strives to repeat the steps of its manufacture, or improve them if the original coatings were not durable. Applying coatings, especially high-performance coatings, requires specialized skills and equipment outside the expertise of art conservation. However, conservators need to understand the specific application requirements of the paint stack, which are essential to a long-lasting paint job and will extend the time between repaintings. This is important in order for conservators to effectively manage the treatment. Repainting an OPS is always a complex and costly proposition (Figures 3 and 4). Ideally, the best place to do the work is in a professional painting facility where dust, wind, and drying temperatures can be controlled. But to do this, sculptures must be deinstalled and transported offsite, a process that can require the use of cranes, flatbed trucks, street closures and traffic control. If a sculpture cannot be deinstalled due to expense or logistical challenges, *in situ* repainting must consider the implications of executing an industrial process in a public environment. This means managing paint application (e.g. preventing overspray), the use of solvents, chemicals, and heavy equipment (e.g. boom lifts, generators, compressors, and scaffolding) around the public, as well as the effects of heat, cold, rain, and dust on the paint application process.

As with all outdoor artworks, the best way to minimize the number of these labor and cost intensive conservation interventions begins with proper fabrication followed by regular and appropriate maintenance. If a work is not made properly – if metals are combined incorrectly, if the resin of a fiberglass sculpture is not catalyzed properly, if a primer stack is applied too thinly or thickly or incompatibly – the coating will fail rapidly. Similarly, if maintenance is deferred, or done improperly by ill-informed or untrained personnel who resort to harsh detergents or aggressive power washing, the deterioration of sculptures accelerates.

Research and dissemination at the GCI

The OPS project (currently entitled *Outdoor Sculpture*) was launched in 2012 as a subset of the *Modern and Contemporary Art Research Initiative* and in recognition of the fact that this category of objects posed acute challenges that the conservation profession was not fully equipped to meet. The project began with an expert meeting, gathering conservators, fabricators, paint chemists, and representatives from the paint industry, to articulate these challenges and suggest possible responses. These conversations formed the basis of the project plan, which included collaboration with paint formulators to design coatings with greater longevity (Escarsega et al. 2016), case studies (Goukassian 2018; Langenbacher et al. 2018), and improved documentation of original painted surfaces (Langenbacher, Rivenc, and Flavin 2017). Another strand of the project aimed at exploring local retouching of OPS to extend the time between costly and logistically intensive repainting campaigns (van Basten et al. 2014). In addition, the 2012 meeting highlighted the critical need for knowledge transfer from the industry to conservators, and improved dissemination and networking for conservators to share experiences and problem solve together. The workshop was created specifically to address these needs and aligns with the GCI's commitment to enhance formal education with professional courses.

Continuous professional development aims to equip professionals with new skills, keep them up to date with new knowledge and help them address challenges. Conservation approaches reflect wider societal, economic, environmental and institutional changes, and are moving away from strict protocols and standards, exemplified, for example, by the expansion of environmental parameters in museums and storage as part of sustainable practices (Taylor et al. 2023). Professional courses offer new insights, discuss alternative ways of working on real-life case studies and are delivered by specialists and practitioners who have developed solutions for common challenges in their years of experience. The complexity of OPS conservation requires an informed yet flexible approach with technical and soft skills, such as project management, negotiation and communication skills, which are necessary to work with different stakeholders and achieve the best possible outcome.

While acknowledging that the skills required to care for OPS are developed over time, the workshop aims to equip participants with methodologies to apply in



Figure 3. Alexander Calder, *Five Swords* 1976, during treatment, evaluating application of topcoat. Image: A. Mack.

their own contexts. The core of the course's teaching team is made up of the conservators authoring this paper, practitioners from both private practice and institutions – two distinct environments where resources and approaches can vary. A technical representative from the paint industry is also key to helping participants understand the exigencies of the paint stack. Participants are selected, firstly, based on their demonstrated need to develop their skills on this topic, and secondly, to build a cohort representing a range of experiences, geographical location, workplaces and career stages. This diversity of backgrounds

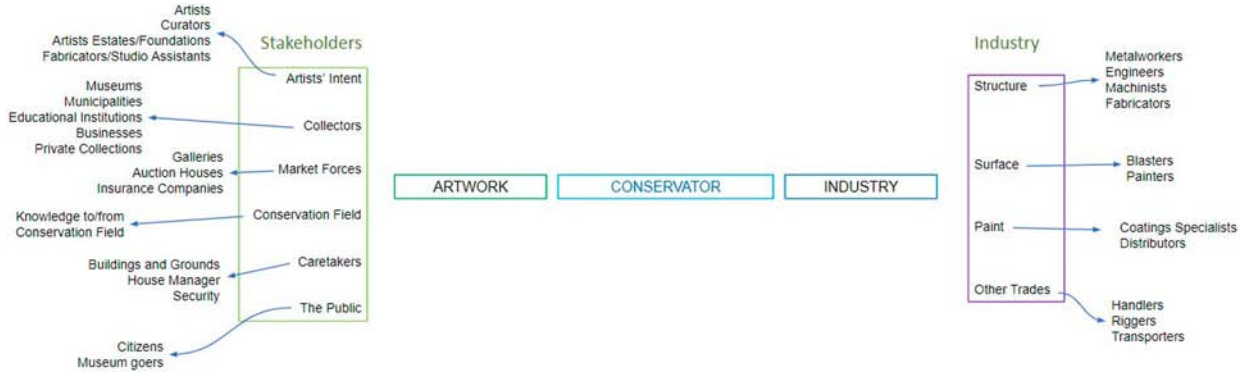


Figure 4. Stakeholder map presented at workshop. Design by A. Mack.

enriches the peer-to-peer exchange that occurs over the course of the workshop during discussions, activities and shared meals. A significant outcome of the workshop and part of its sustainability resides in creating a network of alumni who consult and support each other when treatment questions arise back in their respective institutions/practice.

The workshop's key topics evolve to reflect changes in approaches, new scientific knowledge and developments, new materials, instructors from different geographical regions, and other advances in the field. When applying to attend a workshop, applicants are prompted to submit challenges they hope to learn to solve during the workshop, which also informs teaching. These topics fall into two camps: technical ones, that are about condition issues, environment, and coating systems; and those that require soft skills, about decision-making, partnering with specialized tradespeople and managing expectations of various stakeholders.

The primary learning objective of the workshop is to equip participants with the skills to develop effective treatment plans that balance an artwork's structural and esthetic needs with financial and logistical parameters. This is achieved through thematic lectures that are reinforced by case studies shared by instructors, discussions, and activities such as practical sessions, site visits and exercises using local sculptures. In addition, the workshop aims to introduce participants to common considerations for OPS. These include location and access, identifying qualified tradespeople, identifying stakeholders, and factors that are specific to the artwork such as the presence of toxic materials and treatment options. Treatment options are explored through the lens of decision-making tools in order to provide the participants with a framework for developing useful and realistic treatment plans. An online learning platform goes live in advance of the workshop to help prepare participants for the time together in person. This includes videos, readings, templates for case studies, and a discussion feature. The online component remains live for a year following the workshop, and serves as a repository for relevant resources and a means for the cohort to stay connected and develop new networks.

Specifically, the workshop looks at the entire range of possible treatment activities to ensure that the correct courses of action are undertaken to preserve artwork. If a full-scale treatment is absolutely necessary and timely, a temporary or interim treatment will ultimately be a waste of time and resources. It is the goal of the workshop to help participants develop the judgment to know when full-scale treatments are needed. In other instances environmentally and economically sustainable activities can be undertaken in line with the following tenets.

Involvement in design phase

When conservators have the opportunity to weigh in on decisions in the commissioning, installation or acquisition phase, they can help to reduce the cost and carbon footprint of a sculpture's long-term conservation by contributing to conversations on its manufacture and installation. Lectures are given on construction methods – and common flaws therein – for the most commonly-employed substrates for outdoor sculpture. Participants also learn about different high-performance paint systems, their compatibility with substrates and other coatings, and application factors that impact their performance. Visits to local paint shops allow participants to get first-hand exposure to the skills, equipment, and environment an industrial painter provides for a restoration project.

Participants are also taught to assess locations for OPS when involved in the siting phase of production. Through lectures on the distinct challenges of different locations, case studies from different parts of the world, and a condition assessment activity on local sculptures, participants learn to link condition issues on OPS with their underlying causes.

Local, interim treatments and maintenance

Most OPS have monochrome, smooth surfaces that are particularly unforgiving to isolated scratches, gouges,

and vandalism. Though such marring is rarely fully restored with localized treatment, the workshop teaches methods for local retouching, using both traditional conservation approaches, and those used by professional industrial painters as a means of extending the lifespan of the paint stack. The latter are more invasive; they involve sanding and repainting well beyond the lines of the damage, but this may be required to restore a painted sculpture's uninterrupted finish. These methods are presented with videos capturing the steps for local retouching, and physical painted panels demonstrating a range of retouching techniques for examination and comparison.

Graffiti removal is also addressed in the workshop. Participants practice different methods of graffiti removal from test panels prepared in advance (Figure 5). For both graffiti removal and retouching activities, the goal is to build the participants' toolkit with knowledge of available media and techniques for local treatment.

Often overlooked in commission or acquisition budgets, maintenance of OPS is crucial to extending the lifetime of paint jobs, and it is the ultimate sustainable measure to extend the life of these artworks. Basic maintenance can look similar across different geographic regions; however, the most effective maintenance plans are adapted to the site and sculpture materials. Through lecture and discussion, the workshop cohort reviews different maintenance strategies and how they can be adapted to various contexts. A key learning objective in this session is effective advocacy for maintenance budgeting: educating relevant decision makers about the importance of maintenance, and how it cuts costs in the long term.

Building a team

In this specialized area of art conservation, conservators act as a bridge between industry and the artwork. This requires building working relationships with skilled tradespeople including metalworkers, riggers, art handlers, coating specialists, painters as well as engineers and fabricators. These tenets surface in the workshop through lectures on working with industry, on industrial paint systems, and a visit to a paint shop, where participants interact directly with professional painters. The conservation of OPS also requires communication and dialogue with stakeholders so that all decision makers can participate in realistic and effective stewardship of the artwork (Figure 6). With time, respect, and trust, the outcome



Figure 5. Graffiti removal exercise during *Treatment Strategies for Outdoor Painted Sculpture Workshop* 16 –20 October 2023, organized by GCI and the Kröller-Müller Museum. Image: A. Mack.

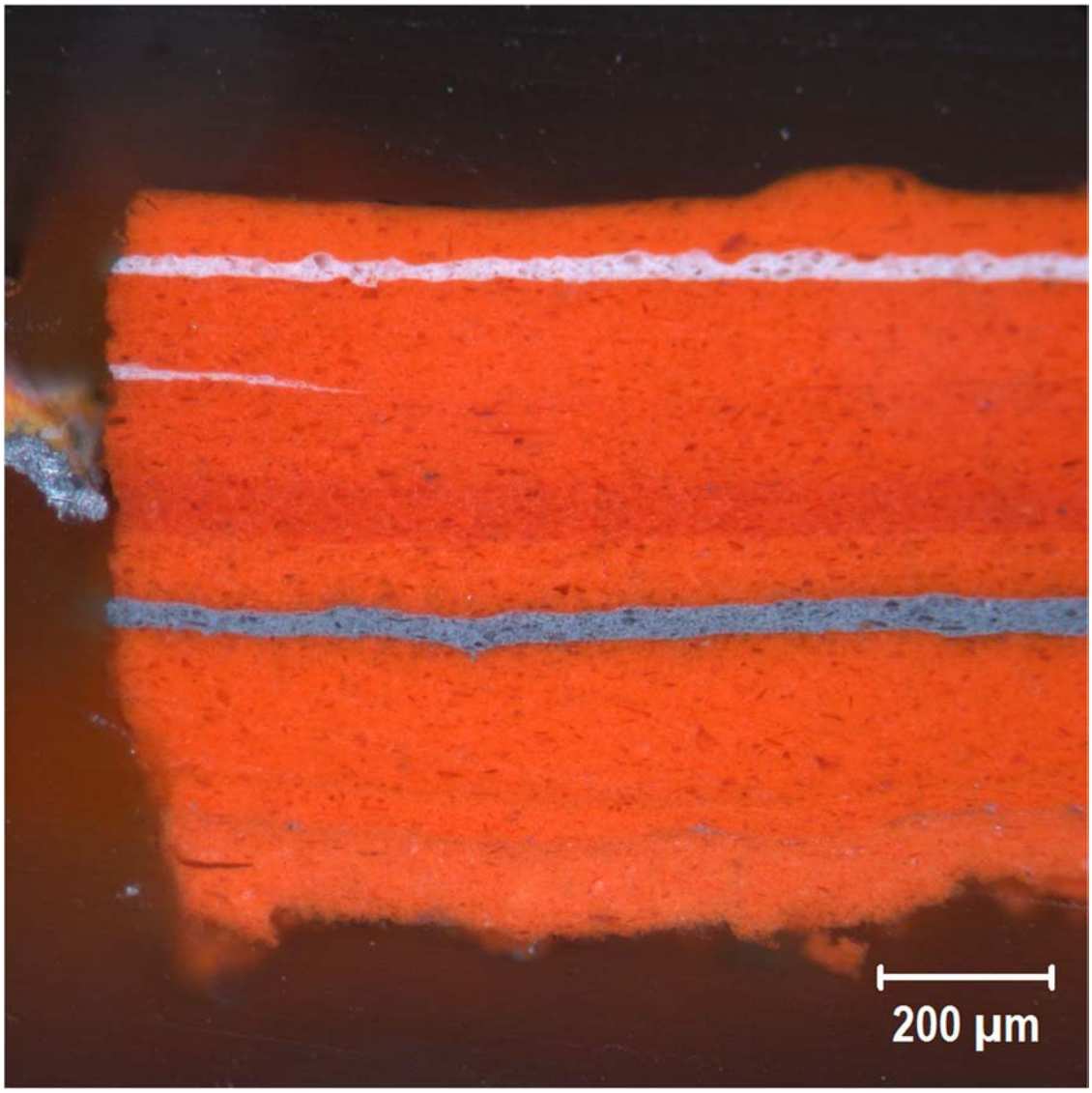


Figure 6. Cross-section viewed under magnification showing repaintings of Calder's *Five Swords* 1976. The first layer was identified using SEM-EDX as a red lead primer. Image: J. Langenbacher.

is an exchange of knowledge that is beneficial to the long-term preservation of OPS. In the session on maintenance mentioned above, participants learn and exchange strategies to engage and enlist a larger caretaking team made up of students, gardeners and/or security guards, to help with monitoring and maintenance.

Conclusion

The oldest contemporary OPS have been in existence for approximately 75 years, a relatively short period compared to other works of art. Like the works themselves, the materials and methodologies for conserving these works are relatively new and continue to evolve. As a result, this subcategory of conservation requires research and training that incorporates the processes of traditional art conservation, architectural conservation, and industrial manufacturing processes. As this subspecialty of conservation further develops, more reflection related to processes and approaches is required, including how to make practices more sustainable, and, meanwhile, GCI's *Treatment Strategies for OPS* workshop continues to evolve with each iteration. Based on the experience of practitioners in the field, it utilizes unpublished case studies and incorporates knowledge from industrial advancements. Its week-long, in-person format allows professionals to focus on the topic and make deep connections. A variety of pedagogic methods are used blending theory with activities such as demonstration and hands-on practical sessions with site visits and online discussions that continue for a year after the completion of the course, cementing the networks created. Professional training courses are delivered in a safe space allowing sharing experiences in a participatory manner and development of the necessary skills required to deal with such works. Instructors from private practice and institutions alike, together with industry partners discuss different approaches

and case studies, covering issues related to working with artists and foundations and managing expectations of stakeholders in relation to the life expectancy of treatments. Learning from practicing professionals is invaluable for these artworks that require collaborating and coordinating with professionals from other fields. The GCI's program aims to continue research into this area, build bridges with industry, offer revised regionally-focused workshops and build networking opportunities for conservators caring for these demanding artworks.

Acknowledgements

The authors would like to thank Tom Learner, who led this project from its inception; Reem Baroody, who helped organize its outputs; and the additional instructors of the two iterations of the course to date: Susanne Kensche, Lydia Beerkeens, Christina Varvi, Chris Hille, Sarah Montonchaikul, Julie Wolfe, Nikki van Basten, and John Escarsega.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Beerkens, L., and T. Learner. 2014. "Conserving Outdoor Painted Sculpture." *Proceedings from the Interim Meeting of the Modern Materials and Contemporary Art Working Group of ICOM-CC*, Kröller-Müller Museum, Otterlo, the Netherlands, *4–5 June 2013*. Los Angeles: Getty Conservation Institute. http://www.getty.edu/conservation/publications_resources/pdf_publications/pdf/conserv_outdoor_painted.pdf.

Davies, H. 2010. *Large Scale: Fabricating Sculpture in the 1960s and 1970s*, edited by J. D. Lippincott, 6. New York: Princeton Architectural Press.

Escarsega, J. A., A. Mack, R. Rivenc, and T. Learner. 2016. "Coat of Arms: Dovetailing the Needs of Outdoor Sculpture and Military Assets to Develop More Durable and Adaptable Paint Systems." *Studies in Conservation* 61 (sup2): 49–54. https://doi.org/10.1080/00393630.2016.1196431.

Goukassian, E. 2018. "US Army Teams Up With Conservators to Preserve Outdoor Art." *Hyperallergic*, 6 April. https://hyperallergic.com/434513/us-army-teams-up-with-conservators-to-preserve-outdoor-art/.

Langenbacher, J., R. Rivenc, and A. Flavin. 2017. *Documenting Painted Surfaces for Outdoor Painted Sculptures: A Manual of Laboratory and Field Test Methods*. Los Angeles, CA: Getty Conservation Institute. https://www.getty.edu/conservation/publications_resources/pdf_publications/documenting_painted.html

Langenbacher, J., C. Varvi, R. Rivenc, and R. Lowinger. 2018. "Case Study: Robert Murray *Duet (Homage to David Smith)*, 1965." In *Far-Sited: California International Sculpture Symposium 1965/2015*, 92–96. Long Beach: California State University.

Lippincott, A. 2014. Personal Communication with Rosa Lowinger, 6 January.

Lippincott, A. 2018. *Lippincott Sculpture: History*. https://www.lippincottsculpture.com/history.

Murray, R. 2015. *Personal Communication with Rosa Lowinger*, May 8.

Rivenc, R., J. Langenbacher, R. Lowinger, C. Varvi, M. Coltharp, and B. Trimble. 2018. "When Art Meets Technology – Can the Love Affair Last? The Legacy of the 1965 Sculpture Symposium at the California State University Long Beach and the Challenges of Maintaining a Sculpture Park on University Campus." In *The Conservation of Sculpture Parks*, edited by S. Sunara, and A. Thorn, 27–31. London: Archetype Publications.

Sims, P. 2010. "Introduction." In *Large Scale: Fabricating Sculpture in the 1960s and 1970s*, edited by J. D. Lippincott, 11–24. New York: Princeton Architectural Press.

Taylor, J., M. C. Henry, V. L. Beltran, W. Crimm, M. Eckelman, J. Henderson, J. Linden, et al. 2023. *Managing Collection Environments: Technical Notes and Guidance*, edited by J. Taylor and V. L. Beltran. Los Angeles, CA: Getty Conservation Institute. https://hdl.handle.net/10020/gci_pubs_mce_technical_notes.

US Admin (United States General Services Administration Records). 1963. *USGSA-MF02-018-p0001* 8 August 1961 – 16 September 1963, John F. Kennedy Museum and Library Archives.

van Basten, N., S. Stigter, S. Kensche, and R. Peschar. 2014. "Retouching Monochrome Outdoor Painted Metal Sculptures: Tests for Claes Oldenburg's *Trowel*." In *Conserving Outdoor Painted Sculpture. Proceedings from the Interim Meeting of the Modern Materials and Contemporary Art Working Group of ICOM-CC*, Kröller-Müller Museum, Otterlo, the Netherlands, 4–5 June 2013, edited by L. Beerkens, and T. Learner, 73–80. Los Angeles: Getty Conservation Institute.

Williams, D., and R. Lowinger. 1995. "Quiet Collaboration: The Special Relationship Between Artists and Their Fabricators." In *From Marble to Chocolate: The Conservation of Modern Sculpture*, edited by J. Heuman, 130–135. London: Archetype Publications.

Wolfe, J. 2023. *Roy Lichtenstein: Outdoor Painted Sculpture*. Los Angeles: Getty Publications.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S218–S226
https://doi.org/10.1080/00393630.2024.2382549

ORIGINAL RESEARCH OR TREATMENT PAPER

OPEN ACCESS Check for updates

Sustainable and Collaborative Solutions for the Long-term Care of Heritage Earthen Sites in Seismic Areas in Peru

Soluciones Sostenibles y Colaborativas para el Cuidado a Largo Plazo de Sitios Patrimoniales de Tierra en Regiones Sísmicas del Perú

Elena Macchioni [1], Paulo B. Lourenço[2], Georgios Karanikoloudis[2], Nuno Mendes[2], Rafael Aguilar[3] and Claudia Cancino[1]

[1]Getty Conservation Institute, Los Angeles, CA, USA; [2]ISISE, ARISE, Department of Civil Engineering, University of Minho, Guimarães, Portugal; [3]Pontificia Universidad Católica del Perú, Lima, Perú

ABSTRACT

The challenges posed by conserving historical earthen structures in seismic-prone regions prompted the initiation of the *Seismic Retrofitting Project* (SRP) by the Getty Conservation Institute (GCI) and the Ministry of Culture of Peru. Since 2009, the SRP has aimed to enhance the structural performance and safety of historic earthen buildings while preserving their historical fabric by combining traditional techniques, local materials, and technical expertise with advanced computational tools. The project has focused on four Peruvian earthen buildings as case studies, including the seventeenth-century adobe church of Kuñotambo. An intervention was carried out between 2016 and 2019 by the regional branch of the Ministry of Culture in Cusco based on techniques developed by the SRP. The GCI is now working on a monitoring and maintenance plan for the site, collaborating with local stakeholders, including the Ministry of Culture of Peru in Cusco, the Archdiocese of Cusco, and the community of Kuñotambo. This paper primarily discusses the practical aspects of on-site monitoring, including the tools and techniques used to track changes in the building and its decorated surfaces. It also outlines the implementation of a structural health monitoring system and the development of capacity-building activities for Latin American engineers. The overarching goal is to provide a sustainable framework for the long-term preservation of historic earthen structures in seismic-prone regions, highlighting the importance of community involvement and multidisciplinary collaboration.

Los desafíos que plantea la conservación de estructuras históricas de tierra en regiones sísmicas impulsaron el inicio del Proyecto de Estabilización Sismorresistente (SRP, por sus siglas en inglés) por parte del Getty Conservation Institute (GCI) y el Ministerio de Cultura del Perú. Desde 2009, el SRP tiene como objetivo mejorar el desempeño estructural y la seguridad de los edificios históricos de tierra y al mismo tiempo preservar su material histórico mediante la combinación de técnicas tradicionales, materiales y experiencia técnica locales con herramientas analíticas avanzadas. El proyecto se ha centrado en cuatro edificios de tierra peruanos como casos de estudio, incluida la iglesia de adobe de Kuñotambo del siglo XVII. La oficina del Ministerio de Cultura del Peru en Cusco restauró la iglesia entre 2016 y 2019 empleando las técnicas de estabilización sismorrestente desarrolladas por el SRP. El GCI ahora está trabajando en un plan de monitoreo y mantenimiento para el sitio, colaborando estrechamente con las partes interesadas locales, incluido el Ministerio de Cultura del Perú en Cusco, la Arquidiócesis de Cusco y la comunidad de Kuñotambo. Este artículo analiza principalmente los aspectos prácticos del monitoreo in situ, incluidas las herramientas y técnicas utilizadas para rastrear los cambios en el edificio y sus superficies decoradas. También describe la implementación de un sistema de monitoreo de la salud estructural, la organización de actividades de desarrollo de capacidades para ingenieros latinoamericanos y la importancia de la participación comunitaria y la colaboración multidisciplinaria.

ARTICLE HISTORY
Received October 2023
Accepted July 2024

KEYWORDS
Earthen architecture; inspection protocol; structural health monitoring; multidisciplinary collaboration; sustainable cities and communities

Arquitectura de tierra; protocolo de inspección; monitoreo de salud estructural; colaboración multidisciplinaria; ciudades y comunidades sostenibles

Introduction

This contribution outlines the implementation and dissemination of the multidisciplinary monitoring and maintenance plan for the church of Santiago Apóstol of Kuñotambo (church of Kuñotambo), located in a small rural community in the Department of Cusco and under the jurisdiction of the Archdiocese of Cusco.

The plan was collaboratively designed by the Getty Conservation Institute (GCI), Peruvian stakeholders, and international consultants, considering the site's

CONTACT Elena Macchioni emacchioni@getty.edu 1200 Getty Center Dr, Los Angeles, CA 90049, USA

© 2024 J. Paul Getty Trust. Published by Informa UK Limited, trading as Taylor & Francis Group
This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (http://creativecommons.org/licenses/by-nc-nd/4.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.



Figure 1. Exterior view of the church of Kuñotambo and the bell tower, after the completion of the restoration and seismic retrofitting. Image: Elena Macchioni. ©2019 Getty Conservation Institute.

unique features and the needs of stakeholders. Its objectives encompass the long-term preservation of the monument, the assessment of the outcomes of treatment, and the establishment of a participatory framework for sustained care of similar heritage sites in the region. Besides defining practices to be shared through publications and capacity-building initiatives, the plan also presents a set of inspection and data collection protocols. These protocols, initially created to work in an integrated manner for Kuñotambo, are adaptable for independent use at other heritage sites, based on their distinct characteristics and existing resources.

The church of Kuñotambo is one of four case studies in the GCI's *Seismic Retrofitting Project* (SRP), a collaboration with the Ministry of Culture of Peru seeking to validate the effectiveness of seismic retrofitting solutions for earthen historic buildings using traditional techniques, local materials, and available expertise (Getty 2023). The SRP used four Peruvian historic earthen buildings that exemplify common architectural typologies across Latin America and their frequent modes of failure so that the results would be applicable to similar sites in the region (Cancino and Lardinois 2012). Built in the Andes during the viceroyalty period, the church of Kuñotambo exhibits thick adobe walls, a wooden truss roof, and extensive wall paintings (Figures 1 and 2).

Studies by SRP consultants from the Pontificia Univesidad Católica del Peru and University of Minho (Lourenço et al. 2019; Torrealva, Vicente, and Michiels 2018) assessed materials and structural systems, identified seismic vulnerabilities and provided recommendations for retrofitting, for each of the four case studies.

Within the SRP's implementation phase, the regional branch of the Ministry of Culture of Peru in Cusco (Dirección Desconcentrada de Cultura Cusco (DDC–C)) joined the SRP to develop technical specifications and construction drawings for the restoration and seismic retrofitting of the church of Kuñotambo; works started in 2016. Detailed information on the implementation of earthquake-resistant retrofitting techniques can be found in Cancino et al. (2020). The completion of the works in June 2019 marked the beginning of the post-intervention phase, including regular monitoring and maintenance, under the responsibility of the Archdiocese of Cusco, owner of the building.

This contribution highlights the significance of developing a monitoring and maintenance plan for the church of Kuñotambo. It outlines the materials and methods used for monitoring, provides insights about the structural health monitoring system (SHM) installed at the site, presents the results of the monitoring to date, and covers the creation of capacity-building activities for Latin American professionals who will take charge of implementing similar strategies at heritage sites with comparable characteristics. Ultimately it discusses the broader implications of such a plan in the context of sustainable heritage conservation.



Figure 2. Interior of the church of Kuñotambo. Image: Anna Flavin ©2019 Getty Conservation Institute.

Materials and methods

The importance of regular care of historic sites, including monitoring systems and maintenance actions, is recognized in most international charters, although the approach to preventive conservation, especially in relation to architectural heritage, has gained prominence in the last decades. This corresponds to a shift in perspective from restoration as an 'event' led by experts, to conservation as a cyclical 'process' considering the perspective of the users (Della Torre 2020).

Monitoring involves the collection of qualitative and quantitative data and the periodic verification of any signs of change that may affect the site, its environment, and its cultural significance, with attention to the various elements that compose it. Periodic inspections with qualitative and quantifiable methods, covering both the pre- and post-intervention phases, as well as regular maintenance, are considered essential to ensure site integrity and to mitigate risk for existing and historic structures (ISO 2010). Monitoring therefore represents a diagnostic tool, essential to the cyclical process of conservation, which must be seen in relation to education and awareness-raising practices (Van Balen 2015).

Within this framework, the monitoring plan created for the church serves as a vital tool for the preservation of the site and the mitigation of damage caused by various risks (including, e.g. earthquakes) by enabling early damage detection and identification of lack of maintenance. It also allows to check the results of the interventions, both the seismic retrofitting techniques and consolidation of wall paintings *in situ*. This data will contribute to evaluate the SRP results and refine the final guidelines of the project, conceived to be applied in heritage earthen buildings in Latin America. Finally, the plan empowers the local community and local stakeholders to be active actors in the long-term care of their heritage.

The stakeholders identified for the development of the plan are the DDC–C, which needs to establish a participatory protocol for the long-term care of the religious buildings in their remit, and the small technical team of the Archdiocese of Cusco, in charge of managing a scattered heritage over a large territory. Then, the Municipality of Rondocan, encompassing the town of Kuñotambo, is responsible for various maintenance activities at cultural sites within its district. Finally, the involvement of the local community is essential; in fact, the conservation of earthen architectural heritage can often count on the permanence of traditional knowledge, and a system of continuous care guarantees the transfer of these skills, alongside decision-making and communal work systems, such as those that exist in the Andean region (Heras et al. 2019; Vázquez, Achig, and Cardoso 2018).

A fundamental activity for the development of the monitoring plan was to carry out and provide the parties involved with a survey of the site after the completion of the works. At the end of 2019, a team from Carleton Immersive Media Studio (CIMS), GCI consultant, carried out a campaign to document the church, its wall paintings, and the bell tower. The obtained

Table 1. The monitoring plan.

Monitoring protocol	Who	How	When
Basic instructions for the local community	Community members	Visual analysis	At least monthly
Rapid and low-tech protocol for the owner	Specialists from the Archdiocese	Visual analysis with inspection form and photographic record	Yearly
Complete protocol for heritage specialists	Specialists from the Archdiocese, with support of DDC–C and/or external consultants	Permanent SHM Digital survey with photogrammetry, condition mapping, and, if needed, non-destructive testing Same as above, with addition of total station/3D laser scanning	Continuous Every 5 years or after major natural events Every 10 years or after extreme natural events

drawings have served as the foundation for all monitoring activities, and the point cloud allows for precise comparison with subsequent 3D acquisitions, to evaluate even the smallest modifications in the geometry of the site. In addition, CIMS contributed to the definition of guidelines for the monitoring of wall paintings (Reina Ortiz et al. 2021).

The team collaboratively designed three short-, medium- and long-term analysis and inspection protocols tailored to the main components of the construction, assigning roles and responsibilities to separate groups of stakeholders, based on their skills, equipment, and time availability (Table 1). Each protocol underwent several rounds of refinements based on inspections conducted on site since 2020, and included the development of capacity-building activities.

The first monitoring protocol involves trained members of the community of Kuñotambo responsible for the regular control of the church. If any alarming conditions are detected, the community contacts the Archdiocese of Cusco. To this end, integration between the community and civil and religious entities has been strengthened. Community members are in charge of the appropriate use of the site and basic maintenance, with roles assigned to individuals holding specific positions according to the traditional system in place (e.g. president of the community, keeper of the keys).

As part of the second monitoring protocol, the technical team of the Archdiocese of Cusco and the DDC–C carry out a rapid inspection of the site once a year, after the rainy season. This makes it possible for the Archdiocese of Cusco to plan maintenance activities during the dry season. The same protocol can be implemented after an alert from the community or the occurrence of major natural events. The rapid protocol includes a visual inspection, the completion of a detailed inspection form, and simplified mapping of conditions on site plans, as well as a production of photographic records (Table 2).

Currently, the Archdiocese team uses a printed version of the form, but the same is also available digitally. The conclusions of the inspection should detail the planned actions: additional investigations, interventions with different priorities (with a maximum period of 3 months; for the next inspection cycle; desirable long-term actions), and/or small renovation works to be carried out by the community without the need for approval documents from the authorities. The Archdiocese implements any other intervention, collaborating with the Municipality of Rondocan and DDC–C, where applicable.

The third monitoring protocol for heritage specialists should take place every 5 years. It includes a detailed condition survey, using the documentation produced after the completion of the works, as-built drawings, and the monitoring forms from previous years, complemented by photographic records and documentation of the site. It is envisioned that the GCI will be involved for at least the first 5 years of monitoring, when the responsibility will be given to the Archdiocese of Cusco. Whitin the protocol for heritage specialists, the University of Minho installed a permanent SHM in 2022, to assess the structural and

Table 2. Outline of the annual inspection form with main sections and content required.

General information	• Type of inspection (annual or upon need) • Inspectors and participants from the community • Time of the day and weather • Site accessibility • Use of the site and/or interventions carried out since previous inspection
Architecture/structural assessment	• Schematic plans, elevations, and sections to mark conditions encountered • Description of conditions encountered • Suggested actions
Monitoring system	• SHM functioning • Readings from tell-tales and crack meters
Systems	• Functioning and/or missing elements
Wall paintings	• Orthophotos of monitoring areas to mark conditions encountered • Description of the conditions encountered • Suggested actions
Movable artworks	• Cross-check presence and conditions
Conclusions	• Recap of actions for the Archdiocese (further investigations, urgent interventions, or in the next maintenance cycle), along with desirable long-term actions
Summary of the meeting with the community	• Recap of actions for the community (appropriate use, small repairs, etc.)

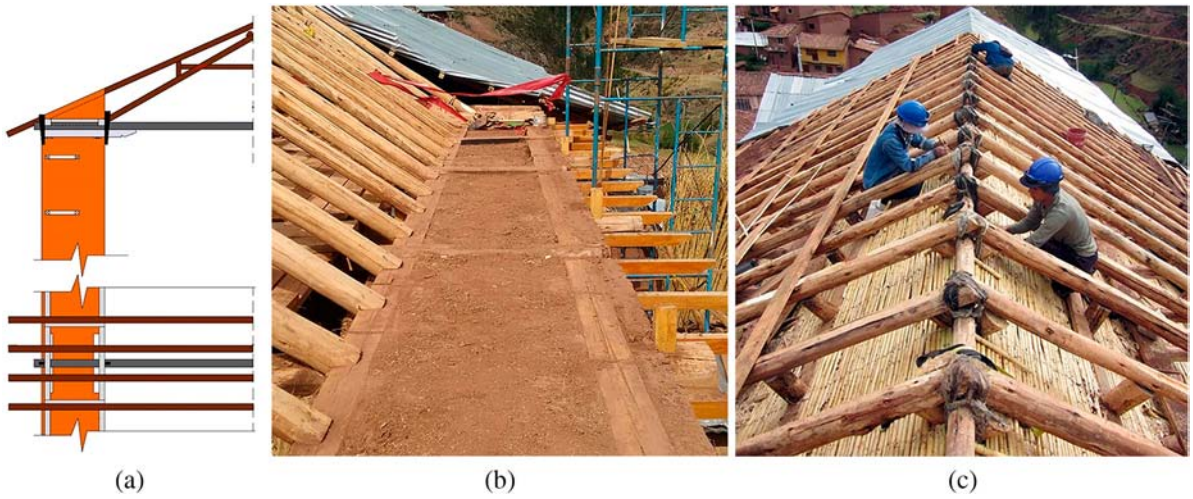


Figure 3. Worksite and implementation of retrofitting techniques of the church of Kuñotambo. (a) Typical section and plan of the lateral walls showing tie beam, bond beam, and roof rafter connections. (b) Lateral bracing in the upper walls and connection with roof rafters. (c) New roof with double rafters. Images: Juan Carlos Mellado ©2019 Getty Conservation Institute and Dirección Desconcentrada de Cultura Cusco.

environmental conditions of the structure after its seismic retrofitting.

SHM can be defined as the recording, data collection, and statistical correlation of structural conditions, seismic actions, and other environmental parameters, establishing a clear relationship between causes and effects (ISO 13822 2010). A crucial part of the process is the association between the qualitative data obtained during monitoring activities (visual analysis, condition mapping, etc.), with the quantitative data obtained by the SHM. Information from assessments and non-destructive testing conducted before the design and implementation of retrofitting techniques, alongside the update of the finite element model of the retrofitted building, are critical to effectively design the SHM (Figures 3 and 4) (Ahmadi et al. 2022).

The SHM for the church of Kuñotambo aims to record alterations in the shape and formation of cracks in relation to environmental and seismic data, to analyze structural capacity and deformation in the structure, and thus understand the probable causes. This type of monitoring has proven to be appropriate for damage detection, especially after earthquakes (Alban et al. 2019; Zonno et al. 2021).

The system installed at the church includes five elements (Figure 5). First, sensors for temperature and relative humidity (RH) which have a direct effect on cracks, outward rotations, and dynamic properties, including interior and exterior data loggers, interior surface thermocouples, and a temperature and RH probe for the external ambient conditions. Their readings are integrated with static and dynamic sensors, to investigate the effect of seasonal cycles. Second, a system of accelerometers for the detection of natural vibrations and seismic events. The main objective is to monitor the out-of-plane modes of the side walls and main façade, in correlation with seismic events, parameters indicative of the effectiveness of bracing and anchoring systems. Third, crack meters are located at selected points, such as interfaces between different materials or existing cracks. Fourth, tilt meters in walls to detect out-of-plane rotations, a type of damage common in unreinforced load-bearing masonry structures. Finally, an integrated system for the acquisition, storage, and processing of

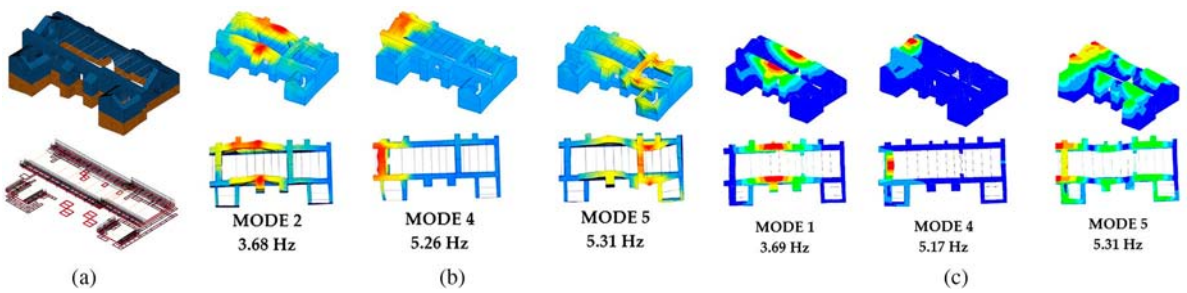


Figure 4. Modelling of the retrofitted church. (a) Configuration of the finite element model (FEM) with timber reinforcements. (b) Three principal mode shapes obtained from ambient vibration tests, during December 2019. (c) The same, from the updated FEM. Images first published in Ahmadi et al. (2022).

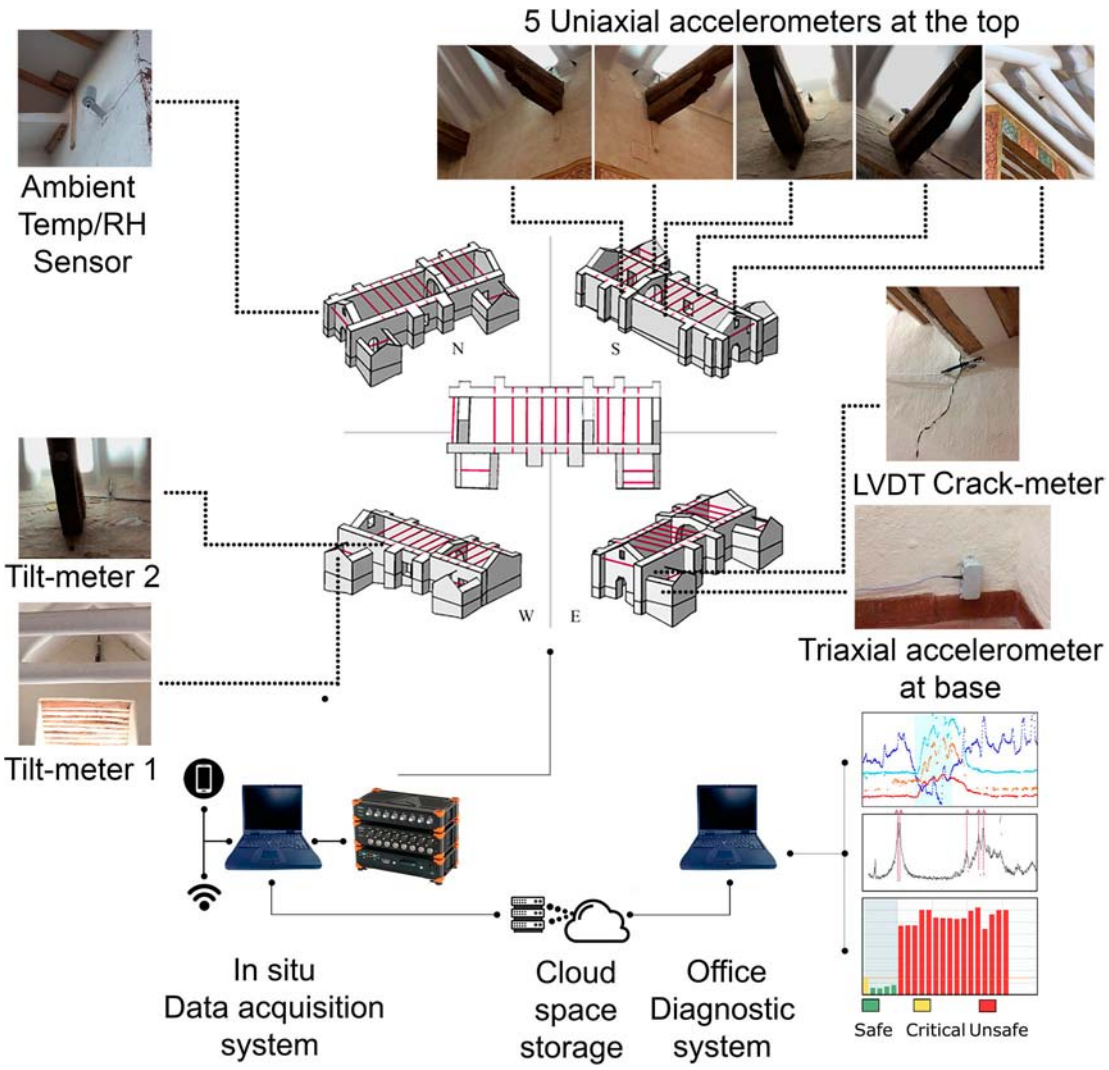


Figure 5. Schematic representation of the SHM system at the church of Kuñotambo. Images: Georgios Karanikoloudis ©2023 Getty Conservation Institute.

the SHM data. Data acquisitions are continuous, with appropriate sampling frequencies. Data from the sensors is collected by a laptop on site and then uploaded to a storage cloud, using automatic procedures for large data series, to be processed remotely.

Results

Inspections have been carried out since 2020, with the GCI staff initially providing guidance and receiving feedback via conference calls, due to the team's inability to travel during the Covid-19 pandemic, and in person from April 2022.

Basic monitoring by community members enabled detection of lost roof tiles, damage to the roof eaves, and the presence of bird droppings inside the church. This served as an early warning system for the Archdiocese of Cusco to plan for site visits and repairs. The community has been conducting basic maintenance activities such as cleaning of the church and its surroundings. Annual inspections were carried out by staff of the Archdiocese of Cusco and the DDC–C. The protocol and form were progressively simplified, allowing the team to complete the inspection in half a day. The Archdiocese planned and implemented maintenance works in 2021 and 2022, before the rainy season, including localized tile replacement, seal of minor cracks in interfaces between parts, and stabilization of small detachments in specific areas of the wall paintings using earth-based injection grouts. Another issue encountered by the team was the condition of the exterior paint, which presented detachment and losses. This was attributed not only to the material, a lime-based paint with several additives commonly used by the DDC–C, but also to the meteorological conditions suffered by the church, which is on the ridge of a mountain exposed to extreme rains and winds. The GCI and consultants conducted several tests and subsequent evaluations to identify an alternative material for the finishes of the church and bell tower (Marcus et al. 2022). As a result, and considering additional factors such as availability, durability, cost, and ease of application, a new earth-based mortar slur and

silicate-based paint was applied in 2022 and is currently being monitored.

The permanent SHM has been recording hourly acquisitions since 2022 with few downtimes due to power failures.

As part of the protocol for heritage specialists, the GCI staff, consultants in engineering and wall painting conservation, alongside the staff from the Archdiocese of Cusco, performed a complete condition assessment of the site in April 2022. Originally planned for early 2020, the assessment was delayed by the Covid-19 pandemic. Digital records of the detailed mapping were shared with the Archdiocese and DDC–C to establish a repository for ongoing monitoring acquisitions.

Much of the structural damage found in the church since 2022 is related to the construction process and foundation or soil settlement in the northeast part of the building. This includes cracks in the top parts of the gable of the main façade, the staircase leading to the choir loft, and the northeast section, including the baptistry. Cracks were observed in the adobe walls, stone base course, and *intrados* of the gypsum plastered roofs, with discontinuities in the interior and exterior pavement.

Non-structural cracks in the interior surfaces of the roof structure are likely due to deformation of the timber elements from hygrothermal variations. Weather-related damage, such as water ingress from missing tiles after the rainy season, in roof eaves, and at the intersection between roofs and adjacent walls is connected to the implementation of traditional tiles without proper waterproofing or flashing. Significant water damage is also evident in many exterior areas near the base course, possibly due to exposure to heavy rainfall patterns.

Environmental conditions in Kuñotambo are characterized by a drier and colder season (May–October) and a wet and rainy season (November–April). Internal air temperature and RH were found to be much less variable than the exterior, and the wall temperatures exhibited a time lag due to the thermal inertia of the adobe walls. The internal RH varies from 15% to 77%, while values higher than 65% and lower than 40% can affect decorative surfaces and artworks.

Continuous monitoring of a crack in the staircase with a linear variable differential transformer (LVDT) crack meter showed seasonal fluctuations. In general, this crack has shown a steady increase during the dry seasons, when adobe is expected to shrink, while the widening slows or reverses during the wet season, alongside the expansion of adobe; its overall, non-recoverable progression is 3 mm per year. Additionally, a seismic event of magnitude 7.2 and with epicenter at 200 km from the church on 26 May 2022 caused a non-recoverable crack increase of 0.14 mm, which corresponds to 5% of the yearly positive progression.

Two highly sensitive tilt meters have been monitoring vertical rotations at the gable end of the baptistery and at the north lateral wall of the nave, with thermocouples in the walls to evaluate temperature effects. Vertical rotations exhibited seasonal fluctuations with maximum positive outward drifts of 0.1% and 0.5% degrees respectively.

Three natural frequencies and mode shapes were identified and monitored continuously over time, based on hourly acquisitions of the five uniaxial accelerometers at the top of the walls in the nave and the façade. The natural frequencies remained stable, with minor variations linked to seasonal cycles, mainly under a slight increase during the wet season. Following the earthquake on 26 May 2022 there was a sudden decrease in natural frequencies by approximately 0.1–0.2 Hz, indicating a loss of stiffness and minor structural damage.

Overall, the collected monitoring data shows oscillating variations due to seasonal effects, sometimes under complex nonlinear correlations with the environmental parameters. Processing of data from more seasonal cycles is therefore needed. The team is also considering some additions to the monitoring system: installing a weather station, given the influence of RH on structural response and the impact of rainfall on the church conditions, and conducting regular measurements to monitor settlements in the northeast part.

Finally, capacity-building has been a fundamental component of the monitoring and maintenance plan. Since 2020, activities have been conducted for community members responsible for basic inspections, cleaning, and small repairs. A manual for the appropriate use of the site (including for example, instructions for avoiding any damage to the decorated elements and surfaces), together with an annual maintenance calendar was prepared by the GCI and updated based on feedback from the community.

Then, staff from the Archdiocese of Cusco and the DDC–C worked alongside the GCI team to refine the methodology for the annual inspection and to test it on site every year after the rainy season.

Furthermore, the GCI and DDC–C convened civil engineers and graduate students of civil engineering from Latin America for a 4-day workshop in Cusco in June 2023. The workshop centered on diagnosis and structural monitoring of historic buildings, with a focus on earthen and masonry constructions. Staff from the University of Minho and the Pontificia Universidad Católica del Perú led the activities, alongside GCI staff. The 22 participants attended lectures on topics such as methodology for inspection, analysis and structural diagnosis of historic buildings, *in situ* testing, and some of the most advanced tools and techniques for the evaluation and monitoring, including the interpretation of data generated by the SHM.

Half of the curriculum of the workshop was practical, with site visits to historic buildings in Cusco to discuss structural damage, as well as exercises and field sessions. Participants performed non-destructive and micro-destructive testing on one traditional earthen residential building in Cusco and visited the SHM at the church of Kuñotambo. The workshop raised awareness of the latest developments in terms of SHM, as well as deepening expertise among participants on monitoring tools and techniques.

Discussion

The development and implementation of a monitoring and maintenance plan for the church of Kuñotambo exemplifies an integrated approach to heritage preservation, emphasizing the importance of long-term sustainability and the rising role of communities and social entities as active caretakers of their heritage.

The primary goal of the monitoring plan is the preservation of the site for future generations. Changes in buildings after construction can happen, especially in the case of earthen structures; some of these changes may be linked to material adjustments, customary building practices that prove inadequate for a changing environment, or limitations during construction. By tracking changes in the building, the plan ensures that the site remains usable, perpetuating and adding to its significance for the local community. To this end, the commitment of the Archdiocese of Cusco to provide religious services to all communities in the region, regardless of their geographical accessibility, is pivotal.

Safety is paramount for all heritage sites located in seismically active regions. Not only does the church of Kuñotambo demonstrate the possibility of intervention with earthquake-resistant repairs using traditional techniques and local materials, but the monitoring plan provides an additional layer of safety by continually assessing the structural integrity of the monument.

The use of an advanced SHM, complementing a regular three-tier monitoring protocol, facilitates the early detection of problems. Any damage is identified promptly, allowing for proactive responses. Additionally, the retrieval and processing of information from the SHM enables verifying the effectiveness of the retrofitting techniques implemented, providing scientific data to support their broad dissemination.

The engagement of the community of Kuñotambo and local stakeholders in the monitoring and maintenance plan enhances public awareness and trust in the preservation of heritage, and stems from the sense of pride for their conserved church. The clear three-tier system offers a transparent record of the church's condition and need for maintenance actions, fostering cooperation between stakeholders. Timely maintenance, such as replacement of missing roof tiles, is more cost-effective and less disruptive than addressing major interventions. Moreover, the plan was created having considered the capacity, availability of time and equipment by each group responsible for the monitoring and maintenance actions. While the three protocols described are intended to be integrated, they can also operate independently so that they can be used, in whole or in parts according to available resources, in other comparable sites.

One notable aspect of the project is dissemination and capacity-building. The GCI has organized activities for professionals responsible for the conservation of similar buildings in the region, offered training to Latin American engineers on advanced tools for structural monitoring, and produced publications available to the larger conservation community.

Preventive and planned conservation have undeniable benefits in terms of resources and impact for communities, owners, authorities, as well as cultural properties (Vandesande et al. 2018). Within this framework, two key sub-themes play a crucial role. First, the implementation of the monitoring and maintenance plan for the church of Kuñotambo is an example of collaborative international and interdisciplinary work. This is a powerful model for addressing complex preservation challenges when expectations and responsibilities of all parties are well set. Second, the focus on preventive conservation is often intertwined with the empowerment of communities and social entities as active caretakers of their heritage. This commitment fosters a sense of belonging and reinforces the idea that the protection and management of cultural properties is a shared responsibility among all interested parties, including institutions, owners, and users (ICOMOS 2014; Van Balen and Vandesande 2015; García et al. 2021). The active involvement of different members of the 'heritage community' (Council of Europe 2005) helps to safeguard the spirit of the place (Čebron Lipovec and Van Balen 2008) and at the same time ensures the sustainability of conservation actions in the long-term.

Acknowledgements

The Seismic Retrofitting Project (SRP) is a partnership between Getty Conservation Institute (GCI) and the Ministerio de Cultura del Peru. The authors would like to thank the DDD-C, Arzobispado del Cusco, Municipalidad Distrital de Rondocan, and Comunidad Campesina de Kuñotambo, as well as the following individuals, who have been collaborating to the design and implementation of the monitoring and maintenance plan at the church of Kuñotambo, and related capacity-building activities: Andres Arce Campos, Felícitas Ttito, Cesar Chacara Espinoza, Angela Delgado Gibaja, Mauricio Gonzales Paliza, Juan Carlos Mellado Flores, Claudia Miranda Sotomayor, Violeta Paliza Flores, Margherita Rago, Rony Reategui Arrue, Miquel Reina Ortiz, Mario Santana Quintero, Leslie Rainer, Alex Ramos, Juana Segura

Escobar, Alessandra Sprega, Clemencia Vernaza Albisser, Luís Andrés Villacorta Santamato, and Carlos Yaya Miranda.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Elena Macchioni http://orcid.org/0000-0001-5442-5950

References

Ahmadi, S. S., G. Karanikoloudis, N. Mendes, R. Illambas, and P. B. Lourenço. 2022. "Appraising the Seismic Response of a Retrofitted Adobe Historic Structure: The Role of Modal Updating and Advanced Computations." *Buildings* 12 (11): 1795. https://doi.org/10.3390/buildings12111795.

Alban, K., N. Cavalagli, and F. Ubertini. 2019. "Temperature Effects on Static and Dynamic Behavior of Consoli Palace in Gubbio, Italy." *Mechanical Systems and Signal Processing* 120:180–202. https://doi.org/10.1016/j.ymssp.2018.10.021.

Cancino, C., and S. Lardinois. 2012. *Seismic Retrofitting Project: Assessment of Prototype Buildings*. 2 vols. Los Angeles, CA: Getty Conservation Institute.

Cancino, C., E. Macchioni, B. Marcus, J. C. Mellado, and J. C. Menéndez. 2020. "Seismic Retrofitting Using Local Materials and Expertise at a Church in Kuñotambo, Peru." *APT Bulletin* 51 (2/3): 23–30.

Council of Europe. 2005. *Council of Europe Framework Convention on the Value of Cultural Heritage for Society (CETS No. 199)*. Council of Europe Treaty Series No. 199.

C̆ebron Lipovec, N., and K. Van Balen. 2008. "Preventive Conservation and Maintenance of Architectural Heritage as Means of Preservation of the Spirit of Place." Presented at 16th ICOMOS General Assembly and International Symposium *Finding the Spirit of Place – Between the Tangible and the Intangible*, Canada, Quebec.

Della Torre, S. 2020. "A Coevolutionary Approach as the Theoretical Foundation of Planned Conservation of Built Cultural Heritage." In *Preventive Conservation: From Climate and Damage Monitoring to a Systemic and Integrated Approach*, edited by A. Vandesande, E. Verstrynge, and K. Van Balen, 11–18. London: Taylor and Francis.

García, G., and A. Vandesande. 2021. "Paths Towards Participatory Governance for Cultural Heritage." In *The Future of the Past: Paths Towards Participatory Governance for Cultural Heritage*, edited by G. García, A. Vandesande, F. Cardoso, and K. Van Balen, 3–10. London: CRC Press.

Getty. 2023. "Seismic Retrofitting Project." Accessed 18 October 2023. https://www.getty.edu/conservation/our_projects/field_projects/seismic/index.html.

Heras, V. C., M. S. Moscoso Cordero, A. Wijffels, A. Tenze, and D. E. Jaramillo Paredes. 2019. "Heritage Values: Towards a Holistic and Participatory Management Approach." *Journal of Cultural Heritage Management and Sustainable Development* 9 (2): 199–211. https://doi.org/10.1108/JCHMSD-10-2017-0070.

ICOMOS. 2014. *The Florence Declaration on Heritage and Landscape as Human Values*. Florence: International Council on Monuments and Sites.

ISO 13822. 2010. *Basis for Design of Structures: Assessment of Existing Structures*. Geneva, Switzerland: International Standards Organization.

Lourenço, P. B., F. Greco, A. Barontini, M. P. Ciocci, and G. Karanikoloudis. 2019. *Seismic Retrofitting Project: Modeling of Prototype Buildings*. Los Angeles, CA: Getty Conservation Institute.

Marcus, B., E. Macchioni, C. Vernaza, and C. Cancino. 2022. "Ensayos de materiales de acabado a base cal y sintéticos para el mantenimiento del enlucido del templo de Santiago Apóstol de Kuñotambo, Perú." In *20 SIACOT Revive la tierra*, edited by A. Ferreiro, Z. Salcedo Gutierrez, and C. Neves, 200–209. Trinidad, Cuba: PROTERRA; Oficina del Conservador.

Reina Ortiz, M., E. Macchioni, C. Cancino, L. Rainer, C. Vernaza, A. Irco Nuñez, S. Fai, and M. Santana Quintero. 2021. "Three Documentation Scenarios for the Long-term Preservation of Decorated Surfaces in the Church of Kuñotambo, Peru." *The ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, VIII-M-1-2021, 125–132. https://doi.org/10.5194/isprs-annals-VIII-M-1-2021-125-2021

Torrealva, D., E. Vicente, and T. Michiels. 2018. *Seismic Retrofitting Project: Testing of Materials and Building Components of Historic Adobe Buildings in Peru*. Los Angeles, CA: Getty Conservation Institute.

Van Balen, K. 2015. "Preventive Conservation of Historic Buildings." *Restoration of Buildings and Monuments* 21 (2/3): 99–104. https://doi.org/10.1515/rbm-2015-0008.

Van Balen, K., and A. Vandesande, eds. 2015. *Community Involvement in Heritage*. Antwerp-Appeldoorn: Garant.

Vandesande, A., K. Van Balen, S. Della Torre, and F. Cardoso. 2018. "Preventive and Planned Conservation as a new Management Approach for Built Heritage: From a Physical Health Check to Empowering Communities and Activating (Lost) Traditions for Local Sustainable Development." *Journal of Cultural Heritage Management and Sustainable Development* 8:78–81. https://doi.org/10.1108/JCHMSD-05-2018-076.

Vázquez, L., M. C. Achig, and F. Cardoso. 2018. "Minga: El patrimonio intangible en la Campaña de Mantenimiento de San Roque, Cuenca – Ecuador." *ASRI Arte y Sociedad Revista de Investigación* 14:121–136.

Zonno, G., R. Aguilar, R. Boroschek, and P. B. Lourenço. 2021. "Environmental and Ambient Vibration Monitoring of Historical Adobe Buildings: Applications in Emblematic Andean Churches." *International Journal of Architectural Heritage* 15 (8): 1113–1129. https://doi.org/10.1080/15583058.2019.1653402.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S227–S234
https://doi.org/10.1080/00393630.2024.2389713

ORIGINAL RESEARCH OR TREATMENT PAPER

Updating Environmental Guidance: the British Museum Approach

Actualización de la orientación medioambiental: el enfoque del Museo Británico

Tatiana Marasco and Louisa Burden

Conservation, Collection Care, British Museum, London, United Kingdom

ABSTRACT

This paper will examine the process taken to review current collection environment practices and the stakeholder management processes applied to various departments across the British Museum. The paper will provide key details on the parameters and controls considered for temperature, relative humidity, and light in the new guidance document, and consider successes and obstacles encountered throughout the project. Two case studies are included to show how the review has impacted on projects and collection environment since the new guidance has been authorised and brought into use.

Este artículo examinará el proceso seguido para revisar las prácticas actuales del entorno de colección y los procesos de gestión de partes interesadas aplicados en varios departamentos del Museo Británico. El documento proporcionará detalles clave sobre los parámetros y controles considerados para la temperatura, la humedad relativa y la luz en el nuevo documento de orientación, y considerará los éxitos y obstáculos encontrados a lo largo del proyecto. Se incluyen dos estudios de casos para mostrar cómo la revisión ha impactado en los proyectos y el entorno de recolección desde que se autorizó y puso en uso la nueva guía.

ARTICLE HISTORY
Received October 2023
Accepted June 2024

KEYWORDS
Preventive conservation; sustainable solutions; collection environment and lighting; stakeholder management; British Museum

Conservación preventiva; soluciones sostenibles; ambiente e iluminación de colección; gestión de los interesados; Museo Británico

Introduction

The British Museum was founded in 1753 as the first national museum covering all fields of human knowledge. The museum's collection has since grown in many ways over the past three centuries through acquisitions from excavation, donations, conflict and colonial activity, and purchase and commissions.

The museum's current collection includes approximately eight million objects covering two million years of history, across six continents. The collection is housed within a multi-site estate comprising the museum itself located in Bloomsbury, London, and off-site collection storage facilities located in the Borough of Hackney, London and Blythe House in West Kensington, London. Blythe House belongs to the government, and they required the Museum to relocate the collection. The collection is being moved to the Museum's newly built facility, the British Museum Archaeological Research Collection (BM_ARC) in Reading, Berkshire. This move is due to be completed in early 2024.

The museum trustees have approved the next major phases of its masterplan. This includes extensive redevelopment of the heating and electrical supply of the Bloomsbury site, to replace ageing infrastructure, and the refurbishment of the western range galleries and collection stores, to improve public access to the collection. As part of the preparation for this work, the Head of Preventive Conservation was tasked by the Head of Collections Care to review and update the collection environment guidance. This review provided the Conservation team with an opportunity to replace numerous guidelines that had developed within the museum with a single source document. The document would be authorised by the Museum's executive level Directorate Group.

Stakeholder engagement was necessary and a key deliverable to ensure collaboration from colleagues to support this project and its successful delivery.

Survey of the museum's collection environment and lighting guidance

An appraisal of the current guidance approach and documentation was carried out by the Head of Preventive Conservation in 2021. A search was made across various departments for hard copies and digital files in circulation.

Three strategic and numerous operational documents were found to be in use: historically these were approved either by department or executive groups. The strategic documents set out temperature, relative humidity (RH) and lighting criteria for the

CONTACT Tatiana Marasco tmarasco@britishmuseum.org Great Russell St, London, WC1B 3DG, United Kingdom
© The British Museum 2024

collection. These were climate criteria for storage, display and outgoing loans dated 2012; lighting criteria for display and outgoing loans dated 2006; and the *Collection Storage Framework* dated 2017.

In addition, various Conservation-led environment and lighting-related policies were found in the digital records during this phase of the project: *Environmental Policy* dated 1993 and 2012; and *Conservation Policy* dated 2019. Both the 1993 and 2012 *Environmental Policies* remained independent from the overall *Conservation Policy*. In 2019 Preventive Conservation and collection environment were incorporated into the *Conservation Policy*. This policy is still operational and is published on the museum website (British Museum 2019, 2020a).

Within the multiple documents from across the museum many variations were found: some obviously had come from Conservation, however some were less transparent in their origins. In several cases, the top temperature range was lower than that recommended for the collection in past Conservation-generated documents, which was unexpected. Follow-up with colleagues identified that some temperature ranges had been set for human comfort.

The review identified that documentation and methodologies were inconsistent across various collection-based activities. Different parameters were quoted in multiple documents, and the various guidelines did not support operating in an ageing and changing building infrastructure at Bloomsbury and Hackney. The numerous documents did not provide a sustainable approach to environmental management for the museum.

It was determined that the multiple documents and parameters needed to be replaced with a single document that would include specifications that could be used internally and with external contractors, so the same approach could be applied throughout the estate. This recommendation was submitted to the Head of Conservation and Head of Collection Care. The development of the updated guidance was included in the 2022 museum's *Operating Plan* and approval of the guidelines would be at the executive level. This would enable authorised roll-out of the guidance and replacement of all other documents quoting environment parameters.

The Head of Preventive Conservation was tasked to develop the holistic guide for immediate implementation where possible, and for medium to long-term developments realised through upcoming redevelopment masterplan phases.

Review of collection environment practices at the British Museum

Part of the review to support the development of the new guidance included investigating environmental practices in place to care for the collection. Both active and passive control measures have historically been used across collection areas. Controls include ambient heating, full heating, ventilation, and air-conditioning (HVAC) systems, static and portable humidification and dehumidification where HVAC infrastructure is not available or possible, and use of silica gel and pollutant scavengers in micro-environments.

In-showcase mechanical RH control has been used in the museum to support the display of more sensitive material and to achieve the tighter RH parameters from older environmental documents. Some collection spaces have multiple in-showcase units, while others have larger units serving several enclosures. Some enclosures also have mechanical pollutant control. Puraspec© sulphur absorption filtered pumps, for example, are used in showcases displaying vulnerable silver objects. This type of management and equipment maintenance requires additional financial and staff resources. Although the units can perform well, long-term performance is heavily reliant on regular maintenance which can become more challenging as the number of units in use increases and ages, resulting in potential increase of equipment failure, and consequently increase risks to the collection. Although it is recognised that in-showcase mechanical RH control does prevent having whole galleries environmentally controlled where not essential, it still requires high-energy consumption and can impact on sustainability.

Resilience and sustainability

The British Museum is working towards a net zero carbon future. With increasing climate shifts and long-term changes in temperature, weather events and patterns, the museum recognised the need to develop an institution-wide approach to sustainability, encompassing both social and environmental concerns. In 2022 an organisation-wide sustainability audit was carried out and included impact mapping of activities across the museum. Energy use was identified as an issue, and collection care environmental parameters and its management approaches could be improved. It was however also noted that lending institutions may ask for more stringent environmental conditions than those we might maintain for our own collection. Visitor comfort and staff comfort while working in the galleries were also considered. It was therefore recognised that flexibility within our environmental control infrastructure going forward was required.

As part of the masterplan redevelopmen,t the heating and electrical supply is being replaced throughout the Bloomsbury estate. The *Energy Centre Programme* (ECP) will introduce a site-wide approach to heating and electrical infrastructure, operated by new state-of-the-art plant. This programme will

improve resilience and flexibility and reduce risk to the collection. Replacing and reducing inefficient and life-expired plant and introducing greater simplicity and operating efficiency will also improve its management and maintenance programmes.

To support this redevelopment, and subsequent phases of the masterplan, and to ensure successful outcome, reviewing and re-defining the museum's collection environment and lighting guidance is essential. This will provide a consistent reference point for the new infrastructure upgrade in line with the museum's approach to collection preservation, and other phases of the masterplan.

Developing the new guidance

The new guidance was developed based on data gathered following the review of the museum's current practices. The review also took into account recent decades of collection environment debate, the sector's moves towards sustainability, and reducing energy consumption. Although the new guidance document also includes updated information on pollutants and vibration, this paper will focus on the revised guidance on temperature, RH and lighting only.

Leskard described (2021) the outcome of a 2007 expert roundtable discussion on climate strategies organised by the Getty Conservation Institute. The panel concluded that in addition for the need to control the environment based on deterioration risk, environmental 'management must be accomplished in a responsible manner, taking into account "proofed" RH and temperature fluctuations (most extreme historic fluctuations), building design and performance, financial costs, energy consumption and global climate change'.

This approach was implemented as part of the development of the new guidance and incorporated within the newly revised environmental parameters and their management. A range of factors for developing the guidance was considered including the museum's external environment and the London climate; the collection and its use; the building fabric and its facilities. Recognition that the collection has a range of requirements, what the various buildings can deliver in London's current climate, and acknowledging the increased frequency of unusual weather events from climate change were factored into the discussion. Passive management of the environment most appropriate to minimising deterioration and supporting sustainability was also considered and included.

London climate

London, and the rest of the UK, has a temperate oceanic climate with cool winters, warm summers and precipitation evenly distributed throughout the year (Beck et al. 2018). Both temperature and RH experience moderate seasonal fluctuations. This has been accentuated by climate change, resulting in the increase of extreme temperature with warmer and drier summers, and wetter winters. Ways in which the museum and its indoor environment have been impacted by extreme weather events include long spells of dry weather followed by sudden outdoor flooding caused by excessive rain, heat waves, and rapid external temperature changes such as the 15°C change from below freezing, up to much milder conditions in less than 12 h which occurred on 19 December 2022.

The collection and its use

The collection includes items made from a widely varied range of materials with differing chemical and physical properties. These include objects of a purely inorganic or organic make-up, with a large portion of the collection being composite. The collection also includes 2D material comprising the national prints and drawings collection, and archival and photographic material. With the museum's ongoing acquisition programme, the collection continues to grow, and a change in the make-up of the objects has been recognised with a noticeable increase in plastics and other modern materials. The collection is used for a variety of activities ranging from permanent displays, temporary exhibitions, touring exhibitions, loans, study and research.

The estate

The museum's architectural landscape is an assemblage of nationally recognised, Grade I-listed buildings with various additions over the centuries, and includes contemporary structures – all designed to safely store, research and display the collection. The expansion of the collection over the years has necessitated successive phases of construction for display and storage. The result of the Bloomsbury building programmes is a complex architecture of different periods, each with its own structural and environmental management challenges. Storage sites have developed as required in repurposed industrial buildings, and most recently with the construction of the BM_ARC completed on 30 August 2022.

Building requirements and environmental performance since 1753 have seen a drastic change with structural efficiency greatly improved and environmental control infrastructures adapted to cope with rapid climate change and extreme weather events. The interior environment of the museum's oldest set of buildings and structures is often influenced by the external environment, and buffering capacity can be minimal. These factors can be complex when

specifically dealing with external climate challenges. Its environmental control infrastructure is also not as well developed or is ageing, and is therefore not effective or sustainable in terms of energy efficiency. On the other hand, the estate also consists of modern structures like BM_ARC where the design and infrastructure were developed to support sustainable preservation approaches and maintain ambient environment more passively to reduce energy consumption.

Stakeholder engagement

A well-implemented stakeholder engagement programme was key to ensure successful review of the museum's approach to collection environment and lighting and take up of the new guidance. Taking consideration of the content of the new guidance document and its potential impact on various collection-based activities, contribution from colleagues with both active and indirect stakes was essential. These included colleagues from the various Collections departments; and Public Engagement, Operations, and Estates and Capital Projects directorates.

In this instance, the most efficient approach was to use all levels of engagement, each with its own strategy, across departments and other internal sections: Inform, Consult, Involve, Collaborate and Empower (Last 2023). Preservation through providing suitable environment must be applied over long periods of time, and so effective engagement of key stakeholders was crucial in building strong relationships to ensure agreement on the best way forward.

> Longer-term impact can emerge from the outcome of the first negotiation or from behaviour during and after the initial negotiation […] In situations that require more complex decision-making, goal sharing helps others to deliver what you want rather than what you've asked for. If everyone understands the common and agreed goals, they can adapt their responses to deliver those outcomes … (Henderson 2023).

This process was carried out in four phases:

- The first phase involved an initial consultation to inform colleagues of the guidance, review scope and gather feedback and understanding of stakeholder's needs, concerns and anticipated use. This phase also included generating collaboration to determine best approach and solutions.
- In the second phase, stakeholders involved in the initial consultation were informed of the results and encouraged to submit final feedback. Indirect stakeholders – those affected by the outcomes of the guidance but not working directly with it, e.g. IT colleagues – were also informed.
- The third phase included submission of the proposed draft to senior management and the executive level group for approval.
- Fourth and final phase post-approval involved roll out and updating all affected documents. Stakeholder engagement continued throughout the roll-out and update phases, so colleagues were aware of changes.

Results

The resulting guidance document titled *Collection Environment & Lighting – Guidance and Implementation*, considers parameters for temperature, RH and lighting, suitable for the entire collection and to be implemented across the museum's various buildings. A trend to increase passive controls within showcases and storage enclosures where possible has been included in the new guidance. It sets out a plan to increase the use of low to zero energy controls as much as is practically achievable, thereby contributing to the museum's wider sustainability developments. In instances where passive control is not suitable, mechanical control options will be considered and used in a targeted manner.

The scope of the guidance document also includes control measures for pollutants and vibration. Integrated pest management has not been included as it is managed separately from the *Conservation Policy*, although both remain closely linked. Table 1 provides details and the outcome of the temperature and relative humidity parameters review.

Two case studies are shared to show how the review has impacted on projects since the new guidance has been authorised and brought into use. Details and outcome of the lighting parameters review are discussed in case study 2.

Case study 1. BM_ARC: changing environment guidance

The BM_ARC (Figure 1) was commissioned to provide an additional 15,627 m^2 of collection storage and research study space as part of the move out of the Blythe House storage facility in London. The original specification was to hold bulk archaeological material, including vulnerable metals and large objects. Specifications were subsequently reviewed part way through the build to accommodate storage of the textile collection on a temporary basis. The project was to have been completed by 2023, but due to the pandemic, it was extended to 2024. The stores environment (Figure 2) was specified to be as physically sustainable as possible.

The Collection Projects and Resources (CPR) department, which led the project, had environmental specifications detailed as part of the *Collections Storage Framework*, developed in 2017. These specifications were set out differently from the Conservation-issued parameters in the 2012 *Environmental Policy*, however, there was some cross-referencing. Conservation parameters for temperature and RH focused on material

Table 1. Outcome of the 2023 collection environment parameters review, for temperature and RH (IIC 2014; Shashoua 2004, 2020).

Material type	2023 Collection environment – temperature and RH
Inorganic and robust material	Temperature: minimum 12°C; should be kept stable and maintain RH as below. RH: 35–60%; rates of change should be limited to a total of 20% within 24 h, for 90% of the time over 12 months.
Organic and sensitive mixed media	Temperature: 16–25°C; should be kept stable. RH: 40–60%; rates of change should be limited to a total of 10% within 24 h, for 95% of the time over 12 months. More sensitive objects may require individual assessment and ranges.
Mummified remains and associated material	Temperature: 16–25°C; should be kept stable. RH: 40–55%; rates of change should be limited to a total of 5% within 24 h.
Archaeological metals	Temperature: 16–25°C; rates of change should be limited to 4°C within 24 h. RH: ≤35% in storage and 30–40% on display; rates of change should be limited to a total of 5% within 24 h.
Mixed media containing cellulose esters; other sensitive plastics	Temperature: 2–6°C RH: aim for 30–50%. Note that RH control is not possible within refrigerator units. (Storage conditions only)
Cellulose esters (non-composite material)	Temperature: −20°C to −16°C RH: aim for 30–50%. Note that RH control is not possible within freezer units. (Storage conditions only)

sensitivity for potential deterioration. The *Collection Storage Framework* parameters instead divided parameters into space design and environmental capacity. Lighting, pollutants and vibration were not included. A number of CPR-listed specifications also included the temperature as 22°C, which is below the parameters being used in the rest of the museum.

As part of the update of the museum-wide collection environment parameters the CPR parameters were fully cross-referenced with the new guidance and the same ranges implemented (Table 2). It was approved at executive level at the same time as the overarching guidance document.

Case study 2: collection lighting for display, masterplan approach

In addition to the ECP the museum's masterplan will also include the redevelopment of a series of galleries in the western section of the museum building. This phase of the masterplan will include renewing ageing building fabric, and creating new and engaging galleries that will enable innovative display.

In support of the upcoming complex refurbishment project and in support of its objective to initiate change in the museum's approach to sustainability and flexibility, it was essential that the parameters considered as part of this review could be applied



Figure 1. Aerial view of BM_ARC. Image: Allan Pollok-Morris.

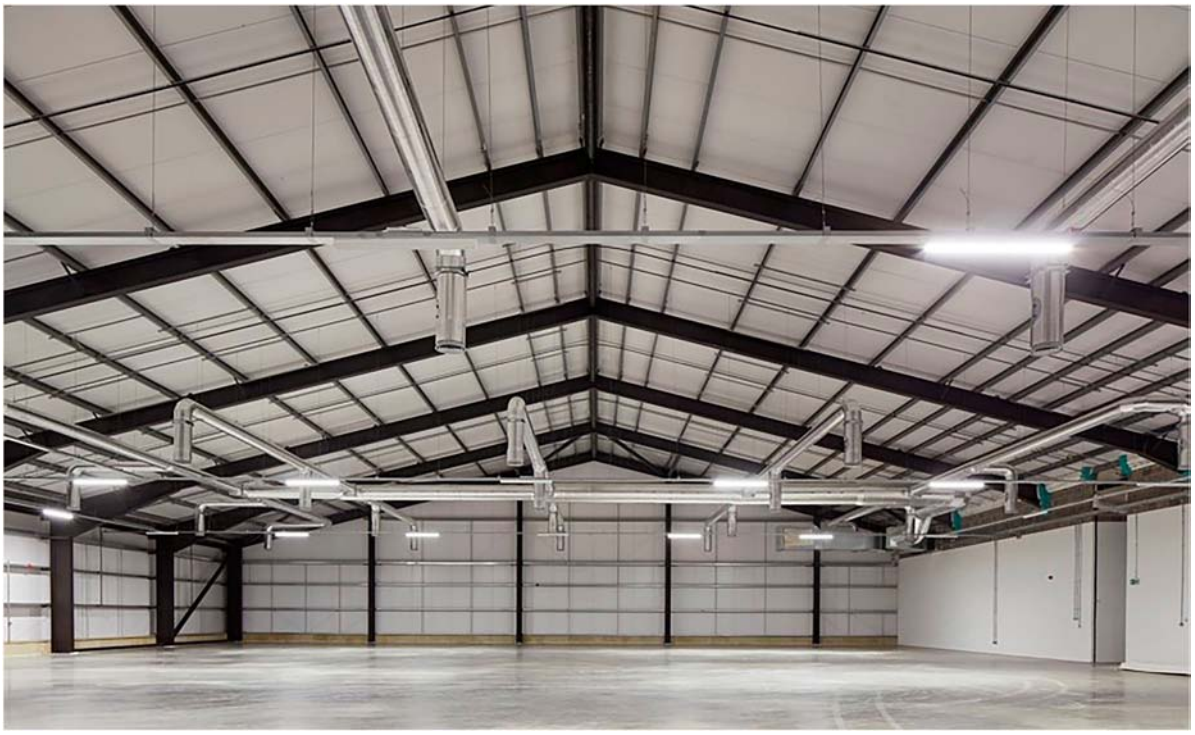


Figure 2. Storage room at BM_ARC. Image: The British Museum.

Table 2. Outcome of the *Collection Storage Framework* environmental parameters review (British Museum 2020b; BSI 2017).

Categories	2017 Collection Storage Framework		Categories	2023 Collection Storage Framework
Basic	14–22°C and 40–60% RH		Basic	Stable temperature that maintains RH with minimum 12°C, 35–60% RH with 20% maximum total variation over 24 h.
			Enhanced basic	Stable temperature 16–25°C and 40–60% RH with 10% maximum total variation over 24 h.
Basic cool	8–16°C and 40–50% RH			Removal of the 'basic cool' category as risk identified from moving collections from warmer display temperatures to lower storage temperatures.
Basic dry	14–22°C and 30–50% RH	→	Enhanced basic low	Stable temperature 16–25°C and 40–55% RH with 5% maximum total variation over 24 h.
Dry	14–22°C and 30% RH		Dry	Temperature maintained at 16–25°C with a maximum 4°C total variation within 24 h and RH up to 35% with 5% maximum total variation in 24 h.
Cold	4–6°C and 30–40 RH		Cool	Temperature maintained at 2–6°C and 30–50% RH.
The 2017 framework provided cool storage parameters as a 'cold' category, but no freezer storage categories was defined. This was redefined as 'cool' and 'cold' in the updated framework.			Cold	Temperature maintained at −20 to −16°C and 30–50% RH where possible to control.

throughout the medium and long-term developments realised through the masterplan. A key consideration was collection lighting for display.

Unlike temperature and RH, a single version of lighting criteria was used across the multiple documents found during this review project. These were defined in 2006 and included five categories of lighting parameters (Table 3).

The outcome of the review identified that there was not a requirement to change lux levels and cumulative exposure for materials classified as insensitive, moderately sensitive and sensitive, with the exception of ultraviolet levels. The 2006 'very sensitive' and 'highly sensitive' categories were considered no longer suitable for the museum's applications to collection lighting, and lacked flexibility required for the masterplan. As a replacement, the two categories were combined into a single 'highly sensitive' category. This provides greater flexibility and protection from light exposure through using more holistic assessment processes including light budgets, display rotations and risk-based conservation assessments.

Conclusion: results, successes and challenges

The museum embarked on reviewing and updating its environment and lighting guidance to prioritise the

Table 3. Outcome of the museum-wide 2023 collection lighting parameters review (Saunders 2020).

Categories	2006	Categories	2023
Insensitive	Lux level: 500+ lux Cumulative exposure: N/A Ultraviolet level: 75 µW/lumen	Insensitive	Lux level: Unlimited. Cumulative exposure: N/A. Ultraviolet level: 0 µW/lumen.
Moderately sensitive	Lux level: 200 lux Cumulative exposure: 600 klux/yr Ultraviolet level: 75 µW/lumen	Moderately sensitive	Lux level: ≤200 lux. Cumulative exposure: ≤600 klux/yr. Ultraviolet level: 0 µW/lumen.
Sensitive	Lux level: 50 lux Cumulative exposure: 150 klux/yr Ultraviolet level: 75 µW/lumen	Sensitive	Lux level: ≤50 lux. Cumulative exposure: ≤150 klux/yr. Ultraviolet level: 0 µW/lumen.
Very sensitive	Lux level: 50 lux (20% display in 10 years) Cumulative exposure: 30 klux/yr Ultraviolet level: 75 µW/lumen	Highly sensitive	Cumulative levels will be restricted to temporary light exposure and a time exposure restriction approach will be applied. This will be managed by using light budgets, display rotations and risk-based conservation assessments.
Highly sensitive	Lux level: 50 lux (10% display in 10 year) Cumulative exposure: 15 klux/yr Ultraviolet level: 75 µW/lumen		

long-term need of the collection, whilst remaining within the scope of its approach to sustainability across all operations and projects. It was also considered necessary to ensure that the new parameters are appropriate for the museum's varied estate, its location in a temperate climate and impact from weather events caused by climate change. The review also provided an opportunity to replace numerous guidelines that had developed over the years, and to provide consistency.

To ensure clear and effective decision-making within a large complex organisation, the decision was made to initiate a single, comprehensive source of guidance for collection environment. This removes ambiguity previously created by these multiple documents.

Older documents and information were held onto as 'standards' in part due to limited museum-wide understanding that research and practice over recent years had moved on. Allocating sufficient time to complete a thorough review, understanding historical internal approaches and decision-making was crucial to success. Considerable stakeholder engagement was also required to help some teams move forward with changes that they initially felt would cause difficulties or were detrimental.

Honesty about what the buildings and environmental control systems can provide in terms of environment when most UK museums are not fully air-conditioned throughout, or have no air-conditioning at all, continues to be required by all involved in care and movement of collections, and needs constructive challenging when misinformation is found. This is now even more crucial when these infrastructures are being impacted by climate change, affecting their efficiency. Engagement by all should also extend to understanding the need to balance safe environment for the collection while achieving it sustainably in the long term and being an active participant in reducing our carbon emissions and footprint. Keeping the now-current guidance at the forefront of discussions about the collection across departments is important. Ongoing vigilance is required from the Preventive Conservation team, particularly regarding other policies and procedures outside of collection such as building guidance, e.g. changes in human comfort temperature and sustainability.

The Estates and Capital Project department, Collection Projects and Resources department, and all involved working on the masterplan continue to be vital partners in supporting the implementation of the new guidance. They, with other departments, have taken up the new guidance and are very happy to have a single document to be working with.

Acknowledgements

The authors would like to thank and acknowledge the support received from colleagues across the British Museum throughout this project and to all consultation participants for providing invaluable information and feedback.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Beck, H. E., N. E. Zimmermann, T. R. McVicar, N. Vergopolan, A. Berg, and E. F. Wood. 2018. "Present and Future Köppen-Geiger Climate Classification Maps at 1-km Resolution." *Scientific Data* 5 (1): 180214. https://doi.org/10.1038/sdata.2018.214

British Museum. 2019. *Conservation Policy*. Accessed September 2023. https://www.britishmuseum.org/sites/default/files/2019-10/Conservation_policy_2019_Approved%20240119.pdf.

British Museum. 2020a. *Collection Care Strategy*. Unpublished internal document.

British Museum. 2020b. *Collection Storage Strategy*. Unpublished internal document.

BSI. 2017. *BS EN 16893:2018 Conservation of Cultural Heritage – Specifications for Location, Construction and Modification of Buildings or Rooms Intended for the Storage or Use of Heritage Collections*. London: British Standards Institution.

Henderson, J. 2023. "Technical Note 15: Negotiation and Consensus Building." In *Managing Collection Environments. Technical Notes and Guidance*, edited by J. Taylor and V. L. Beltran, 214–226. Los Angeles: Getty Conservation Institute.

IIC. 2014. *Environmental Guidelines: IIC and ICOM-CC Declaration*. London: IIC. Accessed August 2023. https://www.iiconservation.org/archives/about/policy-statements/environmental-guidelines.

Last, S. 2023. *Technical Writing Essentials*. Vancouver Island, BC: University of Victoria, 96–100. Accessed August 2023. https://pressbooks.bccampus.ca/technicalwriting/chapter/stakeholderengagement/.

Leskard, M. K. 2021. "Validating the Tecno-Economic Viability of Hemp Lime Construction for Passive and Low Energy Moisture Control in Museum Storage." Unpublished doctoral thesis, University of Bath, 24–69. Accessed September 2023. https://www.academia.edu/61852309/Validating_the_techno_economic_viability_of_hemp_lime_construction_for_passive_and_low_energy_moisture_control_in_museum_storage.

Saunders, D. 2020. *Museum Lighting: A Guide for Conservators and Curators*. Los Angeles, CA: Getty Conservation Institute.

Shashoua, Y. 2004. "Modern Plastics: Do They Suffer from the Cold?" *Studies in Conservation* 49 (Suppl. 2): 91–95. https://doi.org/10.1179/sic.2004.49.s2.020.

Shashoua, Y. 2020. *Conservation of Plastics*. Abingdon: Routledge. (Reprinted from the Butterworth Heinemann first edn 2008).

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S235–S244
https://doi.org/10.1080/00393630.2024.2376926

Check for updates

Building on Successful Mechanical and Passive Environmental Controls for Preventive Conservation Through Data Analysis at National Museum Cardiff, Wales

Aprovechamiento de Controles Ambientales Pasivos y Mecánicos Exitosos para la Conservación Preventiva mediante Análisis de Datos en el Museo Nacional de Cardiff, Gales

Kelly McCauley [1,2], Robert Pearce[1] and Diane Gwilt[1]

[1]Amgueddfa Cymru - National Museum Cardiff, Cardiff, UK; [2]Colonial Williamsburg Foundation, Williamsburg, VA, USA

ABSTRACT

Amgueddfa Cymru's National Museum Cardiff in Cardiff, Wales, houses fine arts, natural science, and archaeological collections in a Grade I-listed historic building. With over 50 individual air handling units in addition to the original building-wide ventilation system, critical examination of how to create sustainable spaces and reduce energy consumption has been a goal of the museum for two decades. This paper will present the evolution of two techniques, and discuss their successes and limitations. The first – system shutdowns – has been successful, and has been taken further by switching some spaces entirely to passive control by blocking ductwork; preventing inappropriate conditions from entering the room via HVAC has led to an improvement in these specific cases. The second technique of seasonal set points required regular manual programming of the set points and was not responsive to short-term varying conditions, often resulting in high RH; a set of four basic guidelines was then developed to change the HVAC programming to better address this risk throughout the year. The impact of both techniques was analyzed using the widely available Microsoft Power BI™ program, whose focus on data visualization makes generating and modifying graphs easier than in Microsoft Excel. Following some of the tenets of sustainable environmental management including the value of a cross-disciplinary team, commitment to an ongoing process, and thorough data analysis, this work has allowed for preservation and energy efficiency beyond initial gains.

El Museo Nacional Cardiff de Amgueddfa Cymru en Cardiff, Gales, alberga colecciones de bellas artes, ciencias naturales y arqueología en un edificio histórico catalogado de Grado I. Con más de 50 unidades individuales de tratamiento de aire, además del sistema de ventilación original para todo el edificio, el examen crítico de cómo crear espacios sostenibles y reducir el consumo de energía ha sido un objetivo del museo durante dos décadas. Este artículo presentará la evolución de dos técnicas y discutirá sus éxitos y limitaciones. El primero (apagados del sistema) ha tenido éxito y se ha ido más allá al cambiar completamente algunos espacios al control pasivo mediante el bloqueo de los conductos; evitar que entren condiciones inadecuadas en la habitación a través de HVAC ha supuesto una mejora en estos casos específicos. La segunda técnica de puntos de ajuste estacionales requiere una programación manual regular de los puntos de ajuste y no responde a condiciones variables de corto plazo, lo que a menudo resulta en una humedad relativa alta. Luego se desarrolló un conjunto de cuatro pautas básicas para cambiar la programación de HVAC y abordar mejor este riesgo durante todo el año. El impacto de ambas técnicas se analizó utilizando el programa Microsoft Power BI™, ampliamente disponible, cuyo enfoque en la visualización de datos hace que generar y modificar gráficos sea más fácil que en Microsoft Excel. Siguiendo algunos de los principios de la gestión ambiental sostenible, incluido el valor Apagado deliberado de de un equipo interdisciplinario, el compromiso con un proceso continuo y un análisis de datos exhaustivo, este trabajo ha permitido la preservación y la eficiencia energética más allá de las ganancias iniciales.

ARTICLE HISTORY
Received November 2023
Accepted July 2024

KEYWORDS
Deliberate HVAC shutdown; HVAC set points; Environmental data analysis

Apagado deliberado de HVAC; Puntos de ajuste de HVAC; Análisis de datos ambientales

CONTACT Kelly McCauley 4kmccauley@gmail.com Amgueddfa Cymru – National Museum Cardiff, Cardiff, UK; Colonial Williamsburg Foundation, 309 1st Street, Williamsburg, VA 23185, USA

© The International Institute for Conservation of Historic and Artistic Works 2024

Introduction

National Museum Cardiff

National Museum Cardiff (Amgueddfa Genedlaethol Caerdydd – NMC), one of the family of seven museums and a collection centre that form Amgueddfa Cymru – Museum Wales, was founded in 1905 and today has grown to house 3.8 million objects. The collection spans disciplines: fine arts, including Renoir's *La Parisienne* and Van Gogh's *Rain – Auvers* along with works by celebrated Welsh artists Gwen and Augustus John and Thomas Jones; natural science, from type specimens and objects collected on historic expeditions to much-loved examples of taxidermy; archaeological objects associated with Wales dating from the Neolithic to Medieval periods; and library and archival collections that add context and deepen interpretation.

This is all housed in a Grade I-listed historic building, meaning it meets criteria for the highest category of interest for preservation, based on its interior and exterior architectural features that contribute to Cardiff's city centre as an example of early twentieth-century civic architecture (British Listed Buildings 2023). It was built over several phases, with the Main Hall completed in 1927; East and West Wings completed in 1990 and 1967, respectively; and the Centre Block in 1992.

It is currently used for research, exhibitions, public events, and outreach, in addition to collections storage. Given the range of environments required within the building, it has been necessary over the years to augment the original building-wide ventilation system with over 50 individual air handling units and multiple downstream components. These make NMC the most energy-intensive building within the Amgueddfa Cymru network, and the resulting carbon footprint and financial burden of energy consumption and mechanical system maintenance drive an institution-wide aim towards greater sustainability.

Sustainability measures

This is not an easy objective and has required steady progress and commitment across departments for over a decade. From an environmental perspective, NMC has upgraded older, less efficient chillers and completely replaced steam humidifiers with ultrasonic ones and relied on the use of cases to provide microclimates where necessary.

Seasonal set points

Broader seasonal set points (17–24℃ and 40–60% relative humidity (RH)) – reflecting changing outside conditions to save energy while still maintaining parameters within a safe range for the collection – were first introduced in 2011 and have become an accepted part of the sustainable environmental management strategy.

These ranges are very close to the Bizot Green Protocols (NMDC 2009), assisted by Cardiff's moderate climate. Temperatures ranged from 2.5 to 22℃ across the year from 1991 to 2020 (Met Office 2023), with a steady rainfall: rain falls (greater than 1 mm) 150 days a year. Even with this added moisture though, plotting the outside environment on a psychrometric chart revealed that heating alone was sufficient to meet the target conditions for much of the year (Cosaert et al. 2022) (Figure 1).

Although more frequent variations in weather, high visitation numbers, and other factors in system operation were cause for exception, overall, these seasonal set points should be achievable with relatively little energy input. However, this required regular manual programming of the set points and was not responsive to short-term variations in external conditions, often resulting in high RH. Additionally, by analyzing the dew points in the spaces, it appeared that dehumidification set points were not being achieved and conservation heating would therefore be the more effective way to control RH while any building-wide issues were further identified and addressed.

System shutdowns

System shutdowns involve turning off the air handling unit (AHU) serving the space for an overnight period and allowing the building envelope to maintain conditions within a specified range (Image Permanence Institute 2017). Although sometimes complicated by the historic building envelope, openness of the floor plan, and late-night events, multiple phases of shutdown testing since the first trial in 2013 demonstrated that many of the spaces, and particularly those on the interior of the building, could maintain conditions overnight successfully. This is consistent with testing performed at other institutions, both within the UK (Bastidas-Spence 2023) and abroad (Bratasz et al. 2018).

A period of several hours when all systems were down for maintenance provided data to prioritize the likelihood that additional spaces would be able to maintain their environment for such a period. This list was further refined based on knowledge of the building, the range and location of zones served by each AHU, collection types and housings, and planned building works. Testing initially began on six AHUs serving first floor galleries, large areas open to each other and surrounded by other parts of the building in all directions. After three months of successful tests, an additional eight AHUs were brought into the shutdown procedures, covering the second-floor galleries that were also interior spaces, and those that had been recently renovated and therefore presumed to have more updated room envelopes.

All spaces have been able to maintain conditions during shutdowns, suggesting that, where occupancy is not a concern, shutdown periods could be extended, or the spaces could possibly be moved towards more

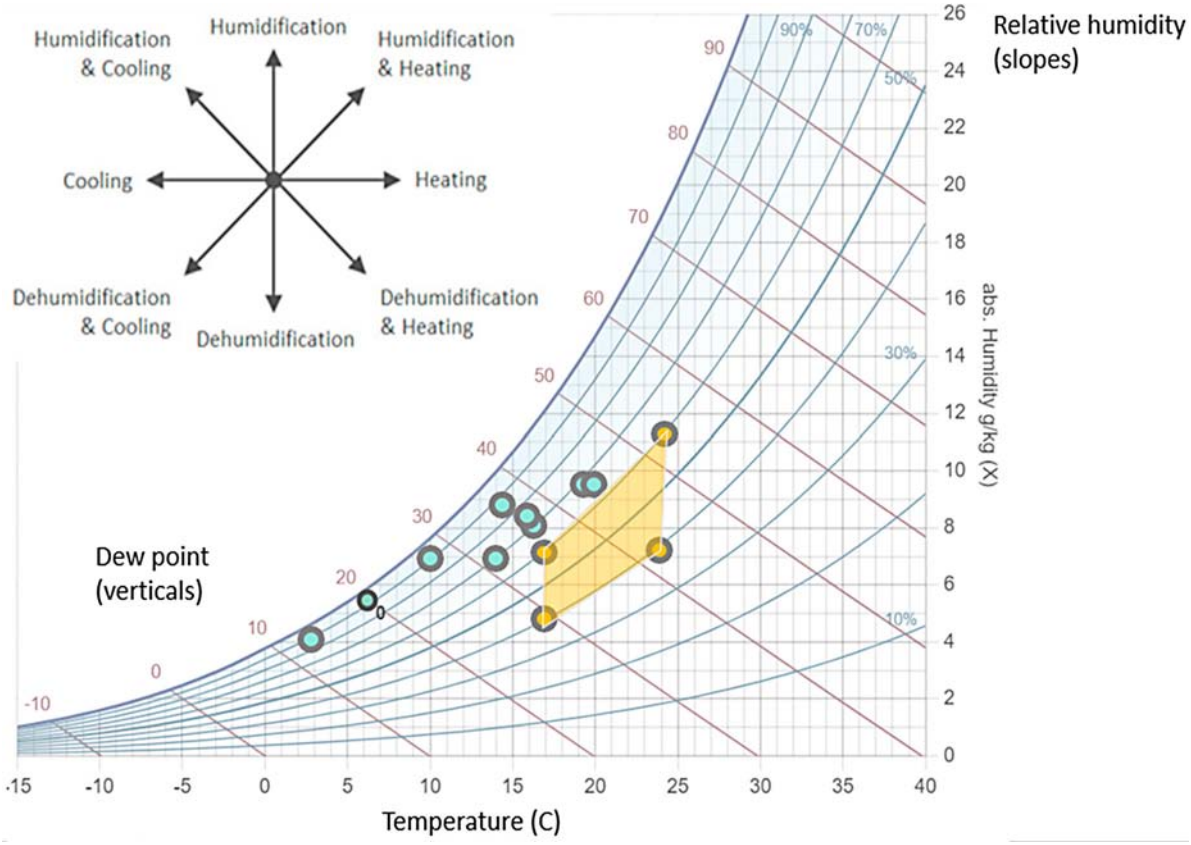


Figure 1. Average monthly dew points (blue) at different RHs, the yellow area bounded by yellow dots showing the target conditions. Using the arrows in the upper left, it appears that heating would drive the majority of the dew points into the yellow area. Note: there are only nine values given, because the average dew point for some months was the same.

passive control. Meanwhile, continued monitoring is necessary to ensure shutdowns remain in place, rather than defaulting to earlier programming.

Goals

Given the high degree of institutional support and the significant work already done, the question then became how to build on this progress, especially facing tightening budgets, a list of critical maintenance and replacement, and increasing variation in the outside climate. This paper will focus on the evolution of two strategies that have been implemented between November 2022 and September 2023 to improve energy usage in particular locations at the institution while still providing for the preservation of the collection. By sharing this work, we would like to provide others with a framework and evidence that will allow them to critically examine their own institutions and develop strategies to minimize reliance on mechanical environmental control.

Methods

Environmental management

Meaco HTX wireless temperature and RH loggers are deployed across NMC, allowing real-time monitoring of 41 galleries and collection stores. The units are calibrated annually by Meaco and they report their sensors as being accurate to +/−0.2℃ and +/−0.8% RH, with a data point recorded every 15 min. Data is reviewed by the preventive conservators on a regular basis, and informs discussions with other collection staff, those in Buildings and Estates responsible for the maintenance of the heating, ventilation and air conditioning (HVAC) systems, and the external building maintenance system (BMS) engineer who programs the HVAC operation. Collection staff and museum assistants are also regularly in the spaces and are encouraged to relay any issues.

Regular meetings with the Building Services Manager and, in particular, one-to-one half-day meetings between preventive conservation and the contracted BMS engineer are also organized to facilitate improving collections environments and energy efficiency.

Data analysis

Data analysis utilized Microsoft's Power BI Desktop, a freeware program for data visualization. While this program still uses Microsoft Excel to process the data, it has several advantages over using Excel on its own. In Power BI, it is easy to combine multiple spreadsheets – either exported from different individual dataloggers or the same datalogger at different points in time – into a single Power BI file for analysis.

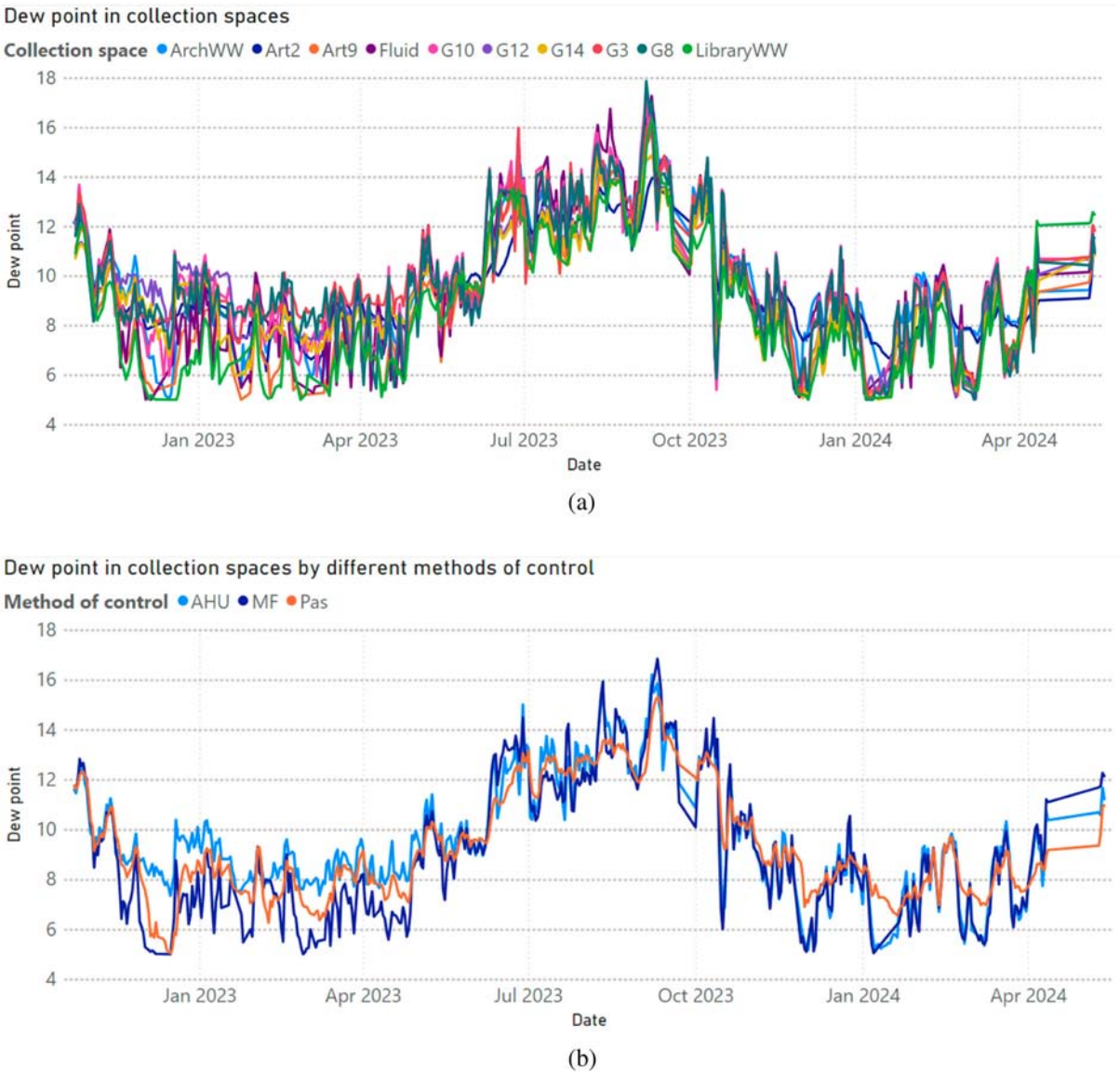


Figure 2. (a) Dew points in three passively controlled spaces in 2023, two on the building-wide ventilation system, and five with individual AHUs. (b) Average dew point based on the type of control, reducing the visual to three lines for easier analysis. AHU indicates individual HVAC units, MF indicates the building-wide ventilation system, and Pas1 indicates passively controlled spaces.

Once they are in a single file, any parameter can be selected for analysis across any set of files without further data manipulation or the creation of formulae. One can switch between parameters by simply dragging the new parameter to the desired axis, and graphs can be changed through filters, applied either to individual graphs or multiple graphs on the same page. Furthermore, averages can be automatically compiled based on any shared characteristic, as seen in Figure 2 based on the type of environmental control for each space. Additional data can be analyzed (comparing by floor, exposure, room use, collection specialty, etc.) without having to create more columns in each spreadsheet, but just by pulling it out of the file name.

While this project does not represent all of the capabilities of Power BI, the program's ability to analyze across multiple spreadsheets and bounce between parameters without having to otherwise combine datasets or run calculations through Excel exclusively greatly enhances the ease of analysis.

Test set-up

Switch to RH programming

Rather than continuing to rely on regular manual programming of set points, it was agreed at a meeting between preventive conservators, the Building Services Manager, and the BMS engineer, to introduce four basic guidelines to the HVAC programming. These would better allow for seasonal fluctuations and prioritize humidity risks, while recognizing the need for human comfort. These were:

- If the temperature drops below 17℃, heat. If the temperature exceeds 24℃, cool.
- Once temperatures are back within the 17–24℃ range, no further action is needed.

- If the RH drops below 40%, humidify.
- If the RH exceeds 60%, heat until the RH is below 60% or temperature exceeds 24°C. (Due to concerns over rates of thermodynamic decay, further increases in temperature were not permitted.)

One AHU was programmed initially and, after several weeks of monitoring its response, the programming was implemented on the additional AHUs. There were several types of spaces that retained different programming, namely specific collection stores with materials requiring lower RH, and those served by the building-wide ventilation system, which does not have the same cooling capacity.

Move to passive spaces

Because NMC already had both passive and mechanically-controlled spaces, trialing the move towards more passive spaces had several components:

- comparing existing data between passive and mechanically-controlled spaces,
- comparing conditions in a room served by the building-wide system before and after becoming passive
- comparing conditions in a room served by an AHU before and after becoming passive.

No additional work to the room envelope was completed as part of this testing. In the building-wide system, the vents were covered over and, for the AHU, a damper was closed. It is important to note that blocking air supply is not generally recommended, since it can disturb the balance of a system, causing distribution of air within a space, and affecting the delivery of fresh and/or conditioned air for occupancy purposes. These concerns were addressed in this case by selecting spaces with no regular or prolonged occupancy; regular monitoring; and discussion with the Building Services Manager and contracted BMS engineer, but other limitations or steps may exist at different institutions.

Results

Switch to RH programming

The change in programming has proven to be an effective way of addressing preservation concerns, although there are limitations. When the programming change was completed at the start of August, temperatures immediately rose in most spaces to near the maximum permitted (24°C). This resulted in a decrease in RH below 60% consistently for the remainder of the summer, as planned.

However, as shown for one of the representative spaces (Figure 3), there were times in the summer that conservation heating alone was not enough to meet the RH targets: the space was already at the maximum temperature and so did not heat additionally, and RH rose above 60%. This was as expected, and the excursions are brief and not significantly above 60%, so they do not represent a significant risk to the collections. This may change though if the climate becomes increasingly hot and humid, necessitating further action to increase the effectiveness of the dehumidification capacity of the AHUs.

It should be acknowledged that the increased temperatures will accelerate the deterioration rate of organic objects, so the strategy is not without trade-offs (Blades et al. 2018) and is therefore another reason it is better considered as a short-term measure. Additionally, since submeter energy monitoring is not available at NMC yet, it is not known how the energy usage here compares to the previous programming, although that is a potential future area to explore; it does seem to use the energy more effectively however, since the desired conditions are achieved on a more regular basis. The BMS engineer also noted that the systems were in alarm less frequently, lessening the pressure put on the Buildings and Estates staff and making it easier to focus on remaining issues.

Move to passive spaces

Comparing existing spaces

Environmental data from the three types of spaces at the NMC building – passive, those served by the building-wide system, and those served by individual air handlers – was compared in an attempt to determine the improvement in preservation gained for the energy spent. It is important to note though that this method is not as clear-cut as examining the same space with and without mechanical control, as conditioning of spaces is related to its room envelope and use; thus, spaces that are less well insulated, open to other spaces, or have added loads from heavy occupancy may have mechanical control to compensate.

All spaces generally met condition requirements. From Figure 4, it is clear that temperature issues are infrequent, but can occur around the building-wide ventilation system during early winter and early spring; this is likely a result of compromises made to try to deliver air across multiple spaces over five floors – many of which are directly influenced by outside conditions – at times of the year when the weather is more unpredictable. Most importantly, while passive spaces tend to be warmer throughout the year, they still largely remain within desired conditions.

This pattern is also seen in RH, where spaces that are served by the building-wide ventilation system often have the highest levels as a result of high outside air usage and no ability to dehumidify. Here passive spaces actually perform better (in terms of percentage of time within desired conditions) than mechanically-controlled ones, due to the slower rate of moisture exchange and slightly higher temperatures. This initial examination demonstrates that mechanically-controlled spaces do not necessarily outperform passive ones in maintaining environmental conditions.

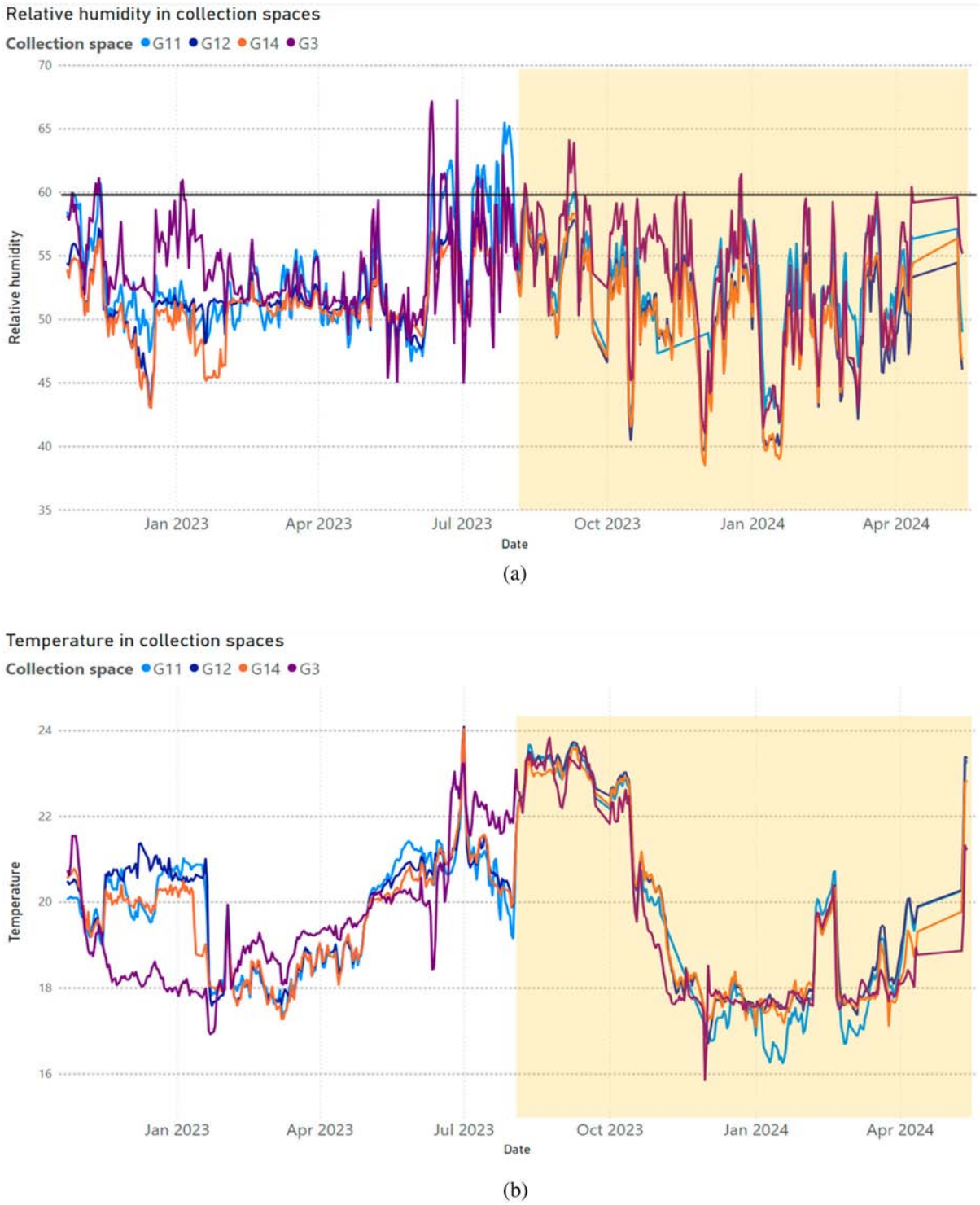


Figure 3. RH in collection spaces. Unshaded: original monthly set points. Shaded: after switching the program. (a) RH, with black line indicating 60%. (b) Temperature, showing the increase for much of the summer and early fall to bring the RH below 60%.

Comparing building-wide ventilation system to passive conditioning

The building-wide ventilation system uses significantly more outside air, does not have the same capabilities as individual AHUs, and is controlled to distribute human comfort conditions to spaces across five levels of the building, which often proves a difficult balancing act, as noted earlier. As a result, the delivered air tends to be warm and humid in the summer, and dry in the winter. Whilst the system achieved slightly lower average temperatures, which will slow the deterioration rate for the collection, this needs to be considered against the higher energy cost and higher degree of moisture fluctuation that is produced.

Vents in two art stores (only one is shown in Figure 5) and a natural science store had already been blocked in an effort to reduce the fluctuations and seasonal extremes in the spaces. The improvement can be seen in comparison to the collection space still served by the building-wide ventilation system: temperatures in the now-passive spaces span

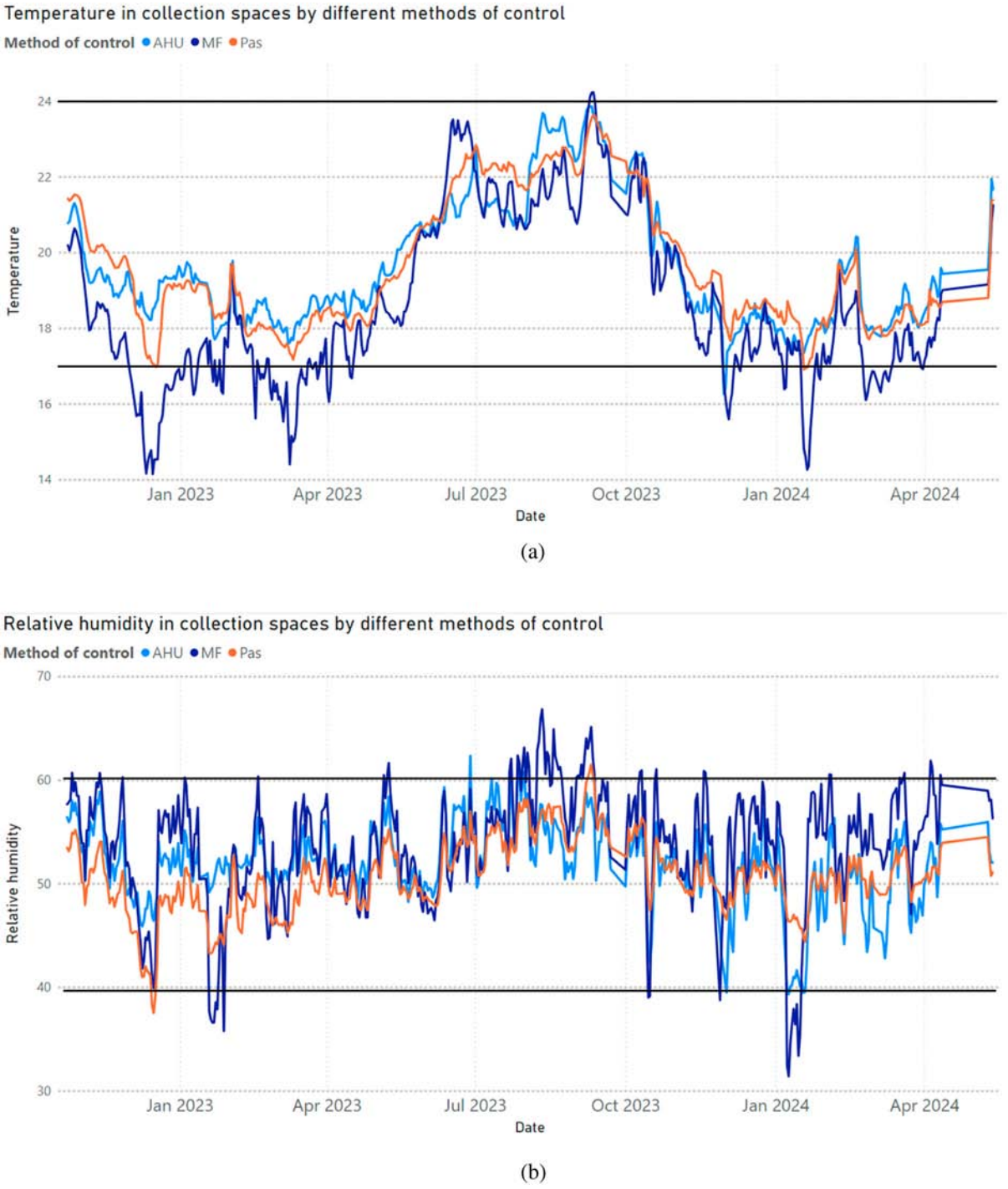


Figure 4. Different methods of control. (a) Temperature. (b) RH. AHU indicates individual HVAC units, MF indicates the building-wide ventilation system, and Pas1 indicates passively controlled spaces. For dew point, see Figure 2. In this case, passive spaces generally perform equal to or better than those with mechanical control, with lower relative humidity throughout the year, due to the slightly elevated temperatures from the lack of cooling capacity.

a smaller range and RH generally displays a buffered version of what is occurring in the space served by the building-wide ventilation system.

Comparing AHU system to passive conditioning

The space selected for this test was a collection store surrounded by other conditioned spaces; the AHU serving it also served the gallery on the other side of the wall, which was in turn open to other gallery spaces. Resulting environmental fluctuations in dew point and temperature caused RH swings of more than 20% in a day. Since there was no evident reason why this would be occurring, it seemed likely that the two spaces – both of which should independently be able to maintain conditions – were fighting each other mechanically, to the detriment of the more-enclosed store.

By closing the dampers to the supply ductwork serving the store (while keeping those to the gallery open), fluctuations in the store were significantly reduced, remaining more stable and overall lower even over the summer than what had been seen previously (Figure 6). The dampers have remained closed, and the store is now

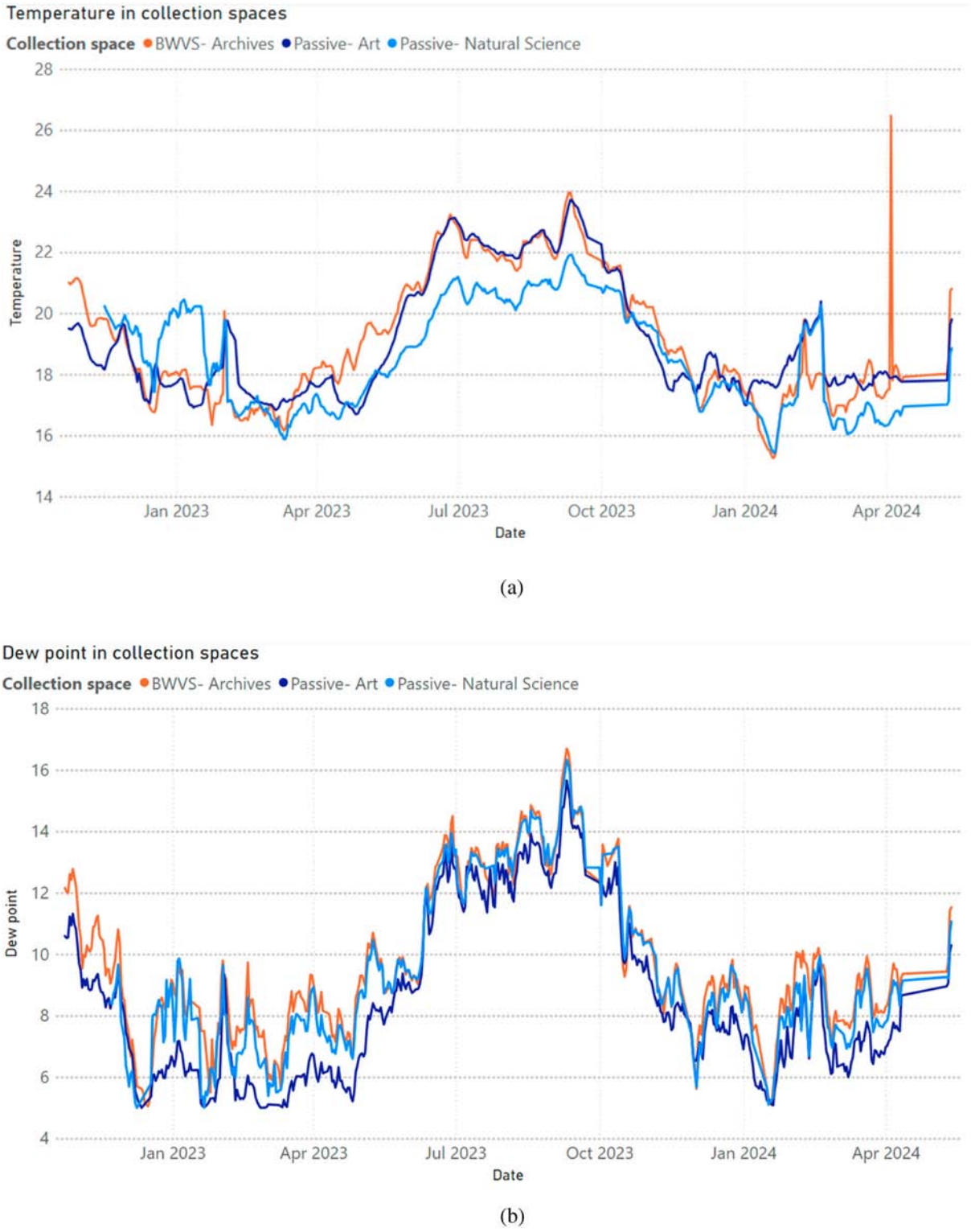


Figure 5. Collections spaces served by the building-wide ventilation system (orange) and two stores (purple, light blue) that have had the supply vents from it blocked to become passive. (a) Temperature. (b) Dew point. The passive spaces experience less seasonal range in temperature than those on the building-wide ventilation system, although they may have less moisture in the winter from the lack of humidification capacity.

able to maintain both temperature and RH year-round without needing mechanically conditioned air delivered.

Discussion

The last 13 years of sustainable HVAC management at NMC have therefore demonstrated success but also proven that, with increasing knowledge of a building's behavior based on testing and collaboration with a cross-disciplinary team, there still exist opportunities to further optimize preservation and sustainability. The change in programming to allow for greater drift within safe parameters and the use of conservation heating to achieve dehumidification where needed

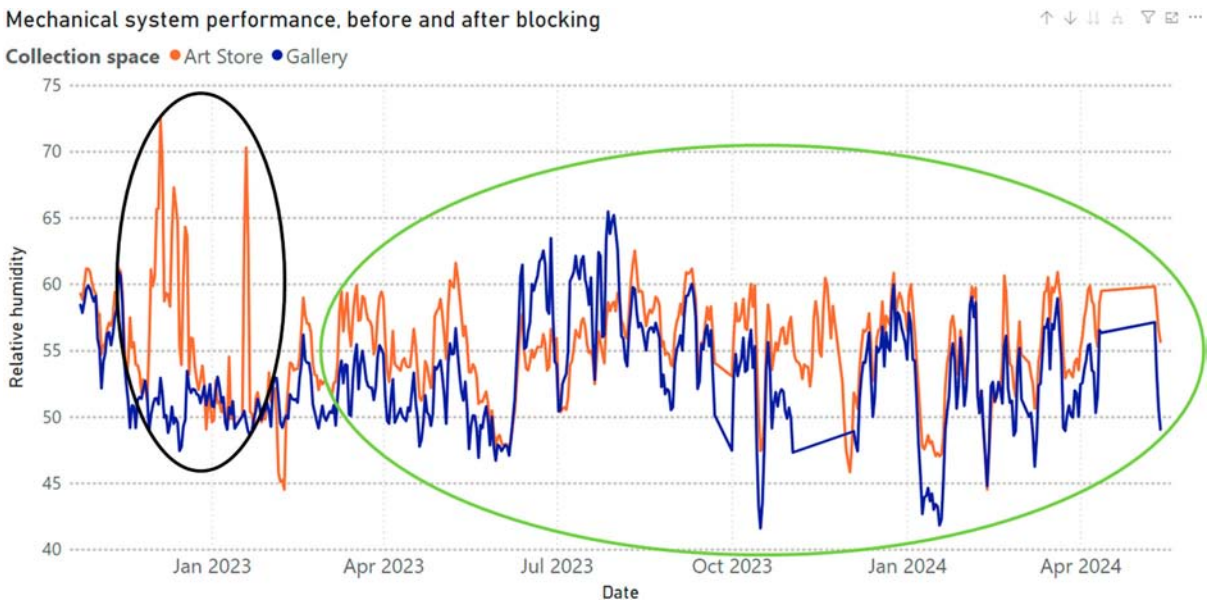


Figure 6. Mechanical system performance, before and after blocking. Black circle indicates RH fluctuations in the store (orange) that raised concerns about the mechanical control; green circle highlights the period after several different phases of testing when the damper serving the store was then closed.

has thus far proven effective at maintaining conditions. Further modifications can also be made to this approach. For example, addressing the dehumidification capabilities of the AHUs would mean that the trade-off between higher temperatures or higher RH would not be needed.

It is still too early to quantify the amount of energy saved by allowing conditions to naturally drift within the range of safe conditions, as compared to using monthly seasonal set points. Research (Ascione et al. 2009; Kompatscher et al. 2019) suggests that it could be significant in minimizing overall AHU operation. It may also prevent individual components from operating at undesirable times of year, such as humidifiers switching on in the late spring/summer.

Results also demonstrate that long-held beliefs in the field regarding the superiority of mechanical system operation and the feasibility of passive spaces may not stand true in all cases, necessitating data collection, analysis, and discussion. For multiple reasons – including a mix of space usages, limitations of mechanical system design and capabilities, and programming issues, as demonstrated in the examples above – building-wide and localized mechanical systems can introduce issues, which may be difficult to recognize when the default is to believe they are improving conditions. Plant is not flawless nor forever reliable, and even when working as intended, can cause fluctuations to happen much more quickly than would occur naturally. Therefore, removing this influence can sometimes (but not always) mitigate or even solve environmental issues within a space.

Other Amgueddfa Cymru sites that have programmed overnight shutdowns (St Fagans National Museum of History in St Fagans outside Cardiff) and where mechanical ventilation to stores has been turned off (The National Collection Centre) show similar results (Pearce 2023). Since 2005, our approach to new builds for collection storage has been passive environmental control effected through building design and materials. This approach has now been extended to the reconstruction of translocated historic buildings at St Fagans where adsorbent materials have been incorporated into the internal finishes of a historic pub that is in the process of being rebuilt.

Finally, this process has allowed for the exploration of Microsoft Power BI as another tool for data analysis of environmental data. While it is not designed for collections specifically, its widespread availability as freeware, support for use through numerous tutorials and forums, and great degree of flexibility in data visualization can make it a viable option for the conservation field, and open up new possibilities for exploring collections environments.

Conclusions

Following some of the tenets of sustainable environmental management including the value of a cross-disciplinary team, commitment to an ongoing process, and thorough data analysis, this work has allowed for preservation and energy efficiency gains over the past 13 years beyond what was initially possible. Through the examples of moving from expanding the range of acceptable conditions and applying seasonal setpoints to changing programming to match preservation concerns year-round, and using what was learned from mechanical operation analysis and overnight shutdowns to explore opportunities to

move towards more passive stores, this demonstrates that the pursuit of sustainable HVAC management is a meaningful complement to the work of preventive conservation.

The National Museum Cardiff is poised to continue addressing challenges in ways that advance dual goals of sustainability and preventive conservation both for the overall institution and to meet local collection needs. Along with any changes, the work to implement sub-meter energy monitoring at NMC will provide data for characterizing the impact of these actions, allowing for the comprehensive discussion and decision-making that will be hallmarks of continued progress in this area.

Acknowledgements

The authors would like to thank the current and former staff at Amgueddfa Cymru's National Museum Cardiff, in particular in the Collection Services and Buildings and Estates departments, without whose collaboration this work would not be possible, especially Dr Christian Baars, Gareth Jones, and Ian Johns. Thanks also to Christopher Bond at Bemac who has served as the Museum's contracted BMS engineer to implement the programming changes discussed in this paper. Finally, a thank you to the two reviewers and the editors for their review and suggestions.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Kelly McCauley http://orcid.org/0009-0005-3367-0240

References

Ascione, F., L. Bellia, A. Capozzoli, and F. Minichiello. 2009. "Energy Saving Strategies in Air-Conditioning for Museums." *Applied Thermal Engineering* 29:676–686.

Bastidas-Spence, M. 2023. "Sustainable Practices Applied to the Environmental Management of Archival Collection Storage Spaces at the Southwest Wing in the National Maritime Museum in London, UK." *Journal of the American Institute for Conservation*, 1–16. https://doi.org/10.1080/01971360.2023.2197106.

Blades, N., K. Lithgow, S. Staniforth, and B. Hayes. 2018. "Conservation Heating 24 Years On." *Studies in Conservation* 63 (supp.1): 15–21. https://doi.org/10.1080/00393630.2018.1504457.

Bratasz, Ł, T. White, S. Butts, C. Sease, N. Utrup, R. Nathan, R. Boardman, and S. Simon. 2018. "Towards Sustainable Management in Yale Peabody Museum Collections: Climate Control, Risk Assessment and Energy Efficiency." *Bulletin of the Peabody Museum of Natural History* 59:249–268.

British Listed Buildings. 2023. "National Museum of Wales". Accessed November 2023. https://britishlistedbuildings.co.uk/300013694-national-museum-of-wales-castle.

Cosaert, A., V. L. Beltran, G. Bauwens, M. King, R. Napolitano, B. Shah, and J. Wickens. 2022. *Tools for the Analysis of Collection Environments: Lessons Learned and Future Development*. Los Angeles, CA: Getty Conservation Institute. Accessed November 2023. https://hdl.handle.net/10020/gci_pubs_analysis_collection_environments.

Image Permanence Institute. 2017. *IPI's Methodology for Implementing Sustainable Energy-Saving Strategies for Collections Environments*. Rochester: Image Permanence Institute, Rochester Institute of Technology.

Kompatscher, K., R. P. Kramer, B. Ankersmit, and H. L. Schellen. 2019. "Intermittent Conditioning of Library Archives: Microclimate Analysis and Energy Impact." *Building and Environment* 147:50–66.

Met Office. 2023. "Cardiff – Climate Station". Accessed November 2023. https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages/gcjszmp44.

NMDC. 2009. "NMDC Guiding Principles for Reducing Museums' Carbon Footprint." National Museum Directors' Conference. Accessed November 2023. https://www.nationalmuseums.org.uk/media/documents/what_we_do_documents/guiding_principles_reducing_carbon_footprint.pdf.

Pearce, R. 2023. "Strategies for Reducing the Energy Consumption of Buildings." Conversations with Change Makers, 28 March 2023. ICON Sustainability Network and the American Institute for Conservation Sustainability Committee. Accessed November 2023. https://www.youtube.com/watch?v = hYePqVFno80.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S245–S255
https://doi.org/10.1080/00393630.2024.2375159

ORIGINAL RESEARCH OR TREATMENT PAPER

Improving Sustainability for the Conservation of the Eravimangalam Subramanyaswamy Temple: Virtual Reconstruction and Greener Formulations as a Means of Involving the Community

Mejorar la Sostenibilidad de la Conservación del Templo Eravimangalam Subramanyaswamy: Reconstrucción Virtual y Formulaciones más Ecológicas como Medio para Involucrar a la Comunidad

Moupi Mukhopadhyay[1] and Chiara Biribicchi[2]

[1]Conservation of Cultural Heritage IDP, University of California, Los Angeles, CA, USA; [2]Department of Earth Sciences, Sapienza University of Rome, Rome, Italy

ABSTRACT

The centuries-old Eravimangalam Subramanyaswamy Temple in the Malappuram district of Kerala, India, is one of many active temples with significant remnants of historical outdoor wall paintings threatened with being rebuilt/replastered with modern materials. As the significance of the site to the local community is the figure of the deity housed within the temple, the shrine's outer structure carrying the historical wall paintings is considered replaceable. This work explores the creation of tools that communities can use in the future to make an informed choice about sustainable conservation of their heritage, and to place some significance on the structure as well as the deity represented. The study uses two main approaches: virtual reconstruction, and the testing of greener formulations for the removal of deposits on outdoor wall paintings. 3D reconstruction and image manipulation were used to create visualizations of a possible finished treatment, and supported by cleaning tests on mock-ups of the wall paintings that reproduce the original materials, techniques, and their present condition. Testing of greener formulations was performed to remove deposits from burning oil lamps, as commonly used in temples in Kerala. The tested products that are derived from natural feedstocks are safer for human beings and will enable the local conservators to work with them without any adverse effects. This work aims to serve as a means to initiate community involvement in decision-making and create opportunities for sustainable conservation.

El centenario templo Eravimangalam Subramanyaswamy en el distrito de Malappuram de Kerala, India, es uno de los muchos templos activos con vestigios fragmentados importantes de pinturas murales históricas al aire libre amenazadas con ser reconstruidas o revocadas con materiales modernos. Dado que la importancia del sitio para la comunidad local es la figura de la deidad alojada dentro del santuario del templo, la estructura del santuario que porta las pinturas murales históricas se considera reemplazable. Este trabajo explora la creación de herramientas que las comunidades puedan utilizar en el futuro para tomar una decisión informada sobre la conservación sostenible de su patrimonio y otorgar cierta importancia a la estructura y a la deidad representada. El estudio utiliza dos enfoques principales: la reconstrucción virtual y la prueba de formulaciones ecológicas para la eliminación de depósitos en pinturas murales exteriores. Se utilizó reconstrucción 3D y manipulación de imágenes para crear visualizaciones de un posible tratamiento terminado, y se apoyó con pruebas de limpieza en maquetas de las pinturas murales que reproducen los materiales originales, las técnicas y su condición actual. Se realizaron pruebas de formulaciones más ecológicas para eliminar los depósitos de las lámparas de aceite presents en el lugar, que son de uso común en los templos de Kerala. Estos productos se derivaron de materias primas naturales y permitirán a los conservadores locales trabajar con materiales de bajo impacto. Este trabajo inició la participación de la comunidad en la toma de decisiones y creó oportunidades para la conservación sostenible.

ARTICLE HISTORY
Received January 2024
Accepted June 2024

KEYWORDS
Built heritage; sustainability; green chemistry; virtual reconstruction; active site; wall paintings

Sostenibilidad; química verde; reconstrucción virtual; sitio activo; pinturas murales

Introduction

The outdoor murals of Hindu temples in Kerala, India, are a subject of growing interest in the field of conservation due to the art historical significance of their paintings and the unique challenges posed by natural and anthropogenic agents of deterioration, as well as the views of active local communities. These temple wall paintings belong to the Kerala mural

CONTACT Moupi Mukhopadhyay moupi206@g.ucla.edu Conservation of Cultural Heritage IDP, University of California, A210 Fowler Building/Box 951510, 308 Charles E. Young Dr. North, Los Angeles, CA 90095, USA

© The International Institute for Conservation of Historic and Artistic Works 2024

tradition (seventh to seventeenth century CE; revived 1989 – present) and establish complex cross-cultural connections that contextualize religious practices, trade, and societal interactions across various historical periods. They depict rich and intricate scenes from Hindu mythology, highlighting the essence and ethos of local history (Frenz and Marar 2004; Ramachandran 2010). Most available knowledge about the materials used in Kerala murals is from the contemporary mural tradition from the revival of this art form in the late twentieth century (Mini 2010; Ramachandran 2010) which claims to be the same as historical practice. This information can be challenging to obtain due to concerns about disrupting devotional activities, perceived disrespect in capturing images of the deity, and resulting restricted permissions, as observed on-site during the study of the temple. Circumstantially, the materiality of these paintings is still a relatively unexplored subject, with few scientific tests conducted to characterize the original materials (Paramavisan 1939). This work is part of an ongoing research project that employs a holistic, materials-based approach to document these murals with minimally invasive techniques. The goal is to augment art historical investigations and establish a foundational understanding of such mural materials for conservation.

Numerous temples in Kerala featuring mural paintings have remained understudied, due to poor visibility resulting from centuries of weathering, whitewashing and repainting that have caused severe degradation of the original paintings, exacerbated by high levels of relative humidity and temperature. The practice of demolishing older shrine structures to erect new ones is prevalent in these active sites. It has historical precedent and can be linked to the assessment of Riegl's 'newness value' within the broader spectrum of heritage values (Ahmer 2020; Riegl 1996). However, this has resulted in the irreversible loss of many wall paintings, the memory of which now survives solely through photographs and descriptions (Frenz and Marar 2004; Ramachandran 2010).

Conserving an active religious heritage site that attracts devoted patrons and visitors presents a challenge due to conflicting visions for its future. Sustainable mural conservation requires harmonizing community values that prioritizes devotion with art and historical preservation. Visual representations through three-dimensional (3D) modeling and image manipulation proves to be a potent tool for conveying ideas during the critical appraisal phase of conservation, also serving as a bridge between conservators and communities (Acke et al. 2021; Dorsey et al. 2008; Tucci et al. 2017).

The Eravimangalam Subramanyaswamy temple in the Malappuram district of Kerala (Figure 1) has a small but devoted community of patrons and trustees with a history of interest in the temple's function, structure and appearance. The larger community has previously focused on plastering the walls, which house historic but deteriorated murals, with exposed laterite bricks. Collaborative efforts from the state department of archaeology and trustees have preserved much of the existing murals except for the Shiva Shrine which is entirely covered with plaster. Despite friction with the community, a state-led conservation project to stabilize the shrine walls was carried out in the past. Future efforts are expected to benefit from the integration of 3D modelling and virtual conservation to



Figure 1. Eravimangalam Subramanyaswamy temple compound in the Malappuram district of Kerala. Image: the authors.



Figure 2. Oils, camphor, and other materials burned for worship on the site. Image: the authors.

facilitate communication between stakeholders and further mural preservation objectives.

In addition to this virtual tool, it is important to understand ways to integrate real-life results of a successful conservation intervention into a virtually conserved 3D model. We try to achieve this by testing the feasibility of greener solutions to the deposition of soot and volatile compounds associated with burning oil and camphor as part of worship in Hindu temples (Figure 2). Part of this work focuses on the implementation of greener low-polar cleaning systems for the removal of soot deposits from the wall paintings of the Eravimangalam Subramanyaswamy Temple.

Sustainable chemistry emphasizes the reduction or elimination of hazardous substances in the design, production, and application of chemical products, and the need for its accessibility to all communities (Anastas and Eghbali 2010). Green chemistry's rising prominence in cultural heritage conservation responds to persistent hazardous methods, especially in cleaning treatments (Joshi and Adhikari 2019). Current research aims to introduce innovative, eco-friendly systems to safeguard operators and minimize environmental impact (Cheremisinoff 2001, 301–326). This is also important for the site of Eravimangalam Subramanyaswamy temple, as it hosts a large variety of flora and fauna in close proximity to the wall paintings.

Soot is mainly composed of ultrafine particles of carbon (ca. 2.5 µm) derived from the gas-phase decomposition of hydrocarbons by fire. It may contain polycyclic aromatic hydrocarbons and aliphatic carbons depending on the fuel source and composition (Tsang and Babo 2011). Traditional procedures to remove soil deposits involve the combined use of direct vacuum, dry-surface cleaning techniques, and wet-cleaning methods, often contemplating ammonia solutions, toxic solvents, or detergents/surfactants in water (Bonnat 2017; Gordon 2010; Spafford-Ricci and Graham 2000). Innovative approaches include the use of nanoparticles, polyvinyl alcohol – borax/agarose double-network hydrogel, atmospheric pressure plasma, biotechnologies, atomic oxygen, and supercritical carbon dioxide (Abd El-Tawab Bader and Ashry 2016; Albéo et al. 2014; Banks 1998; El Aal 2012; Pflugfelder et al. 2007; Shockey 2009; Silverman and Irwin 2009).

The murals in Eravimangalam Subramanyaswamy Temple are partially obscured by the deposition of both the fumes from the burning oil and the volatile fractions of the heated oil, comprising alkanes, alkenes, diolefines, aromatics, unresolved unsaturates, carboxylic acids, heterocyclic compounds, phenols, and sulfur-containing compounds (Chen et al. 2022; Schwab, Bagby, and Freedman 1987). Due to the lipophilic nature of the soot deposit on the wall paintings, the use of greener low-polar cleaning systems is proposed here to show the potential results of a sustainable and feasible cleaning treatment. Indeed, five fatty acid methyl esters (FAMEs) are introduced as easy-to-use and bio-based organic solvents with almost nil environmental and health impact (Belousov et al. 2021; Gonzalez et al. 2007).

The main aim of the application is to combine the 'virtual conservation' of the murals with the tangible results of a sustainable cleaning treatment, thus showing the local community the results of a potential intervention. It is important to ensure stakeholders' involvement in the process, especially when they consist of religious groups, as they are usually most involved in the initial information gathering or 'appraisal' stage of conservation (Henderson and Nakamoto 2016). The results of this work are intended to be shown to contemporary local communities at a future stage of this project to formulate new interpretations of these murals and attach significance to them. This can then foster community-led conservation initiatives, so that it is also socially sustainable.

Materials and methods

Cleaning tests

Cleaning tests were carried out on a mock-up of the wall painting surface as prepared in the contemporary Kerala mural tradition, along with a black deposit replicating the one on the Temple's murals. Fine river sand was mixed with lime to create a layer upon a preparatory layer comprising river sand, lime, jaggery, cotton fiber, and myrobalan powder (Figure 3) (Panackal 2018). The mock-up was exposed to oil blends and camphor fumes through combustion using cotton wicks for over 10 hours. The following day, an emulsion of water and the oil blend was sprayed on the mock-up surface to replicate the effects of active worship, which results in oil and water being splashed on the walls. Both procedures were repeated twice, then the mock-up was placed under ultraviolet light (365 nm) for 16 hours to enhance the polymerization of the oil.

Cleaning tests were conducted using five FAMEs having alkyl chain lengths between C6 to C18, namely methyl hexanoate (MH, CAS 106-70-7), methyl octanoate (MO, CAS 111-11-5), methyl laurate (ML, CAS 111-82-0), methyl myristate (MM, CAS 24-10-7), and methyl oleate (MO CAS 112-62-9), which were individually tested as pure solvents and compared to traditional methods, i.e. dry cleaning and wet cleaning using surfactants:

- Smoke sponge made of vulcanized natural rubber
- Ecosurf™ EH-9 (CAS 64366-70-7) 5% by weight in deionized water: non-ionic surfactant based on ethyl hexanol ethoxylate propoxylate.

In addition, FAMEs and Ecosurf™ EH-9 were also tested on areas pre-treated with the smoke sponge to assess the effectiveness of the combination of dry and wet cleaning methods aimed at reducing the amount of solvent used.

Visible reflectance imaging, digital microscopy, and colour measurement were used both before and after the cleaning tests to assess their effectiveness. A Nikon D780 FX Full Frame 25MP camera was used for visible reflectance imaging. A Jiusion 40–1000x endoscope was used for digital microscopy. Colour measurement was conducted before and after the cleaning tests on the treated areas to assess the ability of the cleaning systems to restore the original colour. The acquisitions were performed nine times on the white lime mixture and three times on each area after the treatment to reduce error. A portable Konica Minolta CM-2600d spectrophotometer was used, with D65 illuminant and an 8 mm size aperture. Measurements were performed with specular component included (SCI) and spectra were collected between 360 and 740 nm. Data were then analyzed using SpectraMagic™ NX software. ΔL^*, Δa^*, Δb^*, and the total colour difference (ΔE) were calculated using the CIELab colour space.



Figure 3. Preparation of the wall painting surface mockup.

3D modelling and image manipulation

Images of the Eravimangalam Subramanyaswamy temple along with an X-Rite ColorChecker were taken in July 2023 using a Nikon D90 camera with filters to limit the wavelength capture range to 400–700 nm. Imaging was done solely from ground level, as there was no access to drones or elevated structures. Agisoft Metashape was used to create the 3D model of the walls of the shrine containing the murals. Due to the permissions granted for the work, sunlight was the only lighting source used, and no images were taken of the shrine's front, to avoid accidentally photographing the deity housed inside. Care was taken to maintain similar levels of exposure in the images during capture for better accuracy in post-processing. The 3D model was exported to Spatial.io to create a 'walkthrough' experience.

A combination of a reproducible protocol to lighten the image based on colorimetric values from cleaning tests was used along with subjective artistic interpretation to create the final images for virtual conservation which will eventually be integrated into the 3D model. The cleaning tests that were undertaken on the sample were used to inform the possible appearance of the wall paintings after cleaning, focusing on using the L* parameter (described below) manually to modify areas with soot deposits on a selected image of a single mural panel. The RAW image was opened in CIELab colour space in Adobe Photoshop, and layers were used to temporarily posterize the image so that dark areas could be selected easily. The layer mode was set to Erase blending mode to create a dynamic mask of the dark areas. A final mask was applied to this group to manually select only the areas that could be visually identified as soot instead of other features, using varying opacity according to subjective interpretation of the degree of darkness. Selected areas were lightened using a Curves mask on the final selection by selecting the L channel and increasing luminosity by the required value, leaving the a and b channels unaltered.

Results

Cleaning tests

Imaging in visible light was utilised to document the cleaning tests (Figure 4). The sample is quite porous as it comprises a mixture of river sand and lime. The porous surface absorbed black fumes and oil, making it challenging for the cleaning system to remove the deposits completely. Consequently, restoring the original colour proved difficult. Despite variations in results due to varying porosity in treated areas, it was observed that a combination of the dry-cleaning method (Smoke Sponge) and wet cleaning methods proved to be more effective. Additionally, this approach was beneficial in minimising solvent usage.

Indeed, cleaning systems involving the combination of the Smoke Sponge and the proposed solvents (nos. 8–13 in Table 1) demonstrated greater efficacy in comparison to areas treated solely with the Smoke Sponge (no. 7 in Table 1) and wet cleaning methods (nos. 1–6 in Table 1). The Smoke Sponge alone can absorb a consistent part of the black deposit but appears incapable of completely removing the final layer, necessitating the use of another cleaning system for a more satisfactory outcome. Although not as effective as the combination of the Smoke Sponge and wet cleaning methods, MH and MO can efficiently eliminate the layer.

The colour measurements further support the findings, indicating that cleaning systems numbered 8, 9, 1, 2, and 13 in Table 1 exhibit the lowest ΔE values, least to most. Lower ΔE values represent minor colour differences between the original colour of the lime and the appearance of the same areas after the cleaning treatment. This colour difference is mostly linked to changes in the L* parameter, with only insignificant changes in a* (green-red) and b* (blue–yellow) components. Cleaning systems numbered 7 and 3 appear to be less effective. This can be attributed to the partial results from the Smoke Sponge and the reduced cleanliness achieved with FAMEs featuring longer alkyl chains. Digital microscopy also highlighted the morphological and chromatic features of the treated areas, showing that the most effective solvents, when used alone, partly interact with the constituent material. On the contrary, the combined application of the Smoke Sponge and wet cleaning methods enabled the preservation of the lime layer due to the reduced amount of solvent and its overall more gentle action.

3D modelling

A 3D model was generated using ca. 380 colour-corrected images as shown in Figure 5. Most of the complex structural elements of the walls were captured, and details were adequately captured for the purposes of a walk-through to illustrate the effects of cleaning. However, the application of the 'virtual cleaning' on the entire 3D model based on adjusting luminosity values of selected areas proved to be cumbersome, as the process, without automation, is time – and labour-intensive. This made it necessary that a single image of a mural panel with soot deposits be subjected to an image manipulation protocol first.

The change in the colour measurements obtained after the cleaning tests was combined with the parameters required to manipulate images of the mural panel selected for the example. Considering the risk

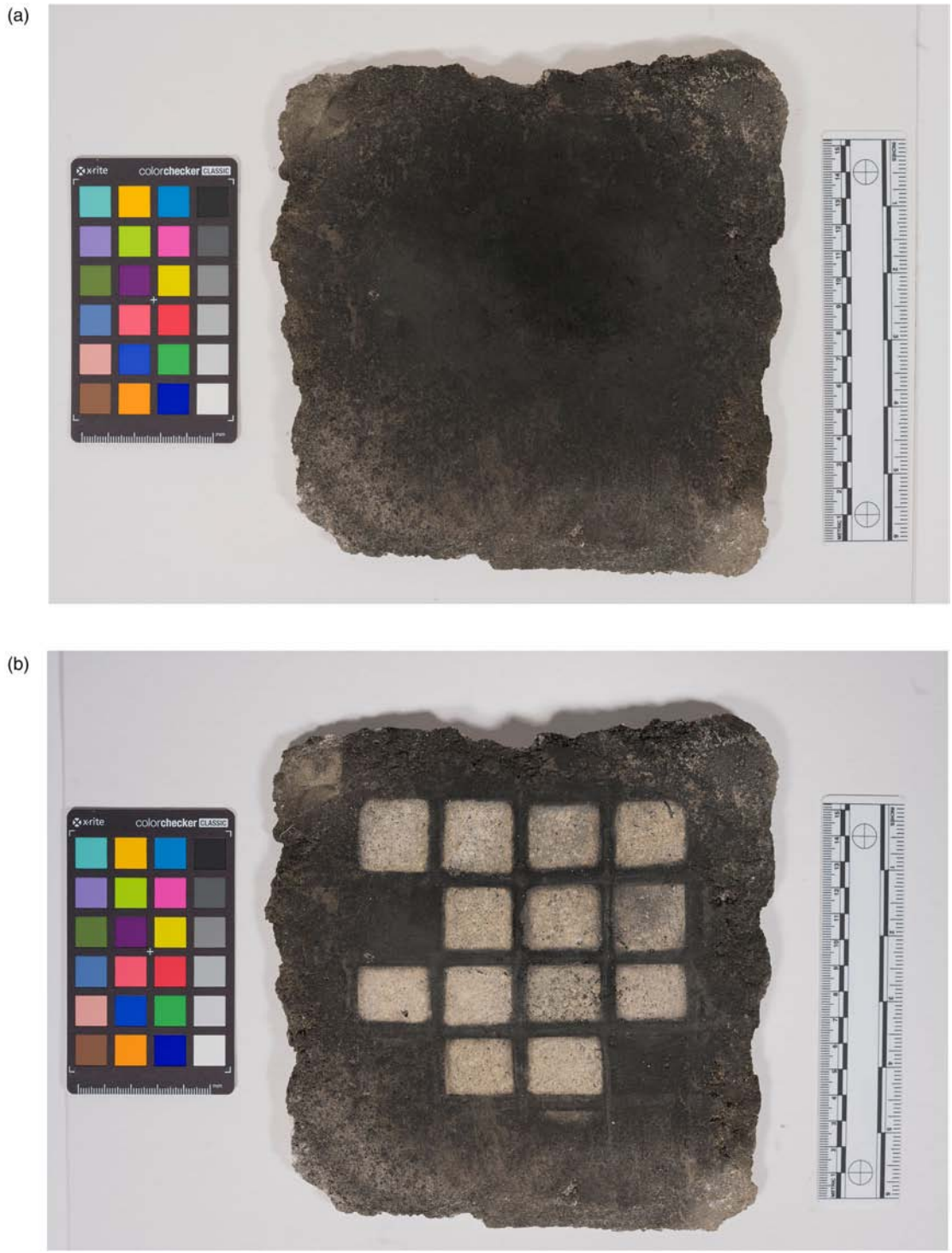
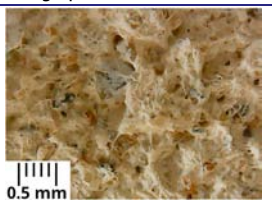
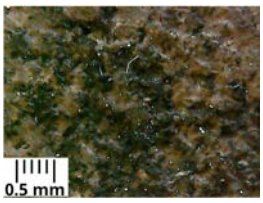
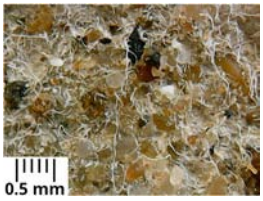
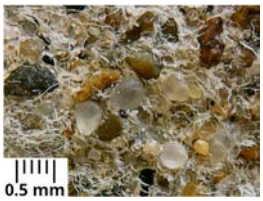
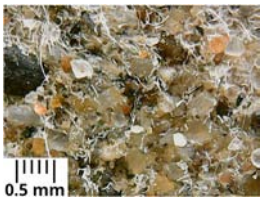
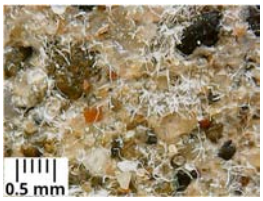
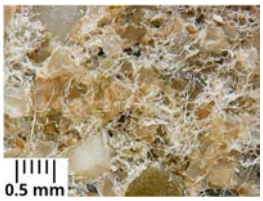


Figure 4. Images of the sample in visible light (a) before the cleaning tests and (b) after.

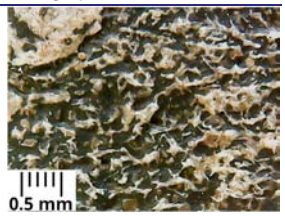
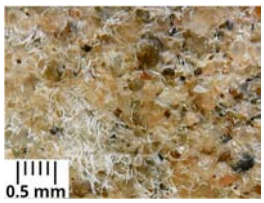
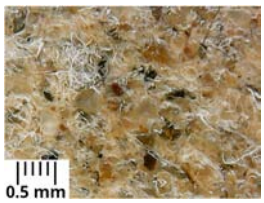
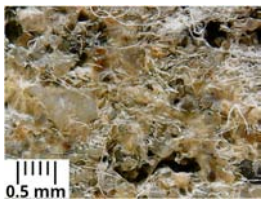
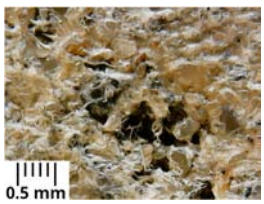
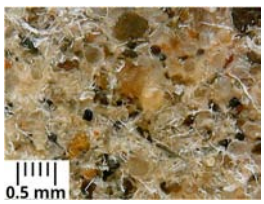
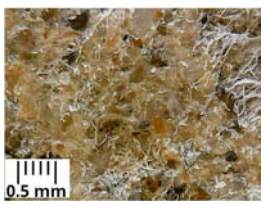
of overcleaning combined with the observation that a system of cleaning with the Smoke Sponge followed by MH yielded the best results in the cleaning tests, the target ΔE* value for the before and after images was determined. The ΔE value for the dark areas in the images cannot exceed 40, which is around the result of the selected cleaning systems. Consequently, the ΔL* value cannot exceed +38. To sufficiently distinguish between these 'cleaned' areas and the untouched areas not manipulated by image processing, this value was further reduced to +37, which yielded colour differences that rendered the changes distinguishable from the untouched areas to the human eye. As this project did not investigate the challenges of manipulating colour values, only luminosity was adjusted. Due to the differences in each area of soot deposit, it was necessary to use another mask to adjust the opacity of the effect of increasing the luminosity in different areas. Ultimately, this digital cleaning integrated the measured findings with considerations akin to those employed by a conservator in the treatment of actual wall paintings.

Table 1. Cleaning test results with colour difference for cleaned areas versus original lime before soiling and after soiling. MH: methyl hexanoate; MO: methyl octanoate; ML: methyl laurate; MM: methyl myristate; MOL: methyl oleate; SS: Smoke Sponge.

ID	Cleaning system	ΔL*	Δa*	Δb*	Colour difference (ΔE_{ab}*) between cleaned and unsoiled area	Colour difference (ΔE_{ab}*) between cleaned and soiled areas	Micrograph (scale shows 0.5 mm)
00	Lime without soot	0	0	0	0	58.6	
0	Lime after soiling	−58.2	−1.5	−6.5	58.6	0	
1	MH	−21.2	0.2	0.9	21.2	36.1	
2	MO	−21.6	0.2	0.9	21.6	39.7	
3	ML	−31.7	−0.2	−1.1	31.7	29.4	
4	MM	−27.0	1.0	2.1	27.1	32.2	
5	MOL	−26.0	0.7	2.2	26.1	35.0	
6	Ecosurf™ EH-9	−26.6	0.7	1.7	26.7	36.6	

(*Continued*)

Table 1. Continued.

ID	Cleaning system	ΔL*	Δa*	Δb*	Colour difference (ΔE_{ab}*) between cleaned and unsoiled area	Colour difference (ΔE_{ab}*) between cleaned and soiled areas	Micrograph (scale shows 0.5 mm)
7	SS	−34.8	−0.5	−2.0	34.8	22.6	
8	SS + MH	−17.3	1.1	3.5	17.7	39.7	
9	SS + MO	−19.0	0.8	2.9	19.2	39.2	
10	SS + ML	−29.0	0.0	−0.6	29.1	31.9	
11	SS + MM	−24.0	0.5	0.6	24.0	33.7	
12	SS + MOL	−24.0	1.1	3.6	24.3	34.3	
13	SS + Ecosurf™ EH-9	−21.4	0.9	3.1	21.7	37.4	

It is important to note that as the a* and b* coordinates were left unchanged, the final effect distorts the colours of the selected areas. As observed in Figure 6, the sides of the panel (outlined in red) which have lost most of their colour appear to be 'cleaner' than the painted areas in the middle. This is because while the method used works well on processing surfaces with white backgrounds, the areas that were painted beneath get desaturated when the luminosity is increased, resulting in light-grey



Figure 5. Screengrabs of the 3D model walk-through of the Mahavishnu shrine at the Eravimangalam Subramanyaswamy Temple.

areas. However, as a tool for facilitating conversations about conservation, this level of image manipulation for virtual 'cleaning' can be used to effectively communicate the vision of the conservator to the community.

Discussion

In the environmental discourse, solvents are usually perceived as problematic, yet judicious solvent selection can offer a sustainable remedy to process-related issues. Beyond low environmental impact, accessibility and affordability is also crucial for sustainability, as the implementation cost of new technologies can hinder the adoption of technically superior processes due to financial and access restraints. To address this, this study presents readily available and user-friendly solutions designed to enhance community engagement in future conservation efforts.



Figure 6. Images of the selected mural panel. (a) with indication of areas corresponding to more effective cleaning treatment in final image (b) final image after applying layer mask.

FAMEs are considered to be accessible biosolvents due to their biodegradability, low toxicity, low vapor pressure and non-flammability (Belousov et al. 2021; Gonzalez et al. 2007). Combining these with dry cleaning methods would enhance results while using a lesser amount of solvent, aligning with sustainability goals, and reducing soot transfer within the porous substrate. Additionally, the Smoke Sponge can be washed and reused, further reducing the amount of material used. The combination of the Smoke Sponge and MH or MO proved to be effective for the easier removal of soot, even though FAMEs with longer alkyl chains (ML, MM, and MOL) showed that similar results can be achieved in a slightly longer time. Additionally, they have lower volatility compared to MH or MO, resulting in a reduction of the evaporation rate and inhalation by the operator. The use of low-volatile cleaning systems is even more crucial when working in an outdoor environment, where volatile organic compounds (VOCs) cannot be captured by a fume hood.

The choice of an appropriate cleaning method necessitates careful consideration of factors beyond mere cleaning efficacy. Due to the Temple's environment and material porosity, it is crucial to choose a low-medium volatility solvent to prevent rapid evaporation and possibly minimize solvent retention in the substrate. Accordingly, the utilization of a combination involving the Smoke Sponge and MO or ML addresses these requirements effectively.

This preliminary manual image manipulation serves as a precursor to establishing a more comprehensive workflow for the 'cleaning' of soot within the 3D model. It underscores the complexity of developing a reproducible image manipulation process based on our experimental design. Our tests were conducted on unpainted surfaces proximate to the original murals' preparatory layer, but challenges arise when dealing with painted regions, where colour shifts at different luminosities cannot be estimated from our experiment's colorimetric data, leading to distortion in the resulting images. This is why the mapped areas in Figure 3, comprising areas of pigment loss revealing the white plaster beneath, exhibit superior results in virtual cleaning compared to painted areas. Future endeavors may incorporate artificial intelligence for detecting areas requiring distinct manipulation techniques to achieve satisfactory outcomes.

This highlights the need for further material investigations involving the suggested cleaning system on surfaces with paint layers beneath the soot layer. Areas that are completely obscured by soot, with no possibility of colour enhancement, may require complementary imaging techniques such as macro X-ray fluorescence imaging and terahertz imaging. When applying such techniques is challenging, such as in the Eravimangalam Subramanyaswamy temple, highly obscured areas should either remain untouched or be represented as a neutral shade in virtual conservation images. Additionally, for reasons of posterity and good practice, original documentation images should be displayed alongside manipulated ones. We believe that efforts in virtual conservation must continue towards higher standards while ensuring that all efforts are made to avoid gross misinterpretation.

The ethical dimensions of virtual monument reconstruction and digital 'cleaning' methods have been extensively debated due to their portrayal of hypothetical scenarios with uncertain authenticity (Mendoza et al. 2023; Pansoni, Tiribelli, and Paolanti 2023). This work employs artistic freedom to illustrate the possibilities of virtual conservation while acknowledging that these images and models cannot replace faithful documentation of the structure and paintings, thus emphasizing their intended use as facilitating communication. We believe that presenting this information as a potential outcome can promote conservation efforts with greater community engagement. In community-based conservation, it is advisable to leave areas with suspected high pigmentation to experienced conservators to preserve the colours, while employing the suggested cleaning method on areas with clear pigment loss, such as the areas outlined in red in Figure 6. An iterative teaching and supervisory protocol should be established to implement this green cleaning approach with community involvement.

Acknowledgements

We are grateful to the State Department of Archaeology, Kerala, to Sri E. Dinesan, Mr Jaikumar and Mr K Krishnaraj, and the trustees of Eravimangalam Subramanyaswamy Temple, to Mr Navin Palolli, Mr Muraleedhar, Mr Bhavadasan Namboothiri and Sri Krishna Namboothiri. Part of this work was made possible through the UCLA/Keck Humanistic Inquiry Graduate Research Award.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by UCLA/Keck Humanistic Inquiiry Graduate Research Award.

References

Abd El-Tawab Bader, N. A., and A. M. Ashry. 2016. "The Cleaning of the Isis Temple's Mural Paintings in Upper Egypt Using Zinc Oxide Nanoparticles and non-Ionic Detergent." *International Journal of Conservation Science* 7 (2): 443–458. https://ijcs.ro/public/IJCS-16-22_Bader.pdf.

Acke, L., K. De Vis, S. Verwulgen, and J. Verlinden. 2021. "Survey and Literature Study to Provide Insights

on the Application of 3D Technologies in Objects Conservation and Restoration." *Journal of Cultural Heritage* 49:272–288. https://doi.org/10.1016/j.culher.2020.12.003.

Ahmer, C. 2020. "Riegl's 'Modern Cult of Monuments' as a Theory Underpinning Practical Conservation and Restoration Work." *Journal of Architectural Conservation* 26 (2): 150–165. https://doi.org/10.1080/13556207.2020.1738727.

Albéo, C., E. Egel, M. Pamplona, and S. Simon. 2014. "Cleaning Graffiti and Soot with Atmospheric Plasma." In *Berliner Beiträge zur Archäometrie, Kunsttechnologie und Konservierungswissenschaf*, edited by S. Buchhorn, 69–76. Berlin: Rathgen-Forschungslabor.

Anastas, P. T., and N. Eghbali. 2010. "Green Chemistry: Principles and Practice." *Chemical Society Reviews* 39:301–312. https://doi.org/10.1039/B918763B

Banks, B. A. 1998. "An Atmospheric Atomic Oxygen Source for Cleaning Smoke Damaged Art Objects." NASA/TM-1998-208506. https://ntrs.nasa.gov/search?published=%7B%22gte%22:%221998-01-01%22,%22lte%22:%221998-12-31%22%7D&q=An%20Atmospheric%20Atomic%20Oxygen%20Source%20for%20Cleaning%20Smoke%20Damaged%20Art%20Objects.

Belousov, A. S., A. L. Esipovich, E. A. Kanakov, and K. V. Otopkova. 2021. "Recent Advances in Sustainable Production and Catalytic Transformations of Fatty Acid Methyl Esters." *Sustainable Energy & Fuels* 5 (18): 4512–4545. https://doi.org/10.1039/D1SE00830G.

Bonnat, M. 2017. "Kungri Tsuglakhang Murals Conservation-Restoration Project." *Revue d'Etudes Tibétaines* 41:249–270.

Chen, Y., Y. Fu, P. Li, H. Xi, W. Zhao, D. Wang, J. Mao, S. Zhang, S. Sun, and J. Xie. 2022. "Characterization of Traditional Chinese Sesame Oil by Using Headspace Solid-Phase Microextraction/Gas Chromatography–Mass Spectrometry, Electronic Nose, Sensory Evaluation, and RapidOxy." *Foods* 11 (22): 3555.

Cheremisinoff, N. P. 2001. "Green Chemistry." In *Condensed Encyclopedia of Polymer Engineering Terms*, 301–326. Oxford: Butterworth-Heinemann.

Dorsey, J., H. Rushmeier, and F. Sillion. 2008. *Digital Modeling of Material Appearance*, 1st ed. New York: Elsevier. https://doi.org/10.1016/B978-0-12-221181-2.X5001-0.

El Aal, A. 2012. "Evaluation of Biotechnology in the Conservation of Wall Paintings in the Mortuary Temple of Ramses III." *Egyptian Journal of Archaeological and Restoration Studies* 2 (2): 79–89. https://doi.org/10.21608/ejars.2012.7464

Frenz, A., and K. K. Marar. 2004. *Wall Paintings in Kerala: 1000 Years of Temple Art*. Stuttgart: Arnoldsche.

Gonzalez, Y. M, P. De Caro, S. Thiebaud-Roux, and C. Lacaze-Dufaure. 2007. "Fatty Acid Methyl Esters as Biosolvents of Epoxy Resins: A Physicochemical Study" *Journal of Solution Chemistry* 36 (4): 437–446. https://doi.org/10.1007/s10953-007-9126-5

Gordon, E. 2010. "Conservation Treatment of Two Ming Dinasty Temple Wall Paintings." In *Conservation of Ancient Sites on the Silk Road: Proceedings of the Second International Conference on the Conservation of Grotto Sites, Mogao Grottoes, Dunhuang, People's Republic of China*, June 28-July 3, 2004, edited by N. Agnew. Los Angeles: Getty Conservation Institute. Accessed May 2024. https://www.getty.edu/publications/resources/virtuallibrary/9781606060131.pdf.

Henderson, J, and T. Nakamoto. 2016. "Dialogue in Conservation Decision-Making." *Studies in Conservation* 61:67–78. https://doi.org/10.1080/00393630.2016.1183106.

Joshi, D. R. and N. Adhikari. 2019. "An Overview on Common Organic Solvents and Their Toxicity." *Journal of Pharmaceutical Research International* 28:1–18. https://doi.org/10.9734/jpri/2019/v28i330203.

Mendoza, M. A. D., E. De La Hoz Franco, and J. E. G. Gómez. 2023. "Technologies for the Preservation of Cultural Heritage—A Systematic Review of the Literature." *Sustainability* 15 (2): 1059. https://doi.org/10.3390/su15021059.

Mini, P. V. 2010. "Preparation Techniques of Pigments for Traditional Mural Paintings of Kerala." *Indian Journal of Traditional Knowledge* 9 (4): 635–639.

Panackal, M. 2018. *Traditional Mural Painting of Kerala*. Chandanathope: Kerala Institute of Design.

Pansoni, S, S. Tiribelli, and M. Paolanti. 2023. "Design of an Ethical Framework for Artificial Intelligence in Cultural Heritage." *IEEE International Symposium on Ethics in Engineering, Science, and Technology (ETHICS)*:1-5. West Lafayette: IEEE. Accessed May 2024. https://ieeexplore.ieee.org/document/10155020.

Paramavisan, S. 1939. *Annual Report of the Archaeological Department of His Exalted Highness the Nizam's Dominions (1936–1937)*. Calcutta: Baptist Mission Press.

Pflugfelder, C., N. Mainusch, I. Hammer, and W. Viöl. 2007. "Cleaning of Wall Paintings and Architectural Surfaces by Plasma." *Plasma Processes and Polymers*. 4 (S1): S516–S521.

Ramachandran, A. 2010. *Painted Abode of Gods Apr*. New Delhi: Vadehra Art Gallery.

Riegl, A. 1996. "The Modern Cult of Monuments: Its Essence and Its Development." In *Historical and Philosophical Issues in the Conservation of Cultural Heritage*, edited by N. Stanley-Price, M. K. Talley, and A. M. Vaccaro, 69–83. Los Angeles: Getty Conservation Institute.

Schwab, A. W., M. O. Bagby, and B. Freedman. 1987. "Preparation and Properties of Diesel Fuels from Vegetable Oils." *Fuel* 66 (10): 1372–1378. https://doi.org/10.1016/0016-2361(87)90184-0.

Shockey, L. H. 2009. "Blow it off: Moving Beyond Compressed air with Carbon Dioxide Snow." *AIC Objects Specialty Group Postprints* 16:13–24.

Silverman, R., and S. Irwin. 2009. "Fire and ice Revisited: A Comparison of two Soot Removal Techniques for Books." *International Preservation News* 49:31–35.

Spafford-Ricci, S., and F. Graham. 2000. "The Fire at the Royal Saskatchewan Museum, Part 2: Removal of Soot from Artifacts and Recovery of the Building." *Journal of the American Institute for Conservation* 39 (1): 37–56. https://doi.org/10.1179/019713600806113310.

Tsang, J. S, and S. Babo. 2011. "Soot Removal from Acrylic Emulsion Paint Test Panels: A Study of Dry and Non-Contact Cleaning." In *Preprints of the ICOM-CC 16th Triennial Conference, Lisbon, Portugal*, 19-23 September 2011, edited by J. Bridgland. Paris: ICOM. https://www.icom-cc-publications-online.org/1248/Soot-Removal-From-Acrylic-Emulsion-Paint-Test-Panels–A-Study-of-Dry-and-Non-contact-Cleaning.

Tucci, G, V. Bonora, A. Conti, and L. Fiorini. 2017. "High Quality 3D Models and their use in a Cultural Heritage Conservation Project." *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XLII-2-W5:687–693. https://doi.org/10.5194/isprs-archives-XLII-2-W5-687-2017

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S256–S262
https://doi.org/10.1080/00393630.2024.2336793

ORIGINAL RESEARCH OR TREATMENT PAPER

OPEN ACCESS Check for updates

Pleasing the Wrathful Deities: Ethical Approaches to the Care of Tibetan Skull Drums

Complacer a las Deidades Iracundas: Enfoques Éticos para el Cuidado de los Tambores de Calaveras Tibetanos

Richard Mulholland and Rachael Durkin

Faculty of Arts, Design and Social Sciences, Northumbria University, Newcastle-upon-Tyne, UK

ABSTRACT

In 2023, a number of sacred Tibetan ritual musical instruments fashioned from human tissue were donated to Northumbria University, England. After lengthy consultation with stakeholders, the university took the decision to accept the donation in order to store and care for these objects in a culturally respectful manner. This process involved working closely with the Tibetan diaspora in exile to manage, research and provide access in a culturally sensitive way until such time as they might be returned to their communities of origin. Framing the university's decision were current and ongoing debates within the heritage sector regarding the ethics of storing, researching and displaying human remains, especially where they belong to cultures from beyond the Global West. However, the cultural and ritual status of these objects, not to mention their geographical origin, is such that they do not fall easily into the same defined status as other historical human remains in western heritage collections. We present here ongoing work to build transparent and sensitive collections and research policies specifically around two Tibetan ritual *thöd-rnga* skull drums, traditionally used in the Chöd (gCod) ritual practised in Tibetan Tantric (Vajrayana) Buddhism. We situate our work within the complex discourse on caring for contested objects in the UK in the midst of the restitution and decolonisation agendas, before considering the objects themselves as material artefacts, and the ethics of caring for and researching these objects within the context of a university collection.

En 2023, se donaron a la Universidad de Northumbria (Inglaterra) varios instrumentos musicales rituales tibetanos sagrados hechos con tejido humano. Después de una larga consulta con las partes interesadas, la universidad tomó la decisión de aceptar la donación para almacenar y cuidar estos objetos de una manera culturalmente respetuosa. Este proceso implicó trabajar en estrecha colaboración con la diáspora tibetana en el exilio para gestionar, investigar y brindar acceso de una manera culturalmente sensible hasta el momento en que pudieran regresar a sus comunidades de origen. La decisión de la Universidad se enmarcó en debates actuales y en curso dentro del sector del patrimonio sobre la ética de almacenar, investigar y exhibir restos humanos, especialmente cuando pertenecen a culturas más allá del Occidente global. Sin embargo, el estatus cultural y ritual de estos objetos, por no mencionar su origen geográfico, es tal que no caen fácilmente en el mismo estatus definido que otros restos humanos históricos en las colecciones del patrimonio occidental. Presentamos aquí el trabajo en curso para construir colecciones y políticas de investigación transparentes y sensibles específicamente en torno a dos tambores de calavera rituales tibetanos *thöd-rnga*, utilizados tradicionalmente en el ritual Chöd (gCod) practicado en el budismo tántrico tibetano (Vajrayana). Situamos nuestro trabajo dentro del complejo discurso sobre el cuidado de objetos en disputa en el Reino Unido en medio de las agendas de restitución y descolonización, antes de considerar los objetos en sí mismos como artefactos materiales, y la ética del cuidado e investigación de estos objetos dentro del contexto de una colección universitaria.

ARTICLE HISTORY
Received November 2023
Accepted March 2024

KEYWORDS
Conservation ethics; decolonisation; musical instruments; Tibetan heritage; damaru

Ética de la conservación; descolonización; Instrumentos musicales; herencia Tibetana; damaru

Introduction

In 2023, sacred Tibetan ritual musical instruments fashioned from human tissue were donated to Northumbria University in the UK by a private donor. After lengthy consultation with stakeholders, the university took the decision to accept the donation in order to store and care for these objects in a culturally respectful manner. This process involved working closely with the Tibetan diaspora in exile to manage, research and

CONTACT Richard Mulholland richard.mulholland@northumbria.ac.uk Northumbria University, Burt hall, Northumberland Rd, Newcastle-upon-Tyne NE1 8JF, UK

© 2024 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group
This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

provide access in a culturally sensitive way until such time as they might be returned to their communities of origin. Framing the university's decision were current and ongoing debates within heritage conservation regarding the ethics of storing, researching and displaying human remains, especially where they belong to cultures from beyond the Global West. However, the cultural and ritual status of these objects, not to mention their geographical origin, is such that they do not fall easily into the same defined status as other historical human remains present in western heritage collections.

The following presents ongoing work to build transparent and sensitive collections and research policies specifically around two Tibetan ritual *thöd-rnga* (skull drums), each formed from the upper part of two human skulls, and traditionally used in the Chöd/gCod ('cutting') ritual practised in Tibetan Tantric (Vajrayana) Buddhism. We first situate our work within the complex discourse on caring for contested objects in the UK at a time when collections are taking stock of their holdings in light of increasing repatriation requests, and the growing decolonisation agenda in both the education and heritage sectors. We then consider the objects themselves as material artefacts, attending to their formal construction, their specific materiality and their status as functional ritual musical instruments, juxtaposed with the specific collections care needs of human tissue. Finally, we will discuss the ethics of caring for and researching these objects within the context of a university collection.

Decolonising provenance

Recent texts have ruminated on contemporary themes of decolonisation, repatriation, and restitution within UK public collections, most notably through the lens of the Benin Bronzes pillaged by British naval forces in 1897 and positioned by Hicks and others as an act to further European imperial ambitions in Africa (Hicks 2020). Hicks' timely work illuminated the discussion during a period of significant mobilisation of the decolonisation agenda in the UK, itself propelled by a period of self-reflection enforced by the global Covid pandemic. The year also saw the toppling and sinking of the Edward Colston (1636–1721) statue in Bristol (Siddique and Skopeliti 2020), the removal of *Shuar Tsantsas* (shrunken heads) from display at the Pitt Rivers Museum in Oxford (Bailey 2020), and wider political and media calls to decolonise curricula in higher education. Similarly, ICOM adopted decolonisation as a key principle of its strategic plan for 2022–2028, (ICOM 2022, 4) with a dedicated working group formed, and a 2020 Museums Association report highlighted the need for proactive approaches to decolonisation across the sector (Museums Association 2020). Decolonisation of collections has since been a significant theme in scholarship (Brulon Soares and Witcomb 2022; McMaster 2019; Narkiss 2022). Work on the decolonisation of collections is therefore a work in progress – an active conversation with the public, scholars, stakeholders, the incumbent government, and the heritage sector. It is against this complex and ever-shifting, almost byzantine, backdrop we are defining research and conservation practice around the *thöd-rnga*, while remaining sensitive to the geopolitical specificities of an object interlaced with political tensions that often clash with Eurocentric perceptions and *othering* of the macabre (Fisher 2016; Thomas 2022).

One of the central tenets of the decolonisation agenda in museums is accurate and reliable provenance. As part of standard due diligence for acceptance and accessioning, and the sale of goods through auction houses in the UK, provenance is required to document the history of the object. Research into provenance, like the wider decolonisation agenda, is of contemporary concern: at the time of writing, Germany and France will launch a new joint fund in February 2024 to research the provenance of objects from sub-Saharan Africa in their museums, as part of each country's pledge to return artefacts obtained through colonialist activities (Hickley 2023). At a subject-specific level relevant to the *thöd-rnga*, provenance is now one of the three strategic pillars of CIMCIM (the ICOM International Committee for Museums and Collections of Musical Instruments), and is indicative of the importance of provenance within the subdiscipline of organology.[1] But while provenance of Western musical instruments can often be relatively easy to prove, objects from the global majority are more often than not unaccompanied by the administration we rely on to evidence origin and ownership of collections objects. This parallels many historic objects accessioned without documentation, such as archaeological finds with no find-spot data, or antiquities without evidence of legal transfer of ownership. A more focussed study is therefore required to rebuild the object's history of custodianship (Lyons 2016). Further, the provenance of objects made from human remains brings with it additional considerations: while the trade in human bones is not illegal in most jurisdictions, and in the UK is governed by the Human Tissue Act of 2004, any trade needs to be ethically grounded (Cassman and Odegaard 2004). The *thöd-rnga*, as both objects made from human remains and objects created specifically for ritual purposes, require a sensitive and nuanced approach to questions of provenance, status and their position within the decolonisation debate.

Many collections have adopted a collaborative approach to provenance, engaging with stakeholders to evidence and enhance knowledge of collections and objects from non-Eurocentric cultures; an approach that is noted as potentially becoming

meaningless given its use as a political tool as part of the decolonisation agenda (Weber-Sinn and Ivanov 2020). Indeed, the act of collaboration may in fact enforce, rather than refute a *West versus the rest* hierarchy, where the power sits with the collection, rather than serving as an equalizer (Weber-Sinn and Ivanov 2020, 69). That said, engagement with an object's stakeholders can unlock a fount of valuable information, often transmitted by those with more culturally informed expertise and/or contained within the oral tradition of the community or culture. This knowledge, gathered from both resident and diasporic groups of stakeholders, has proven to be a key resource for the study of ethnographic items and histories. In addition, ethnomusicology, which encompasses the study of Tibetan ritual instruments, typically employs the skills of the ethnographer to document story, ritual and use, in many cases providing additional information through the capture of music and performance through field recording.

In the case of the *thöd-rnga,* we have taken a stakeholder-led approach to our early work with the objects, particularly around issues of care and display (Reedy 1992), and in thinking about issues of provenance and the wider decolonisation debate. As a result of our consultation, we have taken the view that we serve as custodians of the *thöd-rnga* until such time as their community of origin can be identified and that the infrastructure for their care upon return is in place. By serving as custodians, we also prevent the items entering the antiquities market, and can therefore ensure that they are cared for appropriately, as guided by expertise from their community of origin. The alternative – in other words, to return these items to the Tibetan region – would largely fail to recognise the specificities of these ritual objects to their community practitioners, and would arguably risk them being accessioned into collections considered less suitable by both practitioners and communities. Moreover, the continuing tensions between the Tibetan region and China necessitates a sensitive approach to repatriation. Our custodianship therefore demands continual engagement with diverse regional, resident and diasporic stakeholders, but particularly with extended monastic networks across Tibetan Buddhist communities.

Tantric Buddhism and music

The practice of Chöd (gCod) ritual has its roots in early Tibetan Buddhism, brought to Tibet via Indian masters who created monastic sects that blended religious practice with local Tibetan folk magic. Chöd is a fusion of Prajnaparamita and Tantra, and is in essence a form of meditation. In the Chöd ritual the practitioner employs a meditative visualisation process that invokes inner demons or *kleshas*. In the ritual itself, the practitioner uses their awareness to 'cut' through hindrances for the realisation of their true nature and the nature of all beings. The ritual is performed with chants and via the use of ritual musical instruments whose power is increased both through the skill and knowledge of the practitioner and the specific materiality of the instruments used. Ultimately, its aim is to cut, or separate entirely from the ego (Beer 1999; Vasile 2023).

Chöd practice is said to originate with the eleventh/twelfth- century Tibetan saint, Machig Labdron: a female Tibetan tantric practitioner, and the author of what is reputed to be the earliest explanation of Chöd.[2] Machig Labdron is often depicted in *thang-ka* in a dance posture with a damaru or *thöd-rnga* in her right hand, and a bell or other Tantric ritual object in her left. She is sometimes accompanied by her teacher who carries a thighbone trumpet, the *rkang-gling*, also used in Chöd. The practitioner chants liturgies which call to the mind a series of visualisations, including the invocation of wrathful deities who may be imagined as cutting the body into pieces, and then placing these into a bowl that is fashioned from the top of the practitioner's skull. These are then given as offerings to both malevolent and benevolent beings, which in turn has the intention of relieving the practitioner from karmic debt. The cutting symbolises the detachment from one's own ego, fear and suffering and often takes place in dark, uncanny and foreboding locations, such as cremation areas and charnel grounds (*dur khrod*) (Brousseau 2018).

While this focused visualisation takes place, the practitioner simultaneously plays the *rkang-gling* fashioned from a human thighbone, the *thöd-rnga* fashioned from two human skulls, and other ritual instruments, which are an integral part of the ritual (Beer 1999). The music is said to be pleasant and beautiful in order to appeal to the gods (Monhart 2017, 96), with the sounds of the *rkang-gling* closely associated with charnel grounds and wrathful deities that inhabit such desolate, uncanny places (Brousseau 2018; Rønning 2005). The *rkang-gling* itself is said to be pleasing to wrathful deities who assist in the cutting through of the ego, but terrifying to evil spirits. The *rkang-gling* is always held in the left (wisdom) hand, while the damaru or *thöd-rnga* is held in the right (method) hand.[3] This 'cutting' ritual serves to illustrate two interrelated components of Mahāyāna thought. Firstly, the practitioner accomplishes the severance of malevolent beings through realisation of the emptiness (*śūnyatā*) of the self, and secondly, the offering up of the flesh is seen as an act of compassion to hungry spirits (Beer 1999; Brousseau 2018).

Skull drums and other Tibetan instruments

Thöd-rnga are damaru drums made from human bone: double-sided drums fashioned from sections of the



Figure 1. *Thöd-rnga*, nineteenth century (assumed), British Museum, 1992,1214.83. © The Trustees of the British Museum, CC BY-NC-SA 4.0.

upper frontal and parietal bones of two human skulls. Holes are cut at the crowns, and are joined by a resonator ring often made of brass (Figure 1). This differs from the traditional Indian damaru, which is more often carved from wood mimicking the hourglass silhouette of the *thöd-rnga*, and similarly adorned with a central cloth strap and two striking pellets on cords which, when the drum is rotated, alternately strike the drum skins. As observed by Cupchik (2013, 129), the length of the cord impacts the speed of required rotation, as do the size and weight of the pellets, necessitating a particular tempo for the drum's construction to function: a slower tempo and softer percussive strike of the pellets is preferred, in order to complement the meditation and contribute to the pleasant and beautiful music. Many damaru are decorated with traditional ornamentation of copper and brass, gemstones such as turquoise and coral, shell, paintwork and carving, and adorned with elaborate cloth straps, indicative of their prized status as ritual objects.

Tibetan Buddhist ritual music also makes use of the bronze or brass *dril-bu* (Tibetan bell) and *dorje* (sceptre), matched and used as a pair; the *dungchen* (an elongated and collapsible metal trumpet or horn often used in pairs) and *dung kar* (a conch shell trumpet, typically white); the *gyaling* or *rgya-gling* (shawm with double reed); *dra nyen* (6- or 7-string lute in double courses with a front of animal skin rather than wood); a range of cymbals (e.g. *sbug-chal/rol-mo, silnyen*); the *nga chen* (large suspended drum); and the aforementioned thighbone trumpet known as an *rkang-gling* (Figure 2) (Collinge 1996; Kartomi 1990, 75–83; Egyed 2000). While the *rkang-gling* is preferably made from human femur or tibia bone, many are made from wood, metal, or the bones of other large mammals. The construction of the *rkang-gling* from bone sees the marrow removed and a hole drilled through the ball joint to create the bore. The ends are often furnished with metal plating, at the narrow end to create a mouthpiece, and at the ball joint to create the bell; the plating typically retains the outline of the joint to preserve the appearance of a bone, rather than the flared bell we find in Western woodwind and brass. Like the *thöd-rnga*, *rkang-gling* are further decorated with traditional metalwork and gemstones. All of these monastic instruments are used as part of the ritual, with only a few exceptions particular to certain monasteries (Egyed 2000, 151). The bones for both *thöd-rnga* and *rkang-gling* are part of the wider tantric Buddhist engagement with death, for example: skull cups and other vessels made from portions of the skull, *thod pa*; bone decoration, and *rus rgyan*, such as the bone apron, *ska rags* (Fuentes 2021). When actively serving as ritual objects, they are treated with the utmost of respect: Cupchik (2013, 128) observed that the damaru were then stored secretively, wrapped and/or boxed carefully, and 'never exhibited'.



Figure 2. *Rkang-gling*, nineteenth century (assumed), British Museum, 2016,3040.2. © The Trustees of the British Museum, CC BY-NC-SA 4.0.

The specific materiality of both *rkang-gling* and *thöd-rnga* have significance to the potency of the ritual. Human remains for use in ritual were sourced from charnel grounds and areas where traditional sky burials took place.[4] Beer observes that in tantric tradition, the left femur of a sixteen-year-old girl was considered to have the most potency for the construction of *rkang-gling*, followed only by that of a murder victim and then one who may have died in an accident. Although damaru are frequently used in Buddhist and Hindu ritual practice, the *thöd-rnga* is unique to Tibet. The most powerful tantric damaru are said to be created from the joined skulls of a teenage boy and twelve-year-old girl. Beer observes that today modern forgeries, and skulls of dubious provenance are now openly sold on the international art market for the purposes of creating ritual instruments, where they command high prices, but crucially, from the perspective of tantric practice, he notes that these are considered almost entirely without potency (Beer 1999). Vasile (2023) confirms that the manufacture of

ritual objects from human remains is ongoing in the Himalayas, but exists underground: in Nepal the transport and use of human remains is illegal, but the objects are used freely without consequences.

European musicology places less emphasis on musical instruments as ritual objects, viewing them more as tools for engagement or to enhance the other activities of a religious ceremony. This top down, anthropocentric viewpoint has therefore led to assumptions about the position of musical instruments in other societies: viewed as products of human creation and therefore most suitable for a material culturalist approach, sometimes verging on the clinical dissection of its component parts with little regard for the intangible context.[5] Performance, too, is imbued with notions of entertainment and levity, and even serious religious music-making (such as the use of the organ in the Christian tradition), does not bestow the musical instruments with an identity other than *at the service of* the music and the occasion. However, in many non-western cultures, and specifically Himalayan tantric Buddhism, musical instruments are not musical *per se*, instead serving the specific ritual function of an offering as part of the multifaceted process of summoning and pleasing the deities and cutting through the ego (Monhart 2017; Tsukamoto 1983). The objects therefore demand to be studied unseparated from their community, use, and the specifics of ritual practices.

The care and conservation of the *thöd-rnga*, and the closely related *rkang-gling*, therefore cannot be interpreted solely through a straightforward materialist lens. *Thöd-rnga* are constructed from a mix of materials, mostly organic, and are complex in their construction. This is further complicated by being an instrument that is under tension: two drum skins are adhered to the skull cavities themselves, rather than attached by a frame, and this means that damage to the skins is inevitable. The damaru skins – often goat, but also snake and sometimes human (Fuentes 2021, 234) and typically attached with animal glue – can lose elasticity, and either tear or pull from the edge of the cavity. Fuentes (2021, 236) also notes that treatments are used to keep *thöd-rnga* in playing condition (e.g. alkaline tanning agents), and that in some cases copper carbonates and acetates (verdigris) are used, resulting in the green hues common to some damaru held in museums (Figure 1), and observed in depictions of damaru in Himalayan painting after the eighteenth century. The attached striking pellets are also subject to wear from use, as are the cloth handles. The cloth in particular is at risk of damage from pests (Fuentes 2021, 241–242; Simkin 1998). From the perspective of the conservator, the use of certain original materials (human tissue, snakeskin) to replace lost components or reintegrate losses in a *thöd-rnga*, is largely impossible. Although synthetic substances, or even substances from another animal origin might be substituted to stabilise the instrument and make it visually complete, with objects so intrinsically linked to ritual use, and where the composite materials are imbued with significant meaning, the ethical question of whether to conserve and what materials are appropriate is central to defining an appropriate framework for their care.

Ethical quandary

The *thöd-rnga* present a number of ethical dilemmas. Issues to be considered are their care and conservation, display and handling, policy development, the appropriateness of scientific research and, as functioning musical instruments, performance. This makes the *thöd-rnga* complex items to hold within a collection. Unlike secular musical instruments, where their preservation and playability are governed largely by their condition and the policies of the holding collection, sacred instruments such as the *thöd-rnga* have further intangible considerations that should be respected as far as possible. Taking a respectful and ethical approach helps to counter the rewriting of the object's meaning in light of its changed 'predestined path' as a commodity (Appadurai 1986), viz. a ritual object removed from its social context and resigned from its purpose, to be held in a secular collection to satisfy curiosity; as per Hall's consideration of other Tibetan artefacts (2004, 69), the *thöd-rnga's* 'spiritual nature has been compromised' by this process. Further still, the *thöd-rnga* are both commodities to be possessed and used, and remnants of ancestors of a marginalised people, adding an additional layer of complexity to their interpretation, and our approach as temporary custodians. This draws parallels with many other cases of indigenous remains in collections, and the moves by descendants to reclaim them (Gunning and Challis 2022).

The ethics of holding objects such as the *thöd-rnga* are therefore subject to additional scrutiny, and warrant a careful, collaborative approach to interpretation and policy development. Working with our small preliminary network of stakeholders – a group formed of Tibetan and international scholars, museums professionals, practitioners, and community representatives – we have developed a specific Tibetan Ritual Objects policy for our collection at Northumbria University, to govern all aspects of access to and interaction with the *thöd-rnga*. Through consultation, it was unanimously felt by a number of stakeholders from diverse backgrounds, that the objects should be held by a university collection where they may be cared for with respect and in an appropriate environment, rather than risk falling into private hands where they may be treated as macabre curiosities and handled in an insensitive manner. Although there are recent precedents where

thöd-rnga and other ritual instruments have been displayed in museum exhibitions – for example, *Tantra: Enlightenment to Revolution* (British Museum, 2020–2021) and *Tibet's Secret Temple* (Wellcome Collection, 2016–2017) – the conversation is fluid, and upon discussion it was decided that the Northumbria *thöd-rnga* would not be displayed by default, and would be handled as little as possible until a more comprehensive stakeholder consultation could take place. As a rule, the *thöd-rnga* will not be used for performance, although in exceptional circumstances (and in consultation with stakeholders) permission would be granted to tantric Buddhist practitioners with appropriate ritual expertise and knowledge, and where no damage to the instrument is anticipated.

Research into the *thöd-rnga* can take a variety of forms, from object-based material culture studies to scientific analysis and forensic examination which conceivably could require invasive sampling. However, the ethics of designing appropriate and sensitive research methods, and whether we *should* research them at all, is a decision that is also reached via stakeholder collaboration. Work by Reedy in the 1980s and 1990s on Tibetan Buddhist sculpture, for example, revealed mixed opinions by Tibetans regarding non-Buddhist scientists and art historians studying ritual objects. The opening and emptying of ritual objects (*gau*) and Buddhist sculptures for study was considered to be grossly sacrilegious in some field studies (Hall 2004). Some encounters suggested that the researcher should be initiated in certain texts or practice before attempting to study objects, whereas others felt that scientific study of the non-invasive kind may be permissible where appropriate respect for the object is shown (Reedy 1992, 45). Our work with stakeholders three decades later unveiled similar sentiments, where research was welcomed, but only where objects were handled appropriately, and where non-invasive research methods were prioritised; handling for the sake of curiosity was discouraged. Difficulties therefore emerge when scientific advances would permit us to conduct DNA analysis in order to learn more about the remains, and potentially pinpoint their community of origin with a view to a future where repatriation might be considered. This conflict between a desire to locate the community of origin, but utilising invasive analytical techniques presents a similar ethical dilemma, and is part of ongoing and future discussions with our stakeholders. As such, our policy only permits non-invasive and respectful research to take place, subject to clearance by an institutional ethics panel where necessary.

Conclusion

The acceptance of the *thöd-rnga* has provided us with a welcome opportunity to reflect on current heritage discourse, and our institutional approach to the decolonisation debate. It has also provided us with an opportunity to utilise the case study of the *thöd-rnga* – as a nexus point where multiple debates in conservation practice converge – as an educational tool to develop nuanced discussions with students and colleagues in tandem with our stakeholder network. Indeed, our conversations pivoting around the *thöd-rnga* mirror the moves by museums to present their contested holdings as sites for discussions about power through exhibitions and events (Gunning and Challis 2023). The care and conservation of the *thöd-rnga* will continue to be informed by ongoing discussions with our stakeholder network, which we seek to expand, and consultation with heritage colleagues as the approach to such objects evolves.

Notes

1. Organology is the study of musical instruments, covering scientific, historical, and performance-based approaches.
2. Collected from the original Tibetan manuscripts as *Machig's Complete Explanation* or *Phung po gzan skur gyi rnam bshad gcod kyidon gsal byed* ('clarifying the meaning of chöd: a complete explanation of casting out the body as food'), c.1055–1155.
3. An early description of the Chöd (gCod) ritual in western literature is found in David-Néel's colourful 1932 text on her travels in Tibet. She notes: 'The monotonous *dong, dong* of the deep-voiced drum became slower and finally ceased, the young ascetic seemed sunk in meditation. After a while he wrapped himself more tightly in his zen. The kangling in his left hand, the damaru lifted high in the right and beating an aggressive staccato, the man stood in a challenging attitude, as if defying some invisible enemy' (David-Néel 1932).
4. Beer notes that although once common, the practice of sky burial, whereby the remains of the dead person are prepared ritually and left in charnel areas for carrion birds and other animals to feed upon until only bones remain, is almost non-existent today and that such ritual objects now fetch a high price on the art market in the far East.
5. The authors are grateful to Chris Miller, presently conducting doctoral research into the ontologies of musical instruments in South-East Asia, for his insight on these matters.

Acknowledgements

The authors would like to express their profound thanks to Sonam Tsering Frasi, Ayesha Fuentes, Alex Siedlecki, Julia Lawless, Thupten Kelsing, Anne Bancroft, and others who so kindly contributed their personal and professional views in helping us to shape the policy supporting the *thöd-rnga*. Additional thanks to Chris Miller for his sharing of literature on Tibetan musical instruments and insights into East Asian music.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Richard Mulholland http://orcid.org/0000-0001-5220-3078
Rachael Durkin http://orcid.org/0000-0003-2530-5444

References

Appadurai, A. 1986. *The Social Life of Things: Commodities in Cultural Perspective*. Cambridge: Cambridge University Press.

Bailey, M. 2020. "Oxford Museum Removes 'Racist' Shrunken Heads from Display After 80 Years." *The Art Newspaper*, September 13, 2020.

Beer, R. 1999. *The Encyclopedia of Tibetan Symbols and Motifs*. Boulder: Shambhalah Publications.

Brousseau, J. I. 2018. *Charnel Offerings: The Tibetan Practice of GCod and the Indian Tantric Traditions. Masters Dissertation*. Santa Barbara.: University of California.

Brulon Soares, B., and A. Witcomb. 2022. "Editorial: Towards Decolonisation." *Museum International* 74 (3–4): iv–xi.

Cassman, V., and N. Odegaard. 2004. "Human Remains and the Conservator's Role." *Studies in Conservation* 49: 271–282282. https://doi.org/10.1179/sic.2004.49.4.271.

Collinge, I. 1996. "Developments in Musicology in Tibet: The Emergence of a New Tibetan Musical Lexicon." *Asian Music* 28 (1): 87–114.

Cupchik, J. 2013. "The Tibetan GCod Ḍamaru —A Reprise: Symbolism, Function, and Difference in a Tibetan Adept's Interpretive Community." *Asian Music* 44 (1): 113–139. https://doi.org/10.1353/amu.2013.0005.

David-Néel, A. 1932. *Magic and Mystery in Tibet*. New York: Dover.

Egyed, A. M. 2000. "Theory and Practice of Music in a Tibetan Buddhist Monastic Tradition." Unpublished PhD diss., University of Washington.

Fisher, M. 2016. *The Weird and the Eerie*. London: Repeater.

Fuentes, A. 2021. "On the use of Human Remains in Tibetan Ritual Objects." Unpublished PhD diss., SOAS University of London.

Gunning, L. P., and D. Challis. 2022. "The Plunder of Maqdala: Ethical Concerns Around Belongings and Ancestral Remains in Museums." *Museum International* 74 (3–4): 60–71.

Hall, A. 2004. "A Case Study on the Ethical Considerations for an Intervention upon a Tibetan Religious Sculpture." *The Conservator* 28 (1): 66–73.

Hickley, C. 2023. "Germany and France set up Joint Provenance Research Fund Focussed on Africa." *The Art Newspaper*, October 11, 2023.

Hicks, D. 2020. *The Brutish Museums: The Benin Bronzes, Colonial Violence and Cultural Restitution*. London: Pluto Press.

ICOM. 2022. *Strategic Plan 2022–2028*. Paris: International Council of Museums.

Kartomi, M. J. 1990. *On Concepts and Classifications of Musical Instruments*. Chicago: University of Chicago Press.

Lyons, C. 2016. "On Provenance and the Long Lives of Antiquities." *International Journal of Cultural Property* 23 (3): 245–253.

McMaster, G. 2019. "Decolonising the Ethnographic Museum." In *A Companion to Curation*, edited by B. Buckley, and J. Conomos, 262–276. Chichester: John Wiley and Sons.

Monhart, M. 2017. "Listening with the Gods: Offering, Beauty and Being in Tibetan Ritual Music." *Revue d'Etudes Tibétaines* 40: 92–102.

Museums Association. 2020. *Empowering Collections Report*. Accessed November 2023. https://www.museumsassociation.org/campaigns/collections/empowering-collections/.

Narkiss, I. 2022. "Decolonising Museum Conservation Practice: A View from the UK." *Studies in Conservation* 67 (Sup.1): 183–191. https://doi.org/10.1080/00393630.2022.2079350.

Reedy, C. L. 1992. "Religious and Ethical Issues in the Study and Conservation of Tibetan Sculpture." *Journal of the American Institute for Conservation* 31 (1): 41–50.

Rønning, M. L. 2005. "The Path of Machig Labdron: GCod, its History, Philosophy and Contemporary Practice in Central Tibet." Unpublished Masters Thesis, University of Oslo.

Siddique, H., and C. Skopeliti. 2020. 'BLM Protestors Topple Statue of Bristol Slave Trader Edward Colson'. *The Guardian*, June 7, 2020.

Simkin, M. 1998. "The Conservation of a *Thöd Rnga* (Cranium Drum)." *Journal of Museum Ethnography* 10: 125–130.

Thomas, S. 2022. "'Dark' Heritage? Nudging the Discussion." *Heritage & Society* 15 (2): 163–178.

Tsukamoto, A. 1983. "The Music of Tibetan Buddhism in Ladakh: The Musical Structure of Tibetan Buddhist Chant in the Ritual Bskaṅ-Gso of the Dge-Lugs-Pa Sect." *Yearbook for Traditional Music* 15: 126–140.

Vasile, E. C. 2023. Chod: "The Journey Into Cutting the Self." Doctoral diss., University of Manchester.

Weber-Sinn, K., and P. Ivanov. 2020. """Collaborative" Provenance Research – About the (im)Possibility of Smashing Colonial Frameworks." *Museum & Society* 18 (1): 66–81.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S263–S269
https://doi.org/10.1080/00393630.2024.2336792

CRITICAL ASSESSMENT/PERSPECTIVE

Fostering Inclusive Management and Community Participation: Lessons from the Field
Fomento de la Gestión Inclusiva y la Participación Comunitaria: Lecciones del Campo

Stephanie D. Ortiz

World Monuments Fund, Regional Director, Latin America and the Caribbean, NY, New York

ABSTRACT

World Monuments Fund (WMF) is a leading organization dedicated to preserving the world's most cherished cultural sites. In Latin America and the Caribbean, WMF has collaborated with local communities, funders, and governments on over 186 conservation projects since the 1980s, with a strong emphasis on local partnerships and capacity building. Recognizing the importance of community involvement, inclusive management, and diverse heritage narratives, as well as the need to foster this approach in our Latin American portfolio, recent WMF projects there aim to establish models for participatory heritage conservation. Two ongoing projects where WMF is testing this approach focusing on community participation and inclusive management include Teotihuacán in Mexico, where we aim to create the conditions for sustainable and equitable tourism development by fostering collaboration between local and institutional stakeholders. A second case study explores Rapa Nui National Park, where WMF is addressing the preservation of the endangered Mata Ngarahu petroglyphs in Orongo and empowering the Ma'u Henua Polynesian Indigenous Community in conservation efforts. These projects underscore the importance of long-term commitment, flexibility, and cultural sensitivity in promoting participatory approaches, with the need for adapting engagement strategies based on local dynamics. Lessons learned emphasize that successful implementation requires time, consistency, and alignment with local actors, particularly considering potential conflicts with institutional timing and constraints.

World Monuments Fund (WMF) es la organización líder dedicada a preservar los sitios culturales más preciados del mundo. En América Latina y el Caribe, WMF ha colaborado con comunidades locales, financiadores y gobiernos en más de 186 proyectos de conservación desde la década de 1980, con un fuerte énfasis en asociaciones locales y el desarrollo de capacidades. Reconociendo la importancia de la participación comunitaria, la gestión inclusiva y las diversas narrativas patrimoniales, así como la necesidad de fomentar este enfoque en nuestra cartera latinoamericana, los proyectos recientes del WMF tienen como objetivo establecer modelos para la conservación participativa del patrimonio. Dos proyectos en curso donde WMF está probando este enfoque centrado en la participación comunitaria y la gestión inclusiva incluyen Teotihuacán en México, donde nuestro objetivo es crear las condiciones para el desarrollo turístico sostenible y equitativo fomentando la colaboración entre las partes interesadas locales e institucionales. Un segundo estudio del caso explora el Parque Nacional Rapa Nui, donde WMF se ocupa de la preservación de los petroglifos Mata Ngarahu en peligro de extinción en Orongo y empodera a la comunidad indígena polinesia Ma'u Henua en los esfuerzos de conservación. Estos proyectos subrayan la importancia del compromiso a largo plazo, la flexibilidad y la sensibilidad cultural en la promoción de enfoques participativos, con la necesidad de adaptar las estrategias de participación basadas en las dinámicas locales. Las lecciones aprendidas enfatizan que una implementación exitosa requiere tiempo, coherencia y alineación con los actores locales, particularmente considerando posibles conflictos con el tiempo y las limitaciones institucionales.

ARTICLE HISTORY
Received October 2023
Accepted March 2024

KEYWORDS
Community; inclusive management; traditional management; indigenous; participation

Comunidad; gestión inclusiva; gestión tradicional; indígena; participación

Introduction

The field of cultural heritage is continuously evolving to address the needs of and new threats to heritage sites and places, always looking outward and managing change. Yet, in recent years, there has been a marked reckoning from within the field as individuals, groups, and professionals have acknowledged the exclusionary practices that range from selective designation and interpretation to the marginalization of key stakeholders. There is a wider recognition that the field and its impact must be more inclusive, ensuring that a wider variety of heritage places and the communities

CONTACT Stephanie D. Ortiz sortiz@wmf.org World Monuments Fund, Regional Director, Latin America and the Caribbean, 600 Fifth Ave, 25th Floor, New York, NY, 10020

© The International Institute for Conservation of Historic and Artistic Works 2024

linked to them gain recognition and receive the support and technical assistance they need and want.

World Monuments Fund (WMF) is a leading organization devoted to safeguarding the world's most treasured places to enrich people's lives and build mutual understanding across cultures and communities. Since 1965, our global team of experts has preserved the world's diverse cultural heritage using the highest international standards at more than 700 sites in 112 countries. Partnering with local communities, funders, and governments, WMF draws on heritage to address some of today's most pressing challenges: climate change, underrepresentation, imbalanced tourism, and post-crisis recovery.

Around the world, WMF's approach to heritage preservation has consistently been achieved through local partnerships; we understand that our role as an international organization is to help elevate and enhance the efforts of our local partners and provide technical expertise in conservation to build up local capacities through training and collaboration. Looking at our body of work in Latin America, which includes over 186 conservation projects since the 1980s, reveals that WMF has partnered primarily with institutions of authority, such as heritage regulatory agencies, governments, and site managers. WMF recognizes the need for greater community involvement, improved inclusive management, participatory processes, and the incorporation of inclusive narratives and interpretation of heritage sites.

To address this challenge, WMF aims to establish models for inclusive management and participatory processes in heritage conservation, ensuring wider community engagement. The focus of this paper will be on WMF's work in Latin America, analyzing two ongoing projects that exemplify this approach, under the sub-theme of 'The rising role and involvement of communities and different social entities as active caretakers of their heritage'.

One case study focuses on Rapa Nui National Park, on the Chilean island of Rapa Nui, where WMF aims to address erosion and instability issues while supporting the Ma'u Henua Polynesian Indigenous Community – now responsible for managing the park – in conservation and management decision-making. Another takes us to Teotihuacán in Mexico, where WMF's project focuses on the need for inclusive management planning and community participation for sustainable and equitable tourism development in the Teotihuacán Valley.

Teotihuacán

One of the first urban societies in the Americas, Teotihuacán flourished for nearly a millennium until its decline in the sixth century. Scholars estimate that close to 200,000 people lived in the city at its peak, and it is now seen as the most influential urban center in Mesoamerica. Its significance was such that five centuries after the city was abandoned, the Mexicas continued to revere the site, even giving it the name Teotihuacán, meaning 'the city of the gods'. The site's primary monuments include the Pyramid of the Sun, the Pyramid of the Moon, and the Temple of Quetzalcoatl (the Feathered Serpent) located to the southeast of the main Avenue of the Dead (Figure 1). Teotihuacán is deeply linked to the identity and pride of Mexico and is one of the country's most popular attractions, receiving close to 4.5 million visitors each year.

Excavations in the early twentieth century led to the delimitation of the main archaeological zone of Teotihuacán, which covers 281 hectares of land now administered by Mexico's National Institute of Anthropology and History (INAH). The pre-Hispanic city extended well beyond the modern-day limit known as Zone A. The archaeological area encompasses two additional protection zones, spanning 3,381 hectares across two municipalities of the State of Mexico – San Martín de las Pirámides and San Juan Teotihuacán – with an expanding population of over 90,000 residents.

Teotihuacán's structures have long faced deterioration brought on by exposure to the elements, crystallization of soluble salts on the stone surface, erosion, and biological growth. The site has been open to visitors since 1910, posing additional challenges for conservation, interpretation, and tourism management at the site. Beyond the physical fabric of the archaeological site, pressure from tourism and urban expansion have impacted the social dynamics within the surrounding communities.

The tourism model at Teotihuacán is largely based on day trips to the site from Mexico City. Visitors seldom engage directly with the eight communities surrounding Teotihuacán. Over-representation of the heritage of Teotihuacán overshadows the surrounding communities and their needs. As a result, while many residents rely on the site for a subsistence-level income, they also view it as an obstacle to their own development as they demand more public services that impact the site. Many residents of the adjacent towns feel unable to access the economic opportunity that tourism presents and are driven to offer tourism services in an unregulated informal economy. The interruption of tourism at the onset of the Covid-19 pandemic accelerated the rate of encroachment into unprotected areas outside the principal site that contains valuable archaeological remains. Close to 40% of the ground area in Zone B is already occupied by informal construction. The construction of a new international airport just 15 km away will likely bring more tourism and development pressure to the area.



Figure 1. The Avenue of the Dead and the Temple of the Sun in Teotihuacán. Before the Covid-19 pandemic in 2020, millions of visitors climbed the temples of the Sun and Moon at Teotihuacán each year. Access to the structures is now prohibited, potentially benefiting the ancient buildings but impacting visitor numbers. Image: Bill Perry 2015.

The existing site management plan was approved in 2012 and largely focuses on the internal functioning of the site, with little discussion of the needs of the eight communities that surround Teotihuacán. In turn, these communities' social dynamics directly impact the conservation and sustainability of the site, as evidenced by the growing disaffection toward institutions like the INAH, which is perceived by many of the local actors as the sole agent of their plight. There is an evident dispute over the territory as strict restrictions on development in Zone B, surrounding the main archaeological site, have long spurred evasive practices and illegal constructions. This is evidenced by the proliferation of bars, restaurants, and nightlife venues outside the main archaeological site (Figure 2), just a few feet away from the stone pavement that demarcates the boundaries of Zone A, which is federal land.

The dispute also reaches the realm of local identity and archaeological discourse. As water scarcity drove a change in land use practices – from traditionally farming communities to urban development – the ensuing over-reliance on tourism has also changed a long tradition of artisanry in the valley, where artisans and craftspeople create products that sell instead of reflecting their identity.

Within the eight communities surrounding the site, there is a growing sentiment that the so-called experts or archaeologists reinforce a rift between the *teotihuacanos* who built the ancient city and those that currently inhabit the valley. By pitting the accepted archaeological narratives against traditional practices and beliefs, there is a not-so-tacit acknowledgment that Teotihuacán is separate in time and place from the communities that surround it. The designation of San Martin de Las Pirámides and San Juan Teotihuacán as *Pueblos Mágicos* (Magical Towns) sought to acknowledge the cultural significance of these municipalities and drive tourism to the area outside of the archaeological site. The initiative ultimately failed without the proper governance systems to support it; and the livelihoods of residents continue to be inextricably linked in some way or another to the tourism industry driven by Teotihuacán (Delgado Rubio, Rodríguez Terán, and Ortiz Solla 2023).

Teotihuacán was included on the 2022 World Monuments Watch, calling for inclusive management planning (WMF 2022). In 2023 and 2024, WMF embarked on a project to address the lack of social inclusion and lay the foundation for cohesive collaboration between institutional and local stakeholders for sustainable and inclusive development of the Teotihuacán Valley. Moreover, the project aims to activate important legal protection mechanisms that have remained dormant until now.

WMF's project prioritizes working directly with the community or local actors, leading a series of focus



Figure 2. Rapid development in Zone B is encroaching on the boundaries of the core archaeological site. Image: José Alonso Terán Rodríguez 2023.

groups and interviews to better understand the needs and challenges as expressed by them (Figure 3). The process does not happen in a vacuum, and WMF's team is guided by the existing legal framework for Teotihuacán, specifically the 1977 creation of the *Comisión Intersecretarial* (Interdepartmental Commission) and the Presidential Declaration of Protection of 1988, which expanded the areas of protection around the main archaeological area to include Zone B and Zone C. The 1988 declaration was signed by five departments of government, each assuming responsibility for the protection and sustainable development of the Teotihuacán Valley within their own area of authority.



Figure 3. Discussion with *Ejidatarios* (shareholders of common land) of Cerro Gordo in San Martín de las Pirámides. WMF's project team is leading discussions with various local stakeholders, both within and outside the archaeological site. The Ejidatarios in Cerro Gordo presented an ecotourism project to diversify tourism offerings in the valley. Image: José Alonso Terán Rodríguez 2023.

WMF's approach moves away from previous institutional efforts at the site, which sought to tackle community engagement with a top-down approach, where social issues are consulted with the same individuals, methods, and, consequently, results. On the ground, the project is led by Jaime Delgado Rubio, an archaeologist and anthropologist who has studied the social dynamics associated with Teotihuacán and other archaeological sites in Mexico, and José Alonso Rodríguez Terán, a local journalist who has explored the link between Teotihuacán and the surrounding communities, including his own.

During the first year (2023), the project will identify and analyze the values, conflicts, and proposals for change as expressed by local actors from the eight surrounding neighborhoods connected to the Teotihuacán Archaeological Zone, both from within and externally. This is to understand how they take a collaborative or rejecting stance towards conservation policies and the distribution of tourism benefits. We will collect their interests and intentions to be represented in future negotiation forums.

The second year will focus on institutional outreach to government institutions at a local as well as at a federal level, represented by the departments that signed the Declaration of Protection for Teotihuacán in 1988, as facilitated by the *Comisión Intersecretarial* of 1977. Through working groups, we will present the community's assessments, conflicts, and proposals for discussion via strategic community representation.



Figure 4. Aerial view of the Ceremonial Village of Orongo, located between the edge of the cliff and the caldera of Rano Kau (Kau Volcano). The stone houses, petroglyphs carved on the groupings of boulders on the cliff's edge, and the islet of Motu Nui (not shown) are associated with the *tangata manu* (birdman) cult – the annual ceremony representing the transfer of power between competing clans. Image: Alberto Castel Rapu 2022.

The expected outcome of the project is to establish common goals between the local and institutional actors, the reactivation of the *Comisión Intersecretarial*, and renewed commitment for the sustainable development of the Teotihuacán Valley.

Rapa Nui

Easter Island, known locally as Rapa Nui, is most famous for the hundreds of *moai* statues scattered throughout its coastline. A special territory of Chile that was annexed in 1888, the entire island, located in the southeastern Pacific Ocean, is protected within the UNESCO World Heritage site of Rapa Nui National Park. The ceremonial village of Orongo, in the south of the park, is considered among the most spectacular archaeological sites in the world.

Orongo (Figure 4) was the focal point of the *tangata manu* (birdman) cult that developed at the end of the seventeenth century, and the Mata Ngarahu petroglyphs, of which there are over 1,700, played a vital role in ceremonies associated with this cult. The site occupies a narrow strip along the crater rim of the Rano Kau volcano, with steep cliffs on one side plunging down 300 m to the sea, and an equally steep incline on the other side going down to the caldera base.

WMF has a long history of engagement at Rapa Nui, with over 18 conservation campaigns spanning from the 1960s until 2011. Previous work has covered all aspects of conservation, from physical interventions to management and conservation planning, from training, workshops, and research to improving visitor infrastructure and interpretation, including the creation of the visitor center at Orongo.

In 2017, the Chilean National Forestry Service (CONAF), in charge of managing the Rapa Nui National Park since 1935, signed an agreement of association, in which the local Rapa Nui people through the Ma'u Henua Indigenous Community group will manage the National Park, taking charge of collecting entry fees and the administration of funds, as well as maintenance and care of public spaces.

The Ma'u Henua Polynesian Indigenous Community group nominated Rapa Nui National Park to the 2020 World Monuments Watch, identifying two main concerns, particularly regarding the Mata Ngarahu Petroglyph Site. On the technical side, the concern was for the advanced level of erosion of the slope and crater rim on which the petroglyph blocks are located, which has caused some blocks to fall in the past. Instability in this area has been a concern since at least 1995 when WMF organized the first mission to inspect the condition of Mata Ngarahu. A key social concern expressed in the nomination was the need to support local heritage conservation and management capacities and decision-making.

The project developed jointly by WMF and Ma'u Henua addresses the technical and social challenges expressed by Ma'u Henua (WMF 2020). WMF hired consultants from Arup to provide heritage conservation, geotechnical, and engineering-geological support to diagnose and propose risk management

recommendations for ground stability issues affecting the Mata Ngarahu petroglyph site at Orongo Ceremonial Village. Based on the findings of the desk studies and field verification carried out in 2021 and 2022 (phases 1 and 2), the Arup consultants developed a series of priority recommendations, including slope and boulder stabilization and risk mitigation measures. To support local heritage conservation and management capacities and decision-making, WMF's team of specialists continuously presented the project process and the different scenarios or possibilities of actions to implement at the site, recognizing that the Rapanui needed to decide on the appropriateness and viability of any recommended major interventions. Beyond Orongo, a series of stakeholder meetings assessed the needs and conservation priorities for Rapa Nui National Park and its stewards, which would help develop a roadmap for future engagement by WMF.

The activities planned for phase 3 from October 2023 to May 2024 help advance WMF's main project objective of addressing the advanced level of erosion and instability of the slope, boulders, and petroglyphs of Mata Ngarahu and contribute to the empowerment of the Ma'u Henua Polynesian Indigenous Community in conservation and management decision-making. WMF's team of consultants will work alongside Ma'u Henua to facilitate a series of workshops to develop a risk and emergency management plan for Rapa Nui National Park, with a particular focus on Orongo, where we have obtained detailed assessments from earlier phases of work. A key consideration is that the risk and emergency management plan must be by the Ma'u Henua Polynesian Indigenous Community with collaboration from the Secretaría Técnica Rapa Nui, CONAF, and other relevant stakeholders. A second component involves concerted community outreach to share the different slope and boulder stabilization and mitigation measures identified in phases 1 and 2, with the objective of reaching a formal agreement or consensus with the Rapanui, and development of an implementation plan for any selected major intervention.

WMF's current engagement at Rapa Nui is centered on a fundamental acknowledgment of Ma'u Henua as a partner rather than a stakeholder or client. The work is based on joint fact-finding, collaborative project and workshop development, continuous engagement with multi-sectoral actors, and a commitment to transparency rooted in local customs (Figure 5). Furthermore, WMF strives to be a model of collaboration by fostering open communication and a strong commitment to building upon and connecting with the initiatives of partners like UNESCO and CyARK, who are also working in Rapa Nui, to break the historical cycle of redundancy in heritage conservation efforts.



Figure 5. The project at Orongo focuses on collaborative work and joint fact-finding between the World Monuments Fund, Ma'u Henua, and other local heritage professionals and residents. Image: Matthew Free 2022.

The National Park covers over 40% of the island. Its management was restored to the local indigenous community without a dedicated support system or foundation to effectively manage it. The Rapanui, represented by the Ma'u Henua Indigenous Community group, are now responsible for approximately 20,000 archaeological sites located within the park boundaries, featuring nearly 1,000 *moai*, 300 ceremonial structures, stone dwellings, rock art, and caves (Comunidad Indígena Ma'u Henua 2020). It will take several years to develop a sustainable management and conservation system. To ensure the impact and sustainability of WMF's engagement at Rapa Nui, it is imperative to support the development of local capacities in heritage conservation and management. Acknowledging this, WMF endeavors to continue its long legacy of engagement at Rapa Nui, committing to support the traditional landscape management by the Ma'u Henua.

Learning and looking forward

The success of any participatory approaches applied to projects can only be ascertained in the medium to long term and are contingent upon local partners and stakeholders carrying the work forward. At the time of writing this paper, both projects are still underway, and conclusions about their efficacy cannot be drawn. However, some lessons gleaned at this early stage of work highlights the need for flexibility and cultural sensitivity, acknowledging the dynamic nature of communities will require adapting how we approach and communicate with each group and build relationships.

A key takeaway is that promoting a participatory approach will look different based on the nature of the site and local dynamic. A commonality that can be drawn is that this kind of work takes time and

consistency in engaging local actors. This local timing can often be at odds with institutional timing, budget constraints, and donor demands, and will impact the results that can be achieved in the short term. Given the way organizations like WMF operate and develop targeted projects on a short-term basis, our engagement is a first step to creating the conditions for a more participatory approach and working with the relevant stakeholders to carry the work forward. This is particularly true of the case of Teotihuacán, where our past efforts at the site have centered on physical conservation interventions and where there are deeply rooted biases and rifts between local and institutional actors. By contrast, our long legacy of engagement in Rapa Nui positions us as a trusted partner, a position that was reinforced by the direct invitation by the indigenous administrators of the site to engage at Rapa Nui once again, based on the needs and challenges that they identified.

Through the implementation of these projects, the organization has also gained valuable insights regarding our role that will have a direct impact on shaping future projects. WMF acts as a trusted facilitator to engage participants in the meaningful development and management of a wide range of cultural heritage issues. As leaders in the cultural heritage community, we must guide the approach and discussion relating to representations of heritage, to address long-standing power imbalances through project selection and development that improves access to expertise, planning, and communication platforms for communities, through the implementation of targeted programs that incorporate local knowledge systems, inclusive narratives, and recognition of historic marginalization (Cuss and Bell 2023)

We continue to refine our approach, learning from methods applied in our projects, such as the ones described here, and building our capacity to better understand and develop solutions together with our community-level partners. Moreover, we recognize that we, too, need to adapt and grow our own understanding and capacity to develop and implement participatory projects.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Comunidad Indígena Ma'u Henua. 2020. Recovering the Administration of Ancestral Land: The Establishment of the Indigenous Community Ma'u Henua, Stewards of Rapa Nui National Park, Chile. Accessed March 2024. https://panorama.solutions/en/solution/recovering-administration-ancestral-land-establishment-indigenous-community-mau-henua.

Cuss, A., and J. S. Bell. 2023. *Inclusive Heritage Strategy. Unpublished report*. World Monuments Fund.

Delgado Rubio, J., J. A. Rodríguez Terán and S.D. Ortiz Solla. 2023. *Avances del Proyecto: Teotihuacán* (Informe de octubre 2023). Unpublished report, World Monuments Fund.

WMF. 2020. *Easter Island (Rapa Nui) - Orongo*. World Monuments Fund. Accessed March 2024. https://www.wmf.org/project/easter-island-rapa-nui%E2%80%94orongo.

WMF. 2022. *Teotihuacán*. World Monuments Fund. Accessed March 2024. https://www.wmf.org/project/teotihuacan.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S270–S280
https://doi.org/10.1080/00393630.2024.2336880

ORIGINAL RESEARCH OR TREATMENT PAPER

OPEN ACCESS Check for updates

Green Alternatives for Archaeological Iron Stabilization

Alternativas Verdes para la Estabilización del Hierro Arqueológico

Patrycja Petrasz[1,2], Sami Zhioua[2], Sarah James[3], Saskia Bindschedler[2], Pilar Junier[2] and Edith Joseph[1]

[1]Haute Ecole Arc Conservation Restauration, University of Applied Sciences and Arts HES-SO, Neuchâtel, Switzerland; [2]Laboratory of Microbiology, Institute of Biology, University of Neuchâtel, Neuchâtel, Switzerland; [3]Laboratory of Technologies for Heritage Materials (LATHEMA), University of Neuchâtel, Neuchâtel, Switzerland

ABSTRACT

One of the most challenging types of artifact occurring within museum collections is unstable chloride-contaminated archaeological iron. A high chloride concentration causes cracking, flaking and leads to full mineralization, in effect making objects fragile. Consequently, removal of chloride ions plays a key role in stabilization treatment, while preserving the integrity of the corroded iron object. Despite the variety of stabilization methods, all have significant disadvantages, including a lack of sustainability. Within the framework of the Horizon Europe project GoGreen the potential of microbial biosorption to stabilize archaeological iron artefacts is being investigated. Dry biomass of the fungi *Meyerozyma* sp. and *Saccharomyces cerevisiae* was studied to remove chloride ions. Preliminary tests were carried out on artificially-aged steel samples. To assess the activities of the microorganisms' functional groups and biosorption capabilities as a potential green stabilization treatment, analytical techniques including FTIR, Raman spectroscopy, and SEM-EDX were used. The results demonstrate two promising paths for the development of green stabilization treatments based on fungal biomass: passive adsorption into the cell wall and conversion of reactive corrosion products into more stable compounds. The use of microbial biomass opens up promising perspectives for the development of more sustainable solutions in archaeological iron stabilization, while avoiding the generation of toxic waste in our environment.

Uno de los tipos de artefactos más desafiantes que se encuentran en las colecciones de los museos es el hierro arqueológico inestable contaminado con cloruro. Una alta concentración de cloruro provoca grietas, descamación y conduce a una mineralización completa, lo que de hecho vuelve los objetos frágiles. En consecuencia, la eliminación de iones cloruro juega un papel clave en el tratamiento de estabilización, preservando al mismo tiempo la integridad del objeto de hierro corroído. A pesar de la variedad de métodos de estabilización, todos tienen desventajas importantes, incluida la falta de sostenibilidad. En el marco del proyecto GoGreen de Horizonte Europa, se está investigando el potencial de la biosorción microbiana para estabilizar artefactos arqueológicos de hierro. Biomasa seca de los hongos *Meyerozyma* sp. y *Saccharomyces cerevisiae* fue utilizada para eliminar iones cloruro. Se llevaron a cabo pruebas preliminares con muestras de acero envejecidas artificialmente. Para evaluar las actividades de los grupos funcionales de los microorganismos y las capacidades de biosorción como posible tratamiento de estabilización verde, se utilizaron técnicas analíticas que incluyen FTIR, espectroscopía Raman y SEM-EDX. Los resultados demuestran dos caminos prometedores para el desarrollo de tratamientos de estabilización ecológicos basados en biomasa fúngica: la adsorción pasiva en la pared celular y la conversión de productos reactivos de corrosión en compuestos más estables. El uso de biomasa microbiana abre perspectivas. prometedoras para el desarrollo de soluciones más sostenibles en la estabilización del hierro arqueológico. evitando al mismo tiempo la generación de residuos tóxicos en nuestro entorno.

ARTICLE HISTORY
Received October 2023
Accepted March 2024

KEYWORDS
Green chemistry; chlorides; archaeological iron; micro-organisms; bio-based stabilization

Química verde; cloruros; hierro arqueológico; micro organismos; estabilización de base biológica

Introduction

Archeological iron artifacts undergo complex corrosion phenomena (Simon et al. 2019) and their structure may vary depending on the burial environment: terrestrial or marine. One of the major causes of iron artifacts' instability is contamination with chlorides (Watkinson 2010) which are the main corrosion accelerator (Rimmer, Watkinson, and Wang 2012). A high chloride concentration causes cracking, flaking and leads to full mineralization, in effect making the

CONTACT Patrycja Petrasz patrycja.petrasz@he-arc.ch Haute Ecole Arc Conservation Restauration, University of Applied Sciences and Arts HES-SO, Neuchâtel 2000, Switzerland; Laboratory of Microbiology, Institute of Biology, University of Neuchâtel, Neuchâtel 2000, Switzerland

© 2024 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group
This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (http://creativecommons.org/licenses/by-nc-nd/4.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

objects fragile. Consequently, removal of chloride ions plays a key role in stabilization treatment, while preserving the integrity of the corroded iron object (Drews et al. 2013). Despite evidence that chloride ions may be found in any type of archeological iron artifacts, this article focuses exclusively on iron artifacts recovered from burial environments since their corrosion structure is well studied and better understood.

During burial iron corrodes by an electrochemical process (Selwyn 2004) in which chloride ions are attracted by Fe^{2+} at anodic sites on the metal surface (Watkinson 2010). As a result of ongoing iron corrosion during burial, acidic iron(II) chloride is produced (Turgoose 1993). Recovered, iron artifacts containing acidic iron(II) chloride while exposed to lower relative humidity (RH) and higher oxygen will develop further corrosion, which causes cracking and structural damage (Comensoli et al. 2017). Additionally, in favorable conditions such as the presence of high chloride concentration at low pH the formation of unstable chloride-containing corrosion products such as akaganeite and iron(III) oxyhydroxides is induced (Reguer et al. 2009; Selwyn 2004).

Stabilization of archaeological iron is therefore an essential step in the conservation treatment to prevent the development of further corrosion. In current practice, the primary emphasis is on removing chlorides from artifacts by dechlorination methods. Among the most common and effective treatments are sodium hydroxide and sodium sulphite baths (Kergourlay et al. 2018). During immersion the reduction of corrosion compounds occurs allowing the passive diffusion of soluble chloride ions (Comensoli et al. 2017). Despite the many advantages of this technique, there are also drawbacks regarding efficiency, waste neutralization, human health concerns (Comensoli et al. 2017), and in some cases, occurrence of post-treatment corrosion.

In the past two decades global interest in ethical environmental practices in the cultural heritage field has arisen, following the United Nations climate change policies (Kampasakali et al. 2021). Among the most important points presented in these policies is the need for improvement regarding health and safety, environmental impact, carbon footprint of the products as well as waste management. In certain conservation specializations, a first step has already been made towards green conservation by introducing green materials such as biodegradable solvents, bio-based chelates, bio-originated gels, enzymes and microorganisms. Nevertheless, none of these materials can be successfully applied for archeological iron stabilization. Therefore, considering the drawbacks of currently-used archeological iron stabilization methods mentioned above, green conservation faces the challenge of creating effective iron stabilization treatments, while meeting the latest ethical criteria concerning sustainability.

Research in the field of biotechnology opens up a new opportunity for iron dechlorination using the physicochemical abilities of microorganisms. Biosorption, which utilizes passive adsorption of non-living or living biomass to bind ions to the cell's surface, is one of the possible pathways. This approach has been extensively studied in many domains with successful results in removal efficiency of various pollutants such as heavy metals, phenols, fluoride and dyes (Michalak, Chojnacka, and Witek-Krowiak 2013). Biosorption technologies present- good prospects as they are inexpensive, time efficient, and eco-friendly. Despite all the advantages, it is important to mention that biosorption is very complex and it is affected by many factors: pH, contact time, competition with other pollutants, large surface area, high porosity, type and amount of functional groups as well as the cell structure. Therefore, it is important to consider these criteria in the choice of fungal strain and to determine the conditions that will allow interaction between biomass and pollutant.

This study investigates the possibility of using dry biomass from the fungi *Meyerozyma* sp. and *Saccharomyces cerevisiae* as an alternative sustainable treatment for iron stabilization by biosorption. In the first stage the pH and electrode potential of artificially-aged iron and dry biomass were analyzed to predict favorable conditions for biosorption of chloride ions without interfering with the structure of the iron artifacts. Afterwards, biosorption experiments were conducted to investigate passive adsorption in the selected fungi and the processes that influence efficiency. Due to the preliminary character of these experiments, only artificially-aged iron samples were utilized.

Material and methods

Artificially-aged iron samples

Description of samples

The test samples used in the study were artificially-aged steel coupons, size 10 × 10 × 1 mm. Simulation of archeological iron corrosion was based on an aging protocol presented by Glotch and Kraft (2008) that includes a pretreatment step with 0.2M $FeCl_3$, followed by wet/dry cycles in a climatic chamber (wet – 24 h at 30°C with 80–100% RH and dry – 24 h at 30°C with 50–60%RH). To allow akageneite synthesis, NaOH spray was introduced during the first wet cycle phase.

Elemental composition

To determine the elemental composition of the test samples before and after the experiment, X-ray fluorescence spectroscopy was performed using a Niton XL3t GOLDD+ XRF analyzer coupled with helium flow and using a light range filter (0–12 keV) to permit the

detection of light elements, including chlorine. Acquisition time was 3 min.

Molecular characterization

The chemical composition was analyzed with a Renishaw Virsa Raman system. Spot measurements were conducted at room temperature with a 785 nm diode excitation laser, 50× objective and a spectral resolution of ~2 cm^{-1}. In order to avoid excessive heating and potential transformation of iron compounds, the laser power was set to 2–5 mW (Azoulay et al. 2013). Raman spectra were recorded with an acquisition time between 2 and 10 s with 5–20 accumulations. The interpretation of the Raman spectra was performed by comparison with published scientific data and commercial spectra libraries (Vietti et al. 2022).

Preparation of dry biomass

Fungi strains

The selection of yeast strains was based on literature studies. The choice of a strain of *Meyerozyma* spp. was dictated by a fast growth rate (between 2 and 7 days), a large surface area, and high tolerance towards a saline environment that gives promising prospects for chloride ion removal (Amorim et al. 2018; Navarro-Arias et al. 2019). *Saccharomyces cerevisiae* is characterized by a large surface area (Ivanova et al. 2020), porous cell wall (Hu et al. 2019) as well as the ability to under go meiosis (Paulissen et al. 2020) that makes it also an attractive candidate for biosorption studies. Another advantage of *S. cerevisiae* is that it can be obtained as a waste product from beer production, making it easily accessible and inexpensive.

Preparation

Pre-cultures of *Meyerozyma* sp. and *S. cerevisiae* beer waste were provided by the laboratory of microbiology of Neuchatel University. To produce sufficient amounts of dry biomass, *Meyerozyma* sp. was inoculated in liquid malt broth (15 g malt per liter of deionized water) and cultured for 10 days. The resultant yeast culture was autoclaved and washed twice with deionized water. Following 60 min storage at − 80°C, biomass was then transferred to a freeze-dryer for 32 h. The frozen biomass was then ground using a pestle and mortar and sieved to a fine powder with particle size of 125 µm. The described protocol was applied to both *Meyerozyma* sp. and *S. cerevisiae* beer waste biomass.

Strains characterization

The cell wall surface morphology was examined before and after the experiment using scanning electron microscopy (SEM) coupled with energy-dispersive X-ray spectroscopy (EDS). Biological samples were gold-coated prior to observations. Working conditions were 20 kV electron acceleration voltage and a working distance of 5–7 mm.

To identify the chemical functional groups present in the cell wall, and their role in the biosorption process, Fourier transform infrared spectroscopy (FTIR, using a Thermo Fisher Scientific Nicolet iN10 microscope) was employed in attenuated total reflection mode (using a germanium ATR crystal). The infrared spectra were collected in the range 4000–650 cm^{-1} with 16 scans and a spectral resolution of 4 cm^{-1}. Spectral interpretation was focused on three regions: 2700–3300 cm^{-1} for fatty acids, 1500–1800 cm^{-1} for proteins and peptides, and 600–900 cm^{-1}, as fingerprint regions for microorganisms (Lasch and Naumann 2000).

Determination of pH of point of zero charge (pH_{PZC})

The pH_{PZC} of *Meyerozyma* sp. and *S. cerevisiae* was determined on dry biomass by the salt addition technique (Al-Maliky, Gzar, and Al-Azawy 2021). In a series of 50 ml Sovirel bottles, 25 ml of 0.1M NaCl solution was added and adjusted to pHs of 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 by the addition of few drops of 0.001M NaOH and/or 0.001M HCl. Then 0.05 g of dry biomass was added to each of the pH-adjusted solutions and agitated at 120 rpm for 24 h. Afterwards, the final pH was measured with a digital pH meter. The pH_{pzc} was obtained by plotting ΔpH, the difference between the initial pH of the adjusted NaCl solution (pH_i) and the final pH measured 24 h after the addition of the dry biomass (pH_f), *versus* the initial pH. The pH_{pzc} is the point at which ΔpH = 0.

Biosorption experiment

Tests on artificially-aged iron samples were carried out by immersion in deionized water with dry biomass. In preliminary tests, the dissolution rate of released chloride into water was measured to estimate when the biomass should be introduced. Adsorption capacity and factors that influence adsorption rate were observed by varying the contact time between 15, 30, 45, 60, 90, 120 and 150 min. The bottles were agitated at 120 rpm. For biosorption studies, artificially-aged iron samples were placed in 50 ml Sovirel bottles and 40 ml of deionized water adjusted to pH7 was added. Afterwards, the biomass was collected, filtered and dried in a freeze dryer for 12 h to perform SEM and FTIR analyses. To ensure the reliability of the collected data all tests were run in triplicates.

The efficiency of chloride adsorption was calculated according to following equation:

$$\text{Biosorption efficiency } \% = \frac{C_o - C_e}{C_o} \times 100$$

where C_o is the initial concentration in solution and C_e

is the equilibrium concentration of chlorides released after immersion of the artificially-aged iron samples.

Chloride quantification

The concentration of chloride ions released into the solution was measured using a Hach DR3900 spectrophotometer with LCK311 (mercuric thiocyanate) reagent. Iron concentration was determined by ferrozine assay (Stookey 1970) with a Shimadzu UV-1601 spectrophotometer.

Results

Determination of optimal conditions for the biosorption experiment

pH and Pourbaix diagram

The Fe-H_2O-Cl^- Pourbaix diagram was analyzed to find the optimal conditions of pH and Eh to perform the biosorption experiments. The aim of this analysis was to identify parameters that promote the extraction of harmful ions (Cl^-) without interfering with iron stability. According to the values observed on the diagram, the region between pH 6–8 and Eh −0.65 to −0.22 V was determined to be the most promising area (Figure 1(a)).-(a)). These values were compared with the values of pH of point of zero charge obtained from both fungal biomasses. This allowed us to find pH values that would be in the favorable region for interactions with soluble Cl^- presented in the diagram. From the Pourbaix diagram and the results obtained for both fungi, pH 7 was chosen for the biosorption experiments (Figure 1 (b)) and (c).

Contact time

The effect of *S. cerevisiae* contact time on chloride and iron ions biosorption was investigated for 150 min. After this period a shift in the solution pH level was noticed, with the initially measured pH of 7 dropping to 4.4. Processes of adsorption and desorption were observed in the 150-minute experiment. The concentration of chloride ions in the solution increased and decreased regularly (Figure 2(a)). A similar pattern was observed when measuring iron ions present in solution. Additionally, it was observed that with increasing contact time, the solution turned from bright

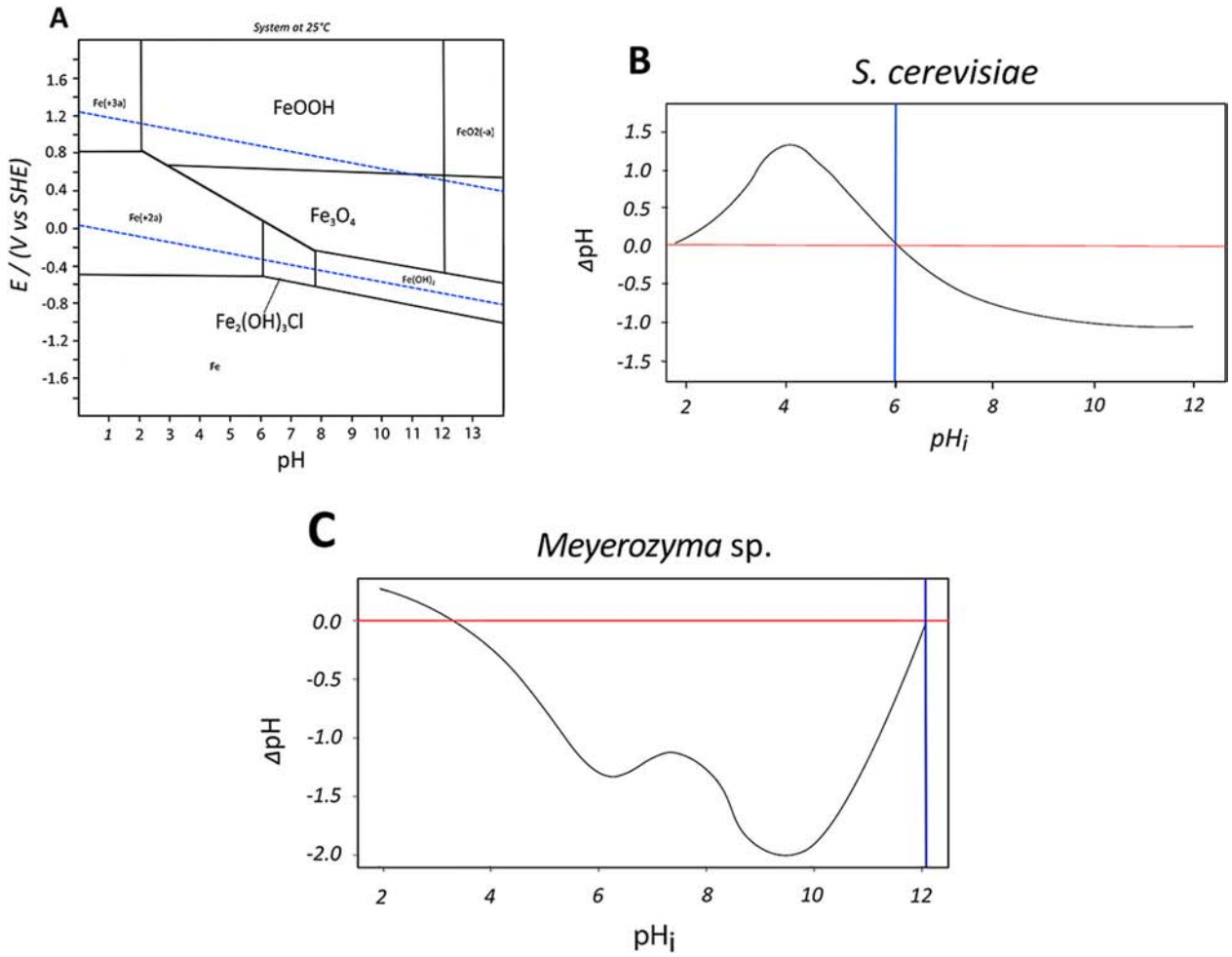


Figure 1. (a) E/pH diagram of Fe-H_2O-Cl^- Diagram was generated using the thermodynamic data published in Rémazeilles et al. 2009, (b) plot of pH_{pzc} for *S. cerevisiae*, and (c) for *Meyerozyma* sp. The pH_{pzc} value is calculated at the intersection of the red and blue lines.

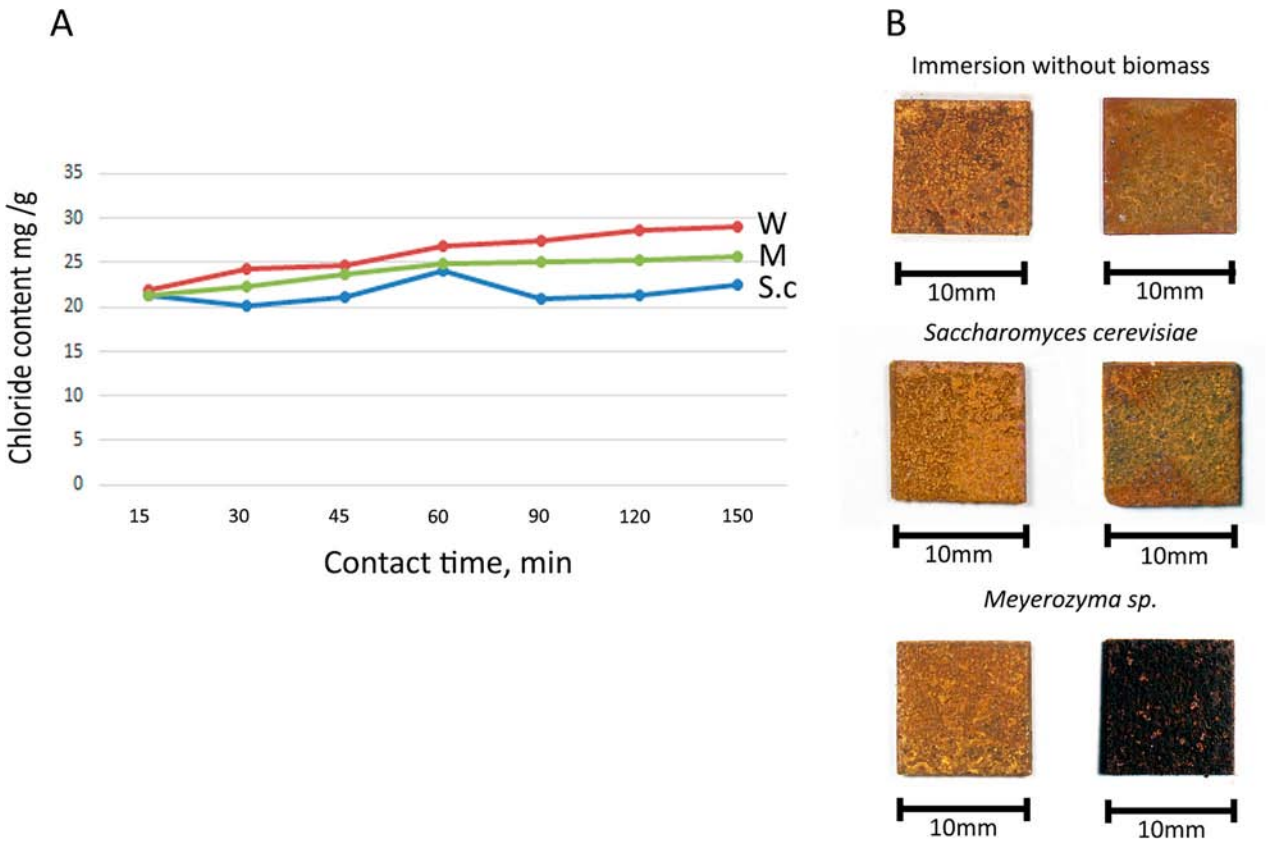


Figure 2. (a) Effect of contact time for biosorption effectiveness: w – immersion without biomass, M – with *Meyerozyma* sp., S.c – *S. cerevisiae*; (b) Surface aspect of the iron samples before and after treatment observed after 150 min of contact time.

orange to transparent. The surface aspect of the iron samples also changed. The initial dark orange corrosion layer (i.e. akaganeite) became less uniform, and the presence of a blue, green, yellow layer was observed (Figure 2(b)). These phases were identified as mixture of lepidocrocite, magnetite and akageneite by Raman spectroscopy (Figure 3).

When the same experiment was carried out with *Meyerozyma* sp. biomass, biosorption capacity was not altered as the contact time increased For the first 90 min, the chloride ion concentration increased and then some adsorption was observed, with an average of 0.2 mg/g (Figure 2(a)). The pH of the solution dropped from 7 to 4, as in the case of *S. cerevisiae*. The color of the solution also shifted during the experiment from vivid orange to translucent. The use of *Meyerozyma* sp. dry biomass also resulted in a change in the artificially-aged iron surface appearance (Figure 2(b)). In this case, the surface went from a dark orange corrosion product to a black uniform and slightly powdery layer identified as magnetite by Raman spectroscopy (Figure 3).

Biosorption Raman spectroscopy analysis

Before the experiment, Raman analysis of artificially-aged iron samples indicates that the main phase occurring on the surface is akageneite with typical vibrational bands identified at 140, 310 and 390 cm^{-1}, and additional weak peaks observed at 121, 205, 487, 537, 607, 720 and 910 cm^{-1} (Figure 3(a)). Peaks at 310 and 390 cm^{-1} are assigned to Fe– O vibration mode of Fe octahedrons present in its structure (Richmond et al. 2004). The third peak at 140 cm^{-1} is likely to correspond to Fe – Cl. Raman peaks observed at 535, 722 and 921 cm^{-1} could be assigned to Fe– OH asymmetric stretching (Szybowicz et al. 2015).

Artificially-aged iron coupons treated with *Meyerozyma* sp. showed a transformation of the corrosion products present on the surface from akageneite to magnetite (Figure 3(b)). An intense peak was noticed at 670 cm^{-1} as well as two weak peaks at 311 and 530 cm^{-1}, all indicating the presence of magnetite.

In comparison to *Meyerozyma* sp., artificially-aged iron samples exposed to *S. cerevisiae* dry biomass presented a less uniform surface appearance after treatment, and corrosion products such as akaganeite and lepidocrocite mixed with goethite were identified (Figure 3(c)). The mixture of lepidocrocite and goethite was characterized by the presence of intense peaks at 249, 299, 384 and 670 cm^{-1} and weak peaks at 485 and 527 cm^{-1} (Cambier, Verreault, and Frankel 2014).

SEM-EDX

To assess if changes occurring on the iron samples surfaces were related to interaction with the biosorbent, SEM-EDS was carried out on biomass of both yeast

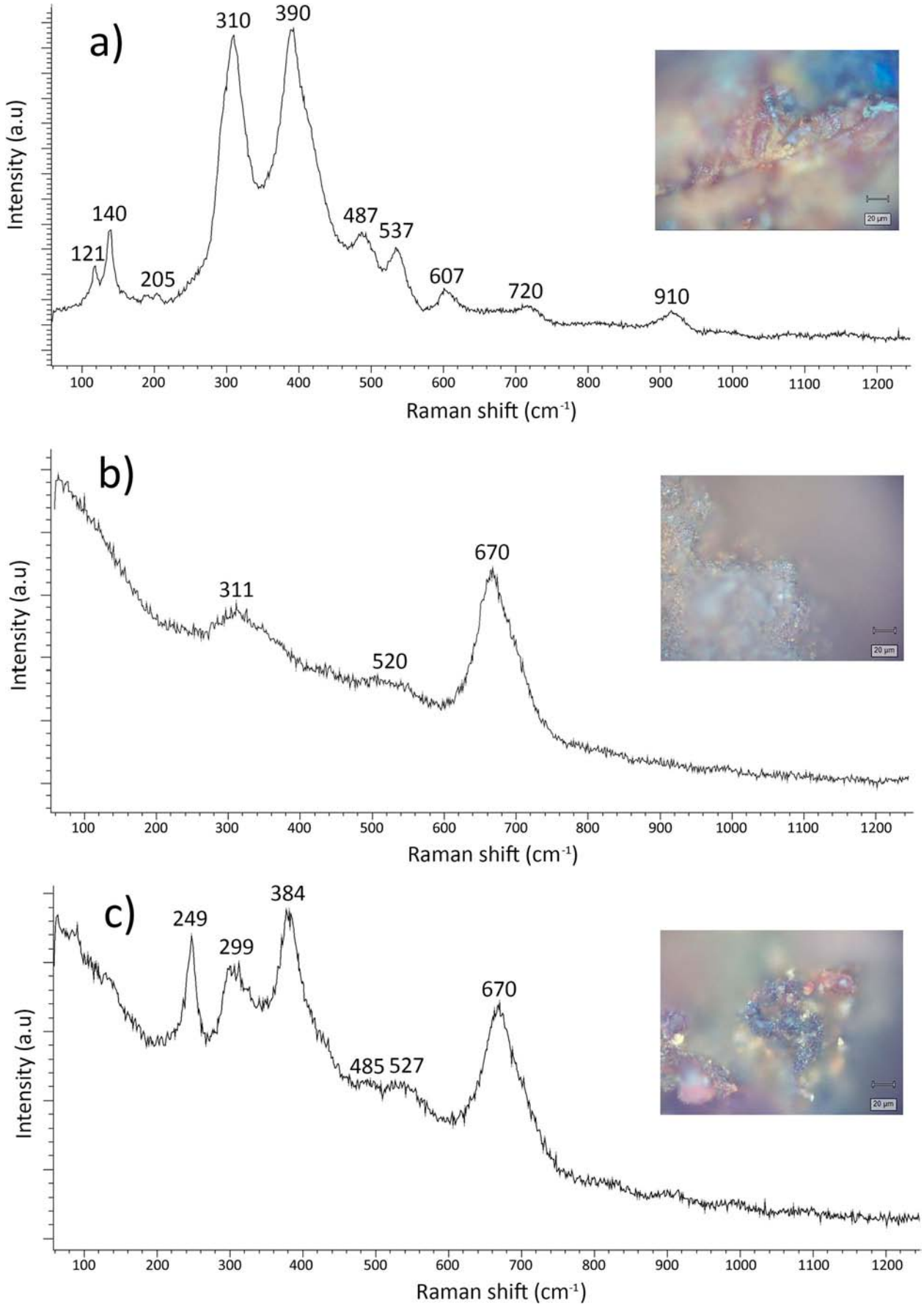


Figure 3. Raman spectra. (a) artificially-aged iron coupon before contact with biomass, (b) after exposure to dry biomass of *Meyerozyma* sp. (c) after exposure to dry biomass of *S. cerevisiae*. Instrumental settings: 785 nm, 3 mW, 7 s, 15 accumulations.

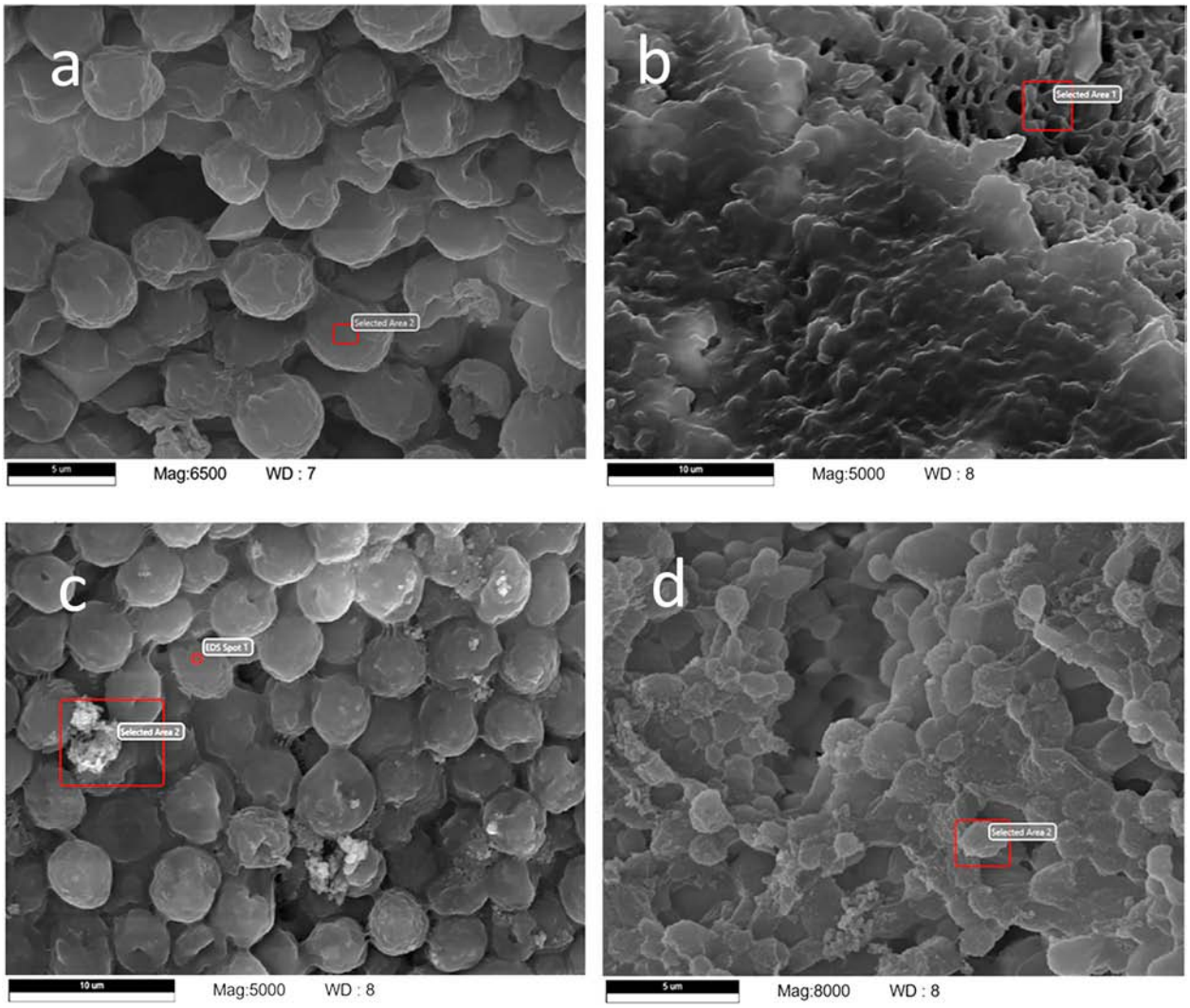


Figure 4. SEM images of dry biomass of (a) *S. cerevisiae* and (b) *Meyerozyma* sp. before biosorption; and of (c) *S. cerevisiae* (d) *Meyerozyma* sp. after biosorption. Areas outlined in red indicate the EDX analysis sites.

strains. During observation of *S. cerevisiae*, irregularity and roughness of the cell wall was clearly spotted on untreated dry biomass. In several areas cracks were visible on the cell wall (Figure 4(a)). This may be associated with the process of drying biomass at high temperature (Cutz et al. 2021).

The surface morphology of the cell wall changed after being in contact with artificially-aged iron samples. SEM images showed a smoother surface and a complete disappearance of cracks after the experiment (Figure 4(c)). EDS analysis confirmed the presence of chloride in both untreated and treated biomass. Additionally, in the sample treated with *S. cerevisiae* a new element – iron – was observed. Higher contents of this element were localized in the brighter spots (Figure 4(c)).

The same protocol was used to observe the *Meyerozyma* sp. cell wall. SEM images of fungal dry biomass revealed a porous and rough surface with many voids before the biosorption experiment (Figure 4(b)). After exposure to artificially-aged iron samples, *Meyerozyma* biomass showed distinct changes on the cell wall surface that became swollen and covered with bright small particles (Figure 4(d)). Changes in the elemental composition were recorded with EDS. Analysis after biosorption showed the presence of two additional elements, iron and chloride. Additionally, these results indicated that the biosorption of iron was almost five times higher than the biosorption of chloride.

FTIR

FTIR spectra of biomass of *S. cerevisiae* and *Meyeroyzma* sp. were recorded before and after the experiments to identify the functional groups potentially involved in the process of biosorption. FTIR spectra revealed highly complex molecular structures for both *Meyrozyma* sp. and *S. cerevisiae* strains (Table 1). After the biosorption experiment, for both fungi, shifts in wavenumbers and relative intensity were observed.

FTIR spectra of *S. cerevisiae* biomass revealed involvement of several functional groups such as hydroxyl groups – OH, amines – NH_2, amides $RCONH_2$, and alkyl chains – CH_2, – CH_3. Also, C = O, amide III and

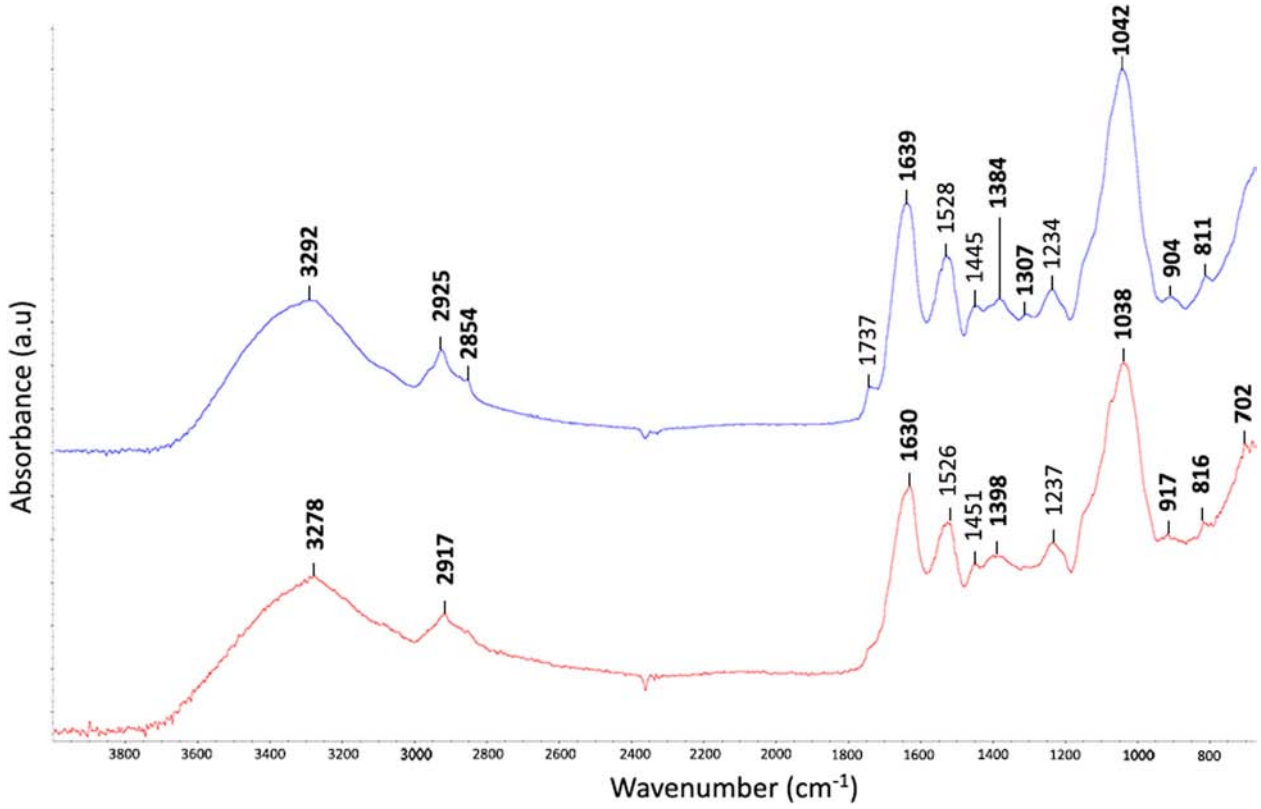


Figure 5. FTIR spectra of dry biomass of *S. cerevisiae* before biosorption (red) and after immersion with artificially-aged iron sample (blue). Shifts in wavenumbers or relative intensity are indicated in bold.

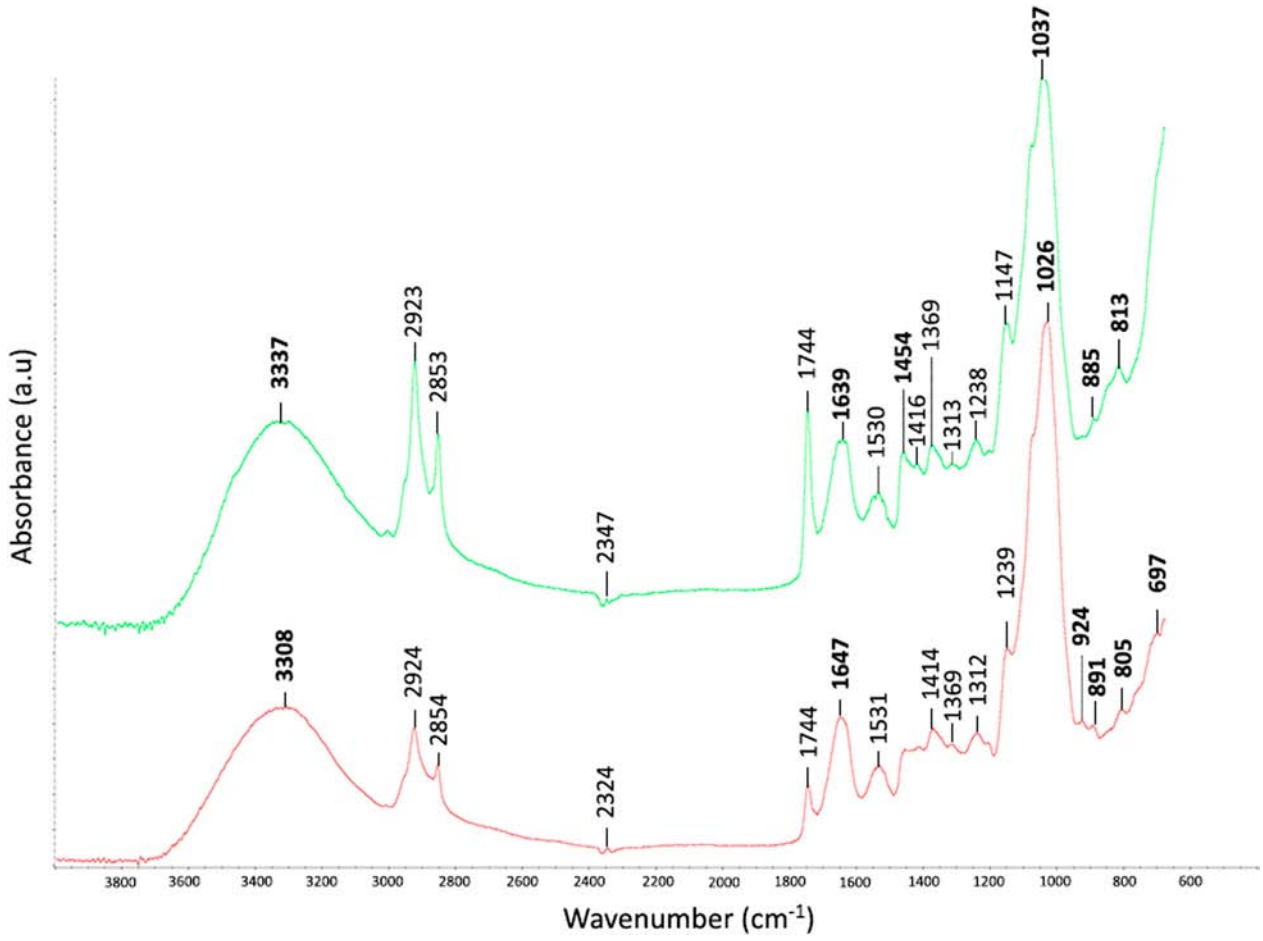


Figure 6. FTIR spectra of dry biomass of *Meyerozyma* sp. before biosorption (red) and after immersion with artificially-aged iron sample (green). Shifts in wavenumbers or relative intensity are indicated in bold.

Table 1. FTIR peak assignment for *S. cerevisiae* and *Meyerozyma* sp. before and after the biosorption experiment.

S. cerevisiae Wavenumbers (cm^{-1})		Meyerozyma sp. Wavenumbers (cm^{-1})		
Dry biomass	Exposed dry biomass	Dry biomass	Exposed dry biomass	Functional group assignment
3278	**3292**	**3308**	**3337**	**O–H and** amines N–H stretching vibration
2917	**2925**	2924	2923	CH_2, CH_3
–	2854	2854	2853	CH_2, CH_3
–	–	2342	2347	CO_2
–	1737	1744	1744	C=O
1630	**1639**	**1647**	**1639**	**Amide I**
1526	1528	1531	1530	Amide II
1451	1445	–	**1454**	CH_2
–	–	1414	1416	C–N
1398	**1384**	1369	1369	$C(CH_3)_2$ symmetric
–	**1307**	1312	1313	Amide III
1237	1234	1239	1238	ν(P=O) asymmetric
–	–	1148	1147	δ(COP), ν (CC), δ(COH)
1038	**1042**	**1026**	**1037**	νC–O of polysaccharides nucleic acids, polysaccharides skeleton –C–OH
917	**904**	**924**	–	Carbohydrates
–	–	**891**	**885**	glycosidic linkage
816	**811**	**805**	**813**	C – H bonds
702	–	**697**	–	C – C twisting

Note: Green color indicates bands with observed shifts of wavenumbers.

polysaccharide bands had changed relative intensity after the biosorption experiment (Figure 5).

The results obtained with *Meyerozyma* sp. biomass suggested that an ion exchange process could be associated with hydroxyl groups, primary and secondary amines, amides and polysaccharides, as indicated by the shift in wavenumbers after the experiment. Additionally, changes in relative intensity of C = O and amide II bands were observed, which implied that these functional groups may also play a role in the biosorption process (Figure 6).

XRF

XRF analysis was conducted to evaluate chloride removal from the artificially-aged iron samples. The highest extraction of chloride ions was recorded with *Meyerozyma* sp. (96% of biomass biosorption) followed by *S. cerevisiae* (78% of biomass biosorption) at a contact time of 90 minutes and biosorbent dosage of 0.02 g. A certain amount (74% biomass biosorption) of chloride ions was also removed by osmotic diffusion in water without biomass as sorbent.

Conclusion

Currently available methods for archeological iron stabilization present several disadvantages including efficiency and safety concerns for human health and environment. For these reasons it is necessary to search for new solutions that will be effective and more sustainable.

During preliminary tests presented in this article the potential of *Meyerozyma* sp. and *S. cerevisiae* for the removal of chloride ions from aqueous solution has been explored. Contact time experiments conducted on artificially-aged iron samples revealed promising feasibility to develop green stabilization treatments based on fungal biomass biosorption.

The results obtained with *S. cerevisie* (obtained as a waste product from beer production) showed the ability to passively bind chloride ions onto surface of fungal cell walls. The biggest increase in the biosorption efficiency was recorded after 90 min of exposure at pH 4 and biomass dosage 0.02 g. However, unexpected processes of adsorption and desorption were noticed after 150 min of contact time. A hypothesis regarding this phenomenon could be associated with impurities present in the initial biomass. In fact, SEM-EDX results confirmed the presence of chloride ions in untreated and treated biomass. One of the possible limitations observed with *S. cerevisiae* is the visual appearance of artificially-aged iron samples after biosorption that may not comply with the conservator aesthetics requirements for archaeological iron artefacts post-conservation.

The outcome obtained from the *Meyerozyma* sp. experiments shows two possible ways of using dry biomass for iron stabilization. SEM-EDX results confirmed the ability of *Meyerozyma* sp. to biosorb chloride and iron ions onto the cell walls. Secondly unexpected changes in appearance of the artificially-aged iron sample surfaces treated with *Meyerozyma* sp. suggested the conversion of reactive corrosion products into more stable compounds. In fact, Raman analysis showed a transformation of corrosion products from akageneite to magnetite. This phenomenon might be associated with an ion exchange process occurring between the iron sample and functional groups present on the fungal cell wall surface. Nevertheless, more research would be needed to fully understand the reaction that leads to this conversion of reactive corrosion products into more chemically stable compounds.

In comparison to traditional methods, the preliminary experiments with biomass biosorption on *Meyerozyma* sp. and *S. cerevisiae* present numerous advantages towards ethical environmental practices such as health and safety, environmental impact, and waste management. Additionally treatment with nonliving biomass showed good results regarding time of application. This outcome will lead to a reduction of water use during the desalination process while maintaining a high extraction rate. Nevertheless, the greatest achievement shown in this article is the absence of toxic materials used during the desalination process. Treatment based on dry biomass and water provides a safer formula, without concerns of human health and environmental pollution. These findings are promising

and provide a solid basis for future optimization in the creation of an efficient and sustainable conservation method for archaeological iron stabilization.

Acknowledgements

The Swiss Centre for Electronics and Microtechnology (CSEM) especially to Dr. O. Sereda and B. Gaëtan for SEM-EDS.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

HESSO is an associated partner in the framework of the GoGreen *Strategies to Conserve the Past and Preserve the Future of Cultural Heritage*, Horizon-RIA project 2022–2026 [grant number 101060768]. The participation is funded by the State Secretary for Education, Research and Innovation (SERI) [grant number 22-00121] as transitional measures program for Horizon 2021–2027.

References

Al-Maliky, E. A., H. A. Gzar, and M. G. Al-Azawy. 2021. "Determination of Point of Zero Charge (PZC) of Concrete Particles Adsorbents." *IOP Conference Series: Materials Science and Engineering* 1184: 012004. https://doi.org/10.1088/1757-899X/1184/1/012004.

Amorim, S. S., F. A. Dias Ruas, N. Rocha Barboza, V. G. de Oliveira Neves, V. A. Leão, and R. Guerra-Sá. 2018. "Manganese (Mn^{2+}) Tolerance and Biosorption by *Meyerozyma guilliermondii* and *Meyerozyma caribbica* Strain." *Journal of Environmental Chemical Engineering* 6 (4): 4538–4545. https://doi.org/10.1016/j.jece.2018.06.061.

Azoulay, I., E. Conforto, P. Refait, and C. Remazeilles. 2013. "Study of Ferrous Corrosion Products on Iron Archaeological Objects by Electron Backscattered Diffraction (EBSD)." *Applied Physics A* 110: 379–388. https://doi.org/10.1007/s00339-012-7174-1.

Cambier, S., D. Verreault, and G. S. Frankel. 2014. "Raman Investigation of Anodic Undermining of Coated Steel During Environmental Exposure." *Corrosion* 70 (12): 1219–1229. https://doi.org/10.5006/1358.

Comensoli, L., J. Maillard, M. Albini, F. Sandoz, P. Junier, and E. Joseph. 2017. "Use of Bacteria to Stabilize Archaeological Iron." *Applied and Environmental Microbiology* 83 (9): e03478-16. https://doi.org/10.1128/AEM.03478-16.

Cutz, L., U. Tiringer, H. Gilvari, D. Schott, A. Mol, and W. de Jong. 2021. "Microstructural Degradation During the Storage of Biomass Pellets." *Communications Materials* 2 (2): 1–12. https://doi.org/10.1038/s43246-020-00113-y.

Drews, M. J., N. G. González-Pereyra, P. Mardikian, and P. de Viviés. 2013. "The Application of Subcritical Fluids for the Stabilization of Marine Archaeological Iron." *Studies in Conservation* 58 (4): 314–325. https://doi.org/10.1179/2047058412Y.0000000079.

Glotch, T. D., and M. D. Kraft. 2008. "Thermal Transformations of Akaganeite and Lepidocrocite to Hematite: Assessment of Possible Precursors to Martian Crystalline Hematite." *Physics and Chemistry of Minerals* 35: 569–581. https://doi.org/10.1007/s00269-008-0249-z.

Hu, Y., Z. Zhu, J. Nielsen, and V. Siewers. 2019. "Engineering *Saccharomyces cerevisiae* Cells for Production of Fatty Acid-derived Biofuels and Chemicals." *Open Biology* 9 (5): 190049. https://doi.org/10.1098/rsob.190049.

Ivanova, T., M. Maier, A. Missarova, C. Ziegler-Birling, M. Dam, M. Gomar-Alba, L. B. Carey, and M. Mendoza. 2020. "Budding Yeast Complete DNA Synthesis After Chromosome Segregation Begins." *Nature Communications* 11: 2267. https://doi.org/10.1038/s41467-020-16100-3.

Kampasakali, E., T. Fardi, E. Pavlidou, and D. Christofilios. 2021. "Towards Sustainable Museum Conservation Practices: A Study on the Surface Cleaning of Contemporary Art and Design Objects with the Use of Biodegradable Agents." *Heritage* 4 (3): 2023–2043. https://doi.org/10.3390/heritage4030115.

Kergourlay, F., S. Réguer, D. Neff, F. Foy, F.-E. Picca, M. Saheb, S. Hustache, F. Mirambet, and P. Dillmann. 2018. "Stabilization Treatment of Cultural Heritage Artefacts: *In Situ* Monitoring of Marine Iron Objects Dechlorinated in Alkali Solution." *Corrosion Science* 132: 21–34. https://doi.org/10.1016/j.corsci.2017.12.028.

Lasch, P., and D. Naumann. 2000. "Infrared Spectroscopy in Microbiology." In *Encyclopedia of Analytical Chemistry*, edited by R. A. Meyers, 102–131. London: Wiley.

Michalak, I., K. Chojnacka, and A. Witek-Krowiak. 2013. "State of the Art for the Biosorption Process—a Review." *Applied Biochemistry and Biotechnology* 170 (6): 1389–1416. https://doi.org/10.1007/s12010-013-0269-0.

Navarro-Arias, M. J., M. J. Hernández-Chávez, L. C. García-Carnero, D. G. Amezcua-Hernández, N. E. Lozoya-Pérez, E. Estrada-Mata, I. Martínez-Duncker, B. Franco, and H. M. Mora-Montes. 2019. "Differential Recognition of *Candida tropicalis*, *Candida guilliermondii*, *Candida krusei*, and *Candida auris* by Human Innate Immune Cells." *Infection and Drug Resistance* 12: 783–794. https://doi.org/10.2147/IDR.S197531.

Paulissen, S. M., C. A. Hunt, B. C. Seitz, C. J. Slubowski, Y. Yu, X. Mucelli, D. Truong, et al. 2020. "Noncanonical Hippo Pathway Regulates Spindle Disassembly and Cytokinesis During Meiosis in *Saccharomyces cerevisiae*." *Genetics* 216 (2): 447–462. https://doi.org/10.1534/genetics.120.303584.

Reguer, S., F. Mirambet, E. Dooryhee, J.-L. Hodeau, P. Dillmann, and P. Lagarde. 2009. "Structural Evidence for the Desalination of Akaganeite in the Preservation of Iron Archaeological Objects, Using Synchrotron X-ray Powder Diffraction and Absorption Spectroscopy." *Corrosion Science* 51 (12): 2795–2802. https://doi.org/10.1016/j.corsci.2009.07.012.

Rémazeilles, C., D. Neff, F. Kergourlay, E. Foy, E. Conforto, E. Guilminot, S. Reguer, Ph. Refait, and Ph. Dillmann. 2009. "Mechanisms of Long-Term Anaerobic Corrosion of Iron Archaeological Artefacts in Seawater." *Corrosion Science* 51 (12): 2932–2941. https://doi.org/10.1016/j.corsci.2009.08.022.

Richmond, W. R., J. G. Hockridge, M. Loan, and G. M. Parkinson. 2004. "A New Iron Oxyhydroxide Phase: The Molybdate-Substituted Analogue of Akaganéite." *Chemistry of Materials* 16 (17): 3203–3205. https://doi.org/10.1021/cm049261o.

Rimmer, M., D. Watkinson, and Q. Wang. 2012. "The Efficiency of Chloride Extraction from Archaeological Iron Objects Using Deoxygenated Alkaline Solutions." *Studies in Conservation* 57: 29–41. https://doi.org/10.1179/2047058411Y.0000000005.

Selwyn, L. 2004. "Overview of Archaeological Iron: The Corrosion Problem, Key Factors Affecting Treatment,

and Gaps in Current Knowledge." In *Metal 04: Proceedings of the International Conference on Metals Conservation*, 294–306. Canberra: National Museums of Australia.

Simon, H. J., G. Cibin, C. Reinhard, Y. Liu, E. Schofield, and I. C. Freestone. 2019. "Influence of Microstructure on the Corrosion of Archaeological Iron Observed Using 3D Synchrotron Micro-Tomography." *Corrosion Science* 159: 108132. https://doi.org/10.1016/j.corsci.2019.108132.

Stookey, L. L. 1970. "Ferrozine – A New Spectrophotometric Reagent for Iron." *Analytical Chemistry* 42 (7): 779–781. https://doi.org/10.1021/ac60289a016.

Szybowicz, M., M. Koralewski, J. Karoń, and M. Melnikova. 2015. "Micro-Raman Spectroscopy of Natural and Synthetic Ferritins and Their Mimetics." *Acta Physica Polonica A* 127 (2): 534–536. https://doi.org/10.12693/APhysPolA.127.534.

Turgoose, S. 1993. "Structure, Composition and Deterioration of Unearthed Iron Objects." In *Current Problems in the Conservation of Metal Antiquities*, edited by A. Shigeo, 35–52. Tokyo: Tokyo National Research Institute of Cultural Properties.

Vietti, A., E. Angelini, S. Grassini, and N. Donato. 2022. "Raman Spectroscopic Characterization of Corrosion Products of Archaeological Iron." *Journal of Physics: Conference Series* 2204: 012066. https://doi.org/10.1088/1742-6596/2204/1/012066.

Watkinson, D. 2010. "Measuring Effectiveness of Washing Methods for Corrosion Control of Archaeological Iron: Problems and Challenges." *Corrosion Engineering, Science and Technology* 45: 400–406. https://doi.org/10.1179/147842210X12754747500801.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S281–S290
https://doi.org/10.1080/00393630.2024.2336765

ORIGINAL RESEARCH OR TREATMENT PAPER

The Application of Remote Sensing in the Conservation of the Archaeological Site of Pachacamac (Second–Sixteenth Century, Peru)

La Aplicación de la Teledetección en la Conservación del Sitio Arqueológico de Pachacamac (siglos II-XVI, Perú)

Denise Pozzi-Escot[1], Maria Ilaria Panaccione Apa[2], Guido Ventura[2], Luigi Magnini[3], Arturo Peralta[1], Hernán Chipana[1], Janet Oshiro[1] and Rommel Angeles[1]

[1]Ministerio de Cultura, Museo Pachacamac, Lima, Peru; [2]Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy; [3]Dipartimento Di Studi Umanistici, Università Ca' Foscari Di Venezia, Venice, Italy

ABSTRACT

Human activity and natural events may deteriorate or destroy archaeological sites. Mitigation is therefore a priority for their preservation. Pachacamac Museum has developed programs for research and conservation since 2008. The archaeological sanctuary of Pachacamac (second–sixteenth century), which consists of buildings made from adobe, roads, enclosures, and platforms, is located along the semi-arid central coast of Peru and was damaged in about 600 due to intense rain related to a major sixth-century El Niño event. More recent damage occurred during the 1925–26 El Niño episode. The Templo del Sol (fifteenth–sixteenth centuries) is one of the main adobe constructions, located on a hill about 60 m high. Orthophotogrammetric data was obtained for the Templo del Sol, to construct a 3 cm resolution digital surface model (DSM) and an orthoimage. Morphometric analysis of the DSM using hydrological and geomorphological quantitative parameters identified areas subjected to water flow or pooling during rainfall, and exposure of the building to wind and solar radiation, the latter responsible for the deterioration of painted walls. Areas of potential collapse were identified. This provides quantitative data for the planning, design, and execution of activities to preserve the site.

La actividad humana y los acontecimientos naturales pueden deteriorar o destruir los sitios arqueológicos. Por lo tanto, la mitigación es una prioridad para su preservación. El Museo Pachacamac ha desarrollado programas de investigación y conservación desde 2008. El santuario arqueológico de Pachacamac (siglos II-XVI), que consta de construcciones hechas de adobe, caminos, recintos y andenes, está ubicado a lo largo de la costa central semiárida de Perú y resultó dañado alrededor del año 600 debido a una intensa lluvia relacionada con un importante episodio de El Niño del siglo VI. Los daños más recientes ocurrieron durante el episodio de El Niño de 1925–26. El Templo del Sol (siglos XV-XVI) es una de las principales construcciones de adobe, ubicada en una colina de unos 60 m de altura. Se obtuvieron datos ortofotogramétricos del Templo del Sol, para construir un modelo digital de superficie (DSM) de 3 cm de resolución y una ortoimagen. El análisis morfométrico del DSM utilizando parámetros cuantitativos hidrológicos y geomorfológicos identificó áreas sujetas a flujos o encharcamientos de agua durante las lluvias, y exposición del edificio al viento y la radiación solar, esta última responsable del deterioro de las paredes pintadas. Se identificaron áreas de posible colapso. Esto proporciona datos cuantitativos para la planificación, diseño y ejecución de actividades para preservar el sitio.

ARTICLE HISTORY
Received October 2023
Accepted March 2024

KEYWORDS
Archaeological sites; remote sensing; morphometry; flooding; adobe; Pachacamac

Sitios arqueológicos; sensores remotos; morfometría; inundación; adobe; Pachacámac

Introduction

Cultural heritage management and conservation are activities of primary importance for the reconstruction of the past and understanding of the interactions between human societies and environments (Kintigh et al. 2014; Xiao et al. 2018). Many archaeological sites are, however, exposed to human activity and damaging natural events. These latter include earthquakes, erosion processes, instability, floods and anomalous increase of temperature due to climate change (Cunliffe 2014). As a result, the recognition of both natural events able to cause deterioration and areas exposed to these events in the past, is a prerequisite of fundamental importance to protect the testimonies of the past (Darvill and Wainwright 1994). Remote sensing data from satellite platforms, aerophotogrammetric surveys, terrestrial and airborne laser scanners provide high resolution measurements aimed at reconstructing archaeological structures and quantifying their degree of preservation (Bettineschi et al. 2022; Contreras and Brodie 2010; Evans et al. 2013; Fisher et al. 2017; Garrison, Houston, and

CONTACT Denise Pozzi-Escot dpozzi@cultura.gob.pe Ministerio de Cultura, Museo Pachacamac, Distrito de Lurín, Lima, Peru
© The International Institute for Conservation of Historic and Artistic Works 2024

Firpi 2019; Inomata et al. 2018; Kincey, Gerrard, and Warburton 2017; Magnini and Bettineschi 2019; Risbøl and Gustavsen 2018). Such data, when combined with information from geomorphology and climate data can be used to determine the exposure of archaeological sites to damaging events (Agapiou, Lysandrou, and Hadjimitsis 2020; Forti et al. 2023; Guiney et al. 2021; Kirby and Kirby 1976; Marsh et al. 2018; Papageorgiou and Hadjimitsis 2021).

The Templo del Sol (hereafter TS, Temple of the Sun; fifteenth–sixteenth centuries) is a building in the archaeological sanctuary of Pachacamac (second–sixteenth centuries). The central coast of Peru and Pachacamac are vulnerable to the effects of the El Niño Southern Oscillation (Sandweiss et al. 2001). The heavy rain, intense winds and hot airflow in the semi-arid region of the central coast of Peru have increased with El Niño frequency in the last 2800–3200 years and have been responsible for the abandonment of ancient temples in historical and pre-historical times.

Pachacamac was affected in around 600 by rain and flooding related to the sixth century El Niño event (Delle Rose 2022; Franco and Paredes 2000; Winsborough et al. 2012). More recently, the buildings have been affected by heavy rain, with severe damage resulting from the 1925–26 El Niño event. The intensity of El Niño rainfall and wind in Peru is expected to increase in coming years due to climate change (Vieira, Vieira, and García 2019). Here we use orthophotogrammetric data from the exterior of the TS to reconstruct its present-day 3D structure and perform a morphometric study aiming to identify:

- areas subjected to water flow or pooling during rainfall,
- the exposure of the adobe building to the sun and wind in a semi-arid region
- zones subjected to potential collapse, i.e. unstable and partly collapsed walls.

We use this approach because other types of investigation, such as the impact of a set of modeled rain events, could provide unrealistic results due to the lack of reliable long-term data and the impossibility of forecasting the magnitude of the El Niño over many years (L'Heureux et al. 2019). To undertake our analysis on the TS, selected morphometric parameters indicative of the above-described types of exposure were extracted from a digital surface model (DSM). The methodology used here is transferable to other sites elsewhere and may be useful for assessing the vulnerability of particular cultural heritage sites and to plan protective action.

Archaeological background and conservation

Archaeological site of Pachacamac

This large archaeological complex is located on the central coast of Peru, 30 km south of Lima (Figure 1). The site covers 465 hectares and is made up of a set of ancient clay structures dating from the second to sixteenth centuries (Pozzi-Escot 2017). The site includes large buildings, such as the Templo Viejo (third–seventh centuries), 16 pyramidal constructions with access ramps (twelfth–sixteenth centuries), the Templo Pintado (eighth–sixteenth centuries), Acllawasi and the TS (fifteenth–sixteenth centuries). Streets, squares, cemeteries, and various enclosures built mostly with adobe and edged stone are also present (Figure 1(b)). The site is part of the Inca road network *Qhapaq Ñan* that linked the capital Cuzco with the entire empire through an organized system of roads and administrative centers. *Qhapaq Ñan* was declared a World Cultural Heritage Site by UNESCO in 2014, including the Xauxa-Pachacamac section, which connects the Pacific coast with the Andes and the capital.

For several centuries, the site has suffered damage, mainly related to rain associated with El Niño/La Niña events and earthquakes. Pachacamac Museum was inaugurated in 2016 and has had a Management Plan since 2014. The objectives of the museum include the conservation and digitization of the site with the production of high-resolution orthoimages and DSMs.

Templo del Sol

TS (fifteenth–sixteenth centuries) is located at the southwestern corner on a 60 m high hill consisting of clay and silty rocks (Figure 1(b,c)). TS lies partially on an ancient cubic adobe structure from the Lima culture (third–fifth centuries). An earlier construction beneathTS is associated with 'Early Lima' construction (Strong, Willey, and Corbett 1943). TS was called *Punchao Cancha* or 'Day Enclosure' (Duviols 1977) prior to the arrival of the Incas and is a symbol of the 'dominion of the Incas over the local kingdoms' (Franco 1996). TS constitutes one of the most important Inca constructions in the Peruvian coast due to its volume and height. It is a 20 m high trapezoidal building with an approximate area of 48,000 m^2 (Figure 1(c)). The construction follows the contour of the hill, with staggered volumes 2–7 m in height arranged in an ascending manner. The southwestern retaining walls, facing the sea, are 218 m long (Figure 1(c)). The width of the platform surfaces varies between 5 and 16 m. An extensive wall projects from TS, known as the first wall, which encloses the main ceremonial constructions and the Uhle cemetery

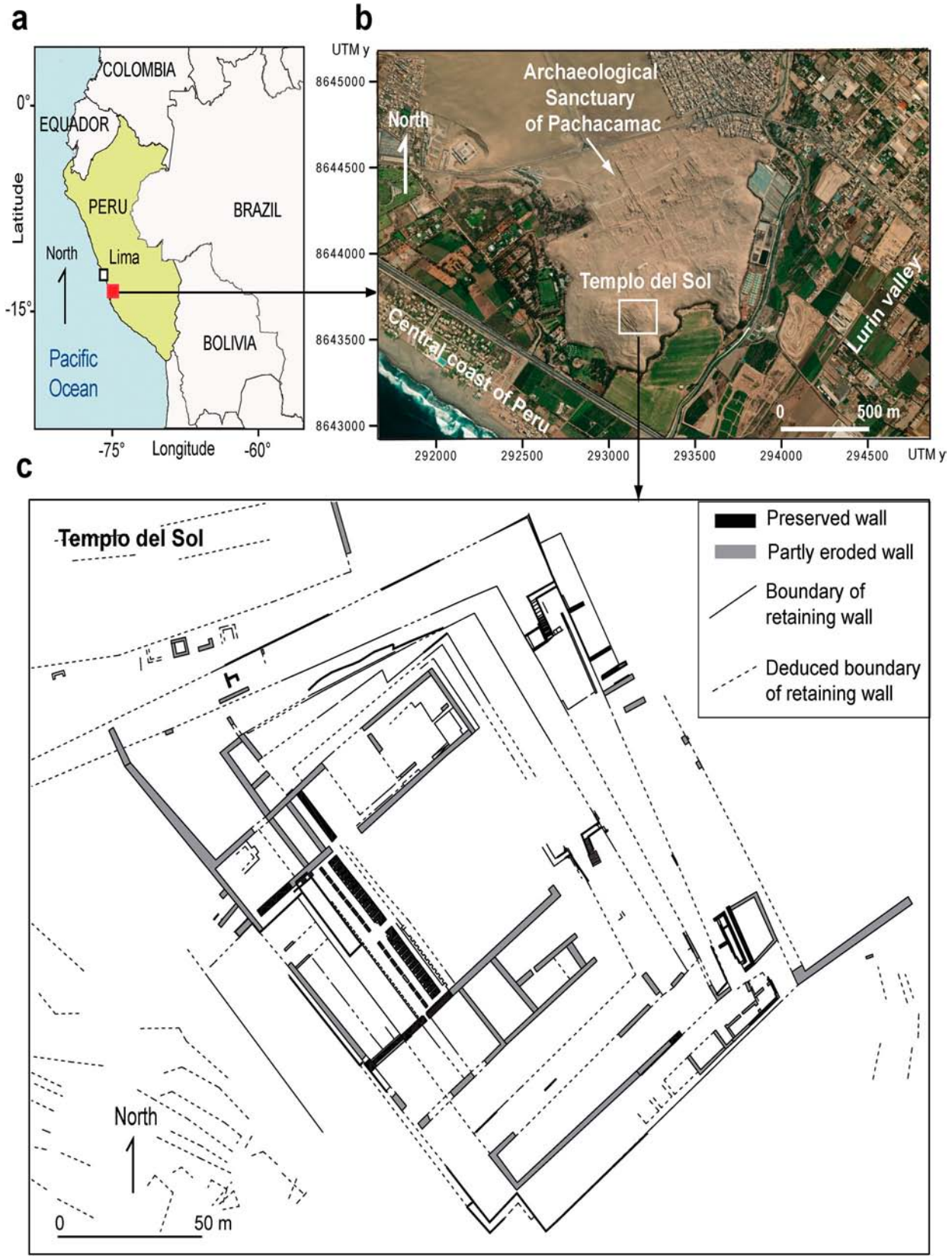


Figure 1. (a) Location of Pachacamac. (b) Satellite image of the archaeological area of Pachacamac (GoogleEarthPro, Image 2022@ Maxar Techonologies) and location of the TS. (c) Its architectural structure.

(Uhle [1903] 1991), forming a rectangular space of probable sacred character. The east front has three entrance portals that allowed access to the upper platforms. Remnants of red paint occur on all the facades and entrances of the TS, also cited by Cobo in his chronicle (Cobo [1653] 1956). The first documentation about the site dates back to the sixteenth century (Calancha 1638; Estete [1535] 1968), continuing over time (Squier 1877) up to the first systematic excavations directed by Uhle ([1903] 1991).

Excavation and conservation of the Templo del Sol

Several excavation campaigns were carried out between 1930 and 1967. Conservation works were carried out by Villar Córdova in the 1930s on the east side of the TS. In 1938, Giesecke intervened on the northeast side of the top of the TS. In 1940, Tello conducted interventions at the vertices of the northern and eastern sides. Another intervention was carried out on the western side, where several architectural elements were preserved, including the niches. In 1963, cleaning and restoration tasks were done (Franco 1996). Most of these interventions lack written, photographic or field reports. In the archives of the Pachacamac Museum, the information recorded by Bueno and Cáceres in their field notebooks gives an account of the work carried out in 1967. In the 1980s, cleaning works were carried out by Jiménez Borja and Bueno on the western and northern sides. In the case of the northern second level of the TS, the debris was thrown onto the first level forming large mounds.

Causes of deterioration and current condition

The uppermost area of the site is deteriorated. Since 2008, the Pachacamac Museum has carried out various works to reduce the damage to walls in critical condition or at risk of collapse. Since 2010, fieldwork and conservation work have been carried out on the north side and a series of walking paths was created around the TS to prevent the public from accessing the summit area. It should be noted that the structural collapses of walls are mostly linked to seismic activity and alluvial infiltration, which produce landslides, as well as to degradation due to site abandonment and lack of maintenance. These factors, along with the effects of wind and high temperature due to solar irradiation on painting, affect the construction elements such as adobe, mortar and stones (Cappai et al. 2023). The weak consistency of the adobe, building technique, and the location of the TS in a zone with clay and silty rocks covered by a blanket of sand, have favored gravity instability and erosion phenomena, with removal of material by water and wind. TS was preserved and restored in the 1940s and 1960s, and the lack of monitoring and maintenance continued in the subsequent decades. Its condition is variable with the best-preserved walls located in the TS western sector (Figure 1(c)). Conservation work continues.

Data and methods

Orthophotogrammetric survey of the Templo del Sol

The orthophotogrammetric survey of TS was carried out between 2019 and 2020 as part of the digital capture of the entire site. The survey flights were carried out at heights between 35 and 50 m with a Phantom 4 pro v.2.0 drone using GPS, equipped with a 20Mpx camera. The flights followed a grid pattern using 13 targets on the ground at the edges and center of the flight polygon. The targets functioned as control points, which allowed us to geo-reference the survey. The control points were measured with a TOPCON Hiper H differential GPS. Aerial photographs were taken during the flights, and oblique photographs were taken manually. In total, about 1500 photographs were obtained. Using Agisoft Metashape V. 1.5.3 (https://www.agisoft.com/), we created a 3D model of the TS. From this model, we were able to

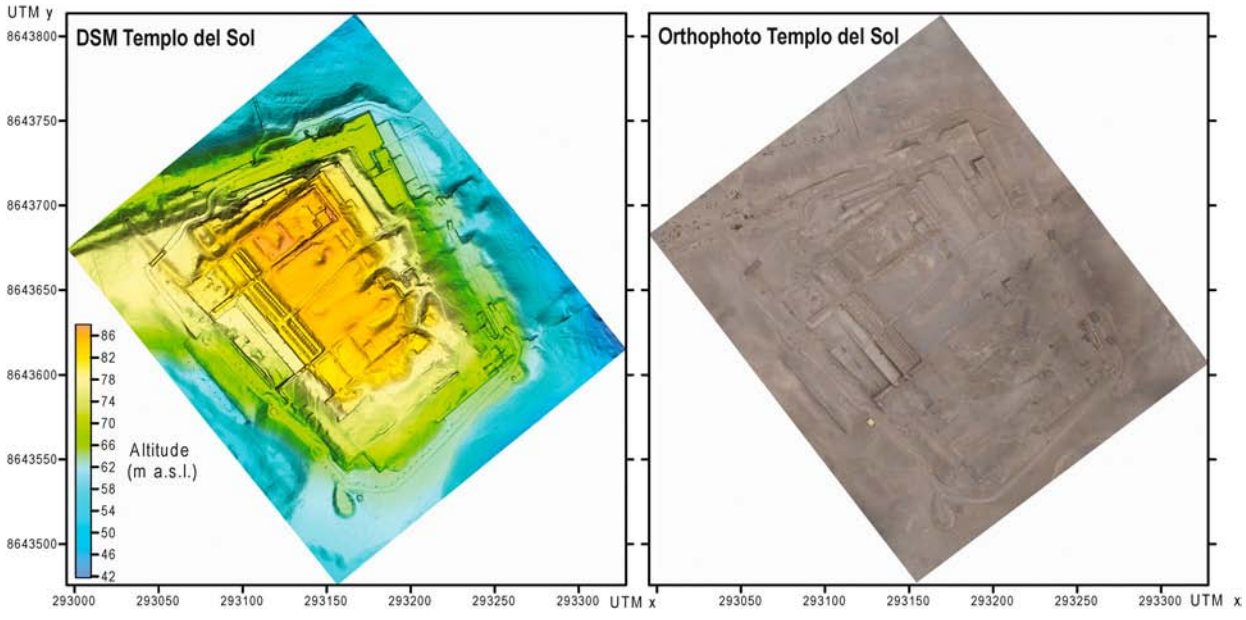


Figure 2. DSM of the TS(left) and orthoimage (right).

obtain an orthoimage with a resolution of 1 cm/px, as well as a DSM with a resolution of 3 cm/px. The estimated errors in the DSM are 1.9 cm on x and y and 0.8 cm on z. These values are acceptable taking into account that for the calculation of the DSM-derived morphometric parameters we use a DSM with 5 cm/pixel. Further detail on the acquisition procedure may be found in Chipana, Abad, and Pozzi-Escot (2020). Figure 2 shows the DSM and the orthoimage obtained.

Morphometric analysis and parameters

The aims of the morphometric analysis based were to identify the areas of TS potentially exposed to:

- flooding or water flow during the rainfall related to future El Niño episodes with the *caveat* that the intensity of heavy rainfall episodes is very difficult to predict (Lagos et al. 2008).
- wind coming off the sea (Goubanova et al. 2011) given that TS is located 1 km northwest of the central coast at 64–85 m above sea level.
- direct incoming solar radiation in semi-arid climatic conditions (Kottek et al. 2006).

The first step in determining the areas subject to flooding is the identification of closed depressions. From a morphological point of view, a closed depression is defined as an area surrounded by higher ground in all directions (Pardo-Igúzquiza and Dowd 2021). We find two types of depressions: areas bounded by morphological or artificial walls and holes related to archaeological excavations. To map the closed depressions at TS and estimate their depth, we apply the algorithm proposed by Wang and Liu (2006). The selected algorithm has been validated in a highly irregular *karst* terrain by Pardo-Igúzquiza and Dowd (2021). The results at the TS are reported in Figure 3(a,b).

We used the topographic wetness index (TWI) to identify the areas where the water may flow during rain events (Beven and Kirkby 1979). TWI is a dimensionless parameter widely used in hydrological analysis of landforms because it defines the catchment water supply and local drainage providing information on potential runoff generation (Kopecký, Macek, and Wild 2021). TWI determination requires two parameters: the local upslope area draining through a certain point per unit contour length A, and the local slope S in radians. The analytical expression is $TWI = \ln[(A)/\tan(S)]$. We map TWI at the TS by applying this formula to the DSM. The calculated TWI values at TS are shown in Figure 4(a). We also determine the total catchment area (TCA), which represents the terrain that collects water after rainfall. Water flows down into these areas and concentrates into streams. TCA measures the extent of the downslope surface flow pathways. To determine TCA, we apply the algorithm by Quinn et al. (1991) as implemented in Conrad et al. (2015) to the DSM of TS. The results are reported in Figure 4(b).

To measure the exposure of TS to the wind, we adopt a value of N165° as the wind direction, this being the prevailing yearly direction along the central coast of Peru (Goubanova et al. 2011). We determine the extent and degree of upwind or downwind exposure in the DSM by calculating

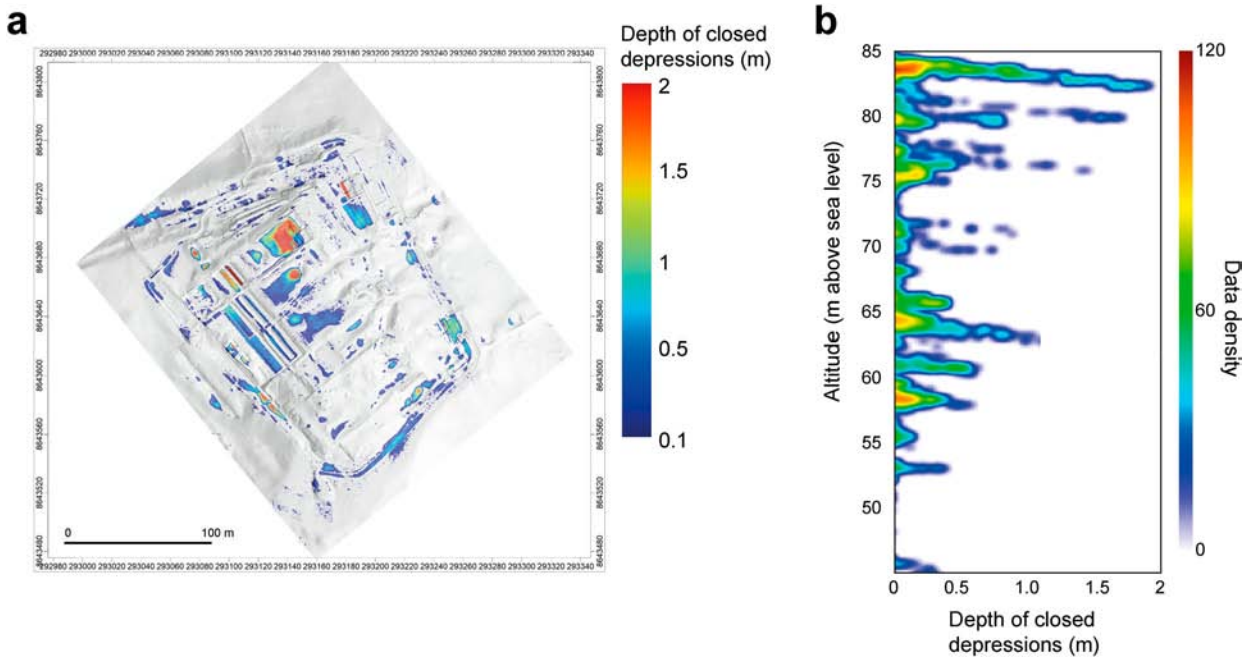


Figure 3. (a) Location and depth of the closed depressions at TS. (b) Depth of the closed depressions *vs* altitude.

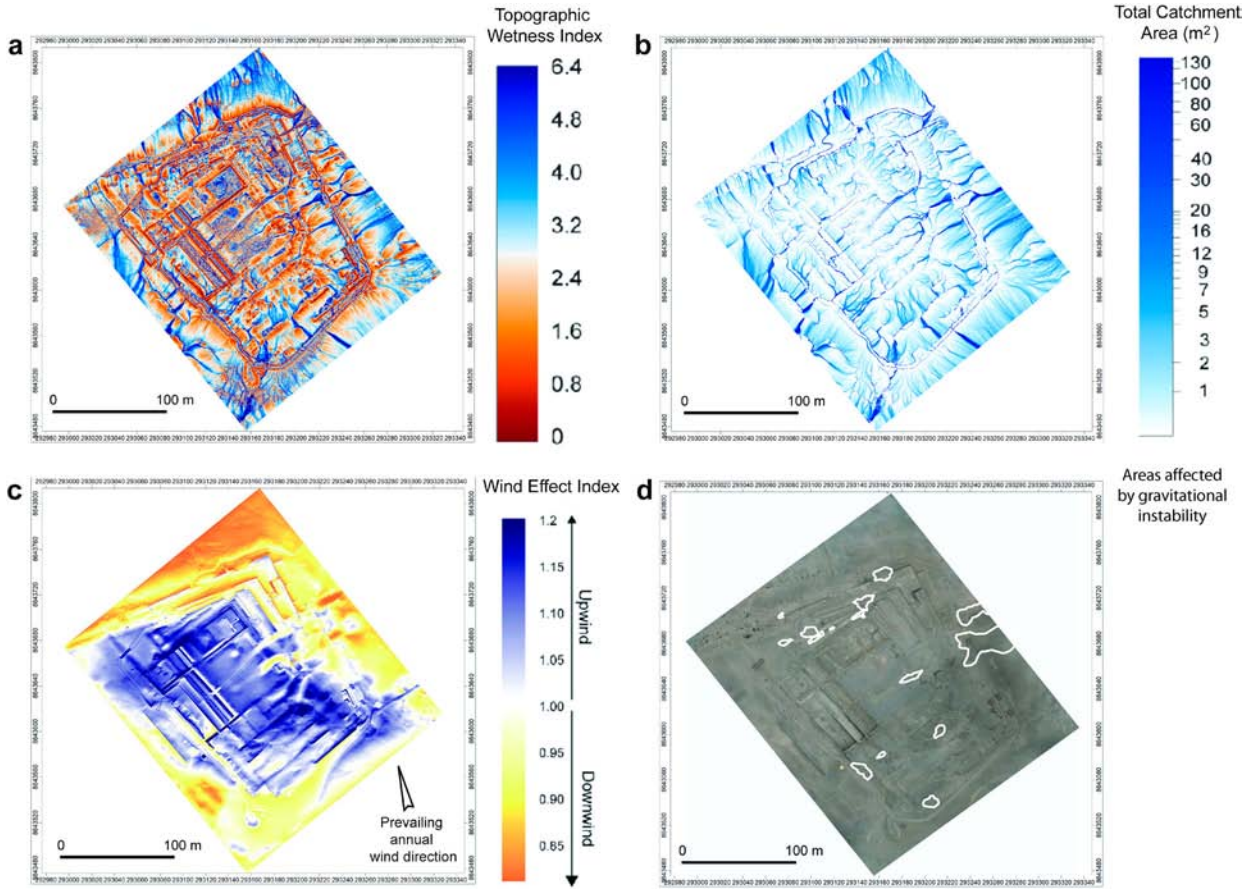


Figure 4. Spatial distribution of (a) TWI, (b) TCA, (c) WEI values at TS. (d) Delimitation of the gravity instability areas superimposed to the orthoimage.

the dimensionless wind effect index (WEI). WEI <1 indicate areas shielded from the wind, whereas WEI > 1 indicate areas exposed to wind. For the calculation of WEI, we follow Boehner and Antonic (2009) and the results obtained are reported in Figure 4(c).

We also identify the TS areas at risk of collapse, i.e. unstable or partly collapsed walls or slopes, based on the combined analysis of DSM and orthophotos. This analysis has been validated by a survey *in situ*. The results are summarized in Figure 4(d).

We use the DSM to map the solar radiation (SR) and the sky view factor (SVF) at the TS following an area-based model (Fu and Rich 1999; 2000; 2002), which provides the SR values by integrating the surface orientation and shadow effects on DSMs. SR can be divided into direct, diffuse and reflected with the direct radiation as the main component of the total irradiance.

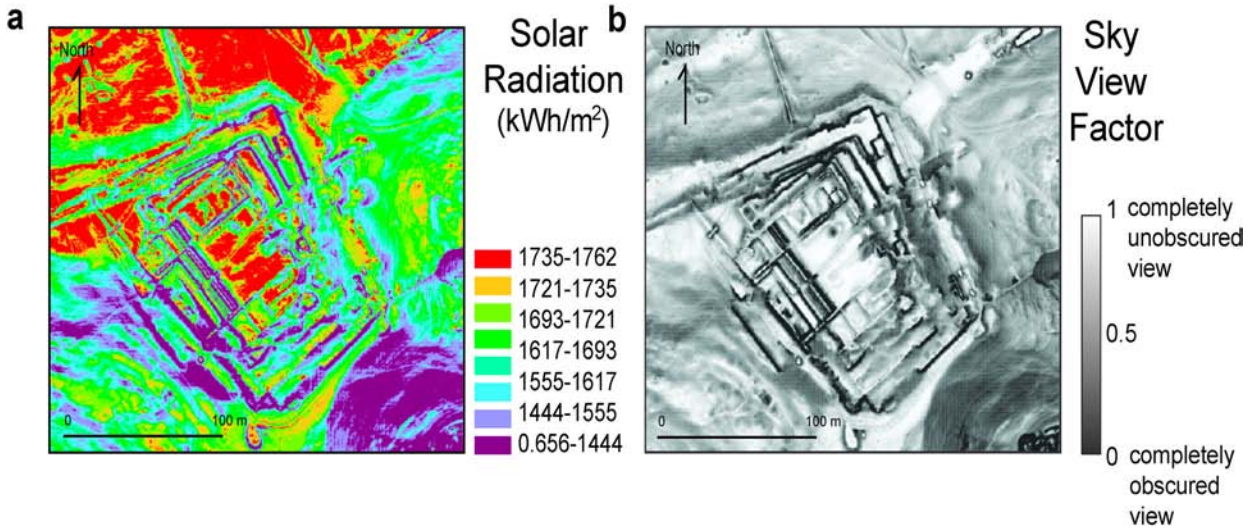


Figure 5. Spatial distribution of yearly (a) SR and (b) SVF values at TS.

Diffuse radiation is the second significant component, while reflected radiation is very small and may be disregarded (Fu and Rich 1999). SVF is a measure of the portion of the sky visible from each point of the DSM and provides a non-dimensional parameter between 0 (obscured view) and 1 (completely unobscured view) (Kidd and Chapman 2012). SVF also provides an indirect estimate of diffuse solar radiation (Zaksek, Oštir, and Kokalj 2011). From an archaeological point of view, SVF allows us to partially identify the remains of elevated structures, especially walls because the SVF values decrease near walls due to the 'shadow' effect. The spatial distribution of SR and SVF at the TS is reported in Figure 5.

Results and discussion

The DSM shown in Figure 2(a) highlights the multilevel structure of the TS with the top level consisting of poorly preserved rooms delimited by walls and the underlying levels consisting of overlapping platforms bounded by retaining walls. The subcircular depressions located in the uppermost level within the two northern rooms are due to archaeological excavations. Sectors of the walls of the lower levels are eroded and/or collapsed. Examples include the northeastern corner of the north-facing wall of the second level at 70 m, and the southern sectors of the southwest and northeast-facing walls between 66 and 76 m. The hill over which TS has been constructed is characterized by significant morphological incisions (small stream valleys) orthogonal to the retaining walls. These incisions also characterize all the levels of the northeastern flank of TS. The southeast-facing walls are less well preserved than the northwestern ones, although the latter still show evidence of partial collapse.

Data from Figure 3(a) show that the summit rooms and the holes related to the excavation are areas where water may pool during rain episodes. These sites are concentrated in the northern sector of the summit part of TS. Also, the depth of closed depressions increases with increasing height (in relation to the levels of the temple) (Figure 3(b)). Therefore, larger amounts of standing water are expected to accumulate at the top of TS, suggesting that water infiltration originates from here. The distribution of the TWI values (Figure 4(a)) shows how the walls of the summit level influence the flow of water (TWI < 1.6), irrespective of their degree of preservation. From a hydrological perspective, they represent morphological ridges and peaks. The areas of TS with TWI > 3.2 are those where the rainwater may pool, according to the results from Figure 3(a), or flow into streams. The distribution of the TCA values in Figure 4(b) shows where the main streams may develop in case of heavy rain. They are expected to affect the flanks of the hill above which the TS is located. Streams are also expected to form along the TS flanks at the two lowermost levels. This has implications for the erosional processes affecting the TS during heavy rain episodes. Our data suggest that the lower TS retaining walls are very vulnerable to deterioration processes caused by concentrated water flowing in streams. In addition, the progressive retreat of the stream heads toward the TS walls due to water erosion could cause the collapse of these TS walls at the two lower levels. On the contrary, the top of the TS structure appears to be minimally affected by stream flow, since its morphology is relatively flat.

Figure 4(c) shows how the TS structure is exposed to the action of winds. The results obtained reveal that the whole structure is exposed with the maximum values (WEI > 1.15) concentrated in the northwestern and southeastern corners of the uppermost TS level. The southeast-facing slope of the hill on which the TS is constructed is also exposed to the wind, whereas the north-facing slope and the two lowermost retaining walls resting on the hill are relatively protected being located in a downwind area where WEI < 1. We conclude that the paint finishes found on the walls of the southern, eastern, and western sectors of TS are exposed to winds and, in consequence, are vulnerable to deterioration. The areas at risk of collapse (Figure 4(c)) concentrated along the northwest-facing walls of the lowermost two levels of TS. Some of these unstable areas are manifested in the partial collapse of these walls, possibly triggered by earthquakes and/or water infiltration. Smaller collapses occur also on the top of TS. The unstable areas located on the western lower flank of TS are related to the partial sliding of the slopes delimiting stream channels.

Figure 5 illustrates the spatial distribution of SR and SVF. The higher values of SR and SVF occur on the top of TS and on the flat surfaces delimited by the retaining walls in the northern and northeastern sectors of TS. High values are also found in the northwestern sector of TS. In general, the vertical walls are not affected by intense SR. This can be also deduced by analyzing the distribution of SVF, which suggests that the vertical walls are predominantly exposed to diffuse rather than direct solar radiation.

These findings allow us to propose some actions aimed at reducing the potential causes and effects of deterioration. We suggest the implementation of an artificial drainage network aimed to avoid or, at least, to reduce water pooling on the top of TS, and to regulate water flow along the main streams, especially those affecting the hill and the lower TS retaining walls. Concerning the reduction of the effects of prolonged exposure to wind and solar radiation, we suggest the use of sloping, windproof, canvas panels. The unstable areas could be strengthened and

protected by stabilizing the collapsed walls and regulating the water flow along the main streams, as described above.

Conclusions

In summary:

- DSMs obtained from the orthophotogrammetric survey of archaeological sites may be used to define areas and structures at risk from natural events.
- The degree of exposure of archaeological sites to rainwater, wind, and solar radiation, as well as the identification of unstable areas, may be obtained from the combined analysis of DSMs, orthoimages, and morphometric and climatic/meteorological parameters.
- At TS, we identified the areas where rainwater may pool or flow and those exposed to wind and solar radiation. The degree of exposure of different sections was also quantified and the zones vulnerable to collapse were mapped out.
- Possible solutions to preserve TS include the introduction of artificial drainage networks, the use of sloping canvas panels to provide shelter, and stabilization of the retaining walls. The multi-temporal acquisition of orthophotogrammetric data and new DSMs of TS will allow us to identify and monitor possible changes related to potential damage related to natural phenomena.

The methodological approach proposed here provides indispensable information for the correct planning of actions aiming to preserve the archaeological heritage and could be used at other sites worldwide.

Acknowledgements

This work has been carried out thanks to the infrastructures of Istituto Nazionale di Geofisica e Vulcanologia, Italy (INGV) and Museo Pachacamac, Peru. We thank the Ministry of Culture of Peru and the Ministero degli Affari Esteri e della Cooperazione Internazionale, Italy (MAECI) for the support to the activities of orthophotogrammetric acquisition and natural hazard evaluation. We thank three anonymous referees for the suggestions and constructive comments. We also thank our colleague Adam Smith for the revision of the English text.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This research was funded by the HUACAS archaeological project of MAECI to INGV and by Pachacamac Museum – *Qhapaq Ñan* Project – Ministry of Culture of Peru.

References

Agapiou, A., V. Lysandrou, and D. G. A. Hadjimitsis. 2020. "A European-Scale Investigation of Soil Erosion Threat to Subsurface Archaeological Remains" *Remote Sensing* 12 (4): 675. https://doi.org/10.3390/rs12040675.

Bettineschi, C., L. Magnini, G. Azzalin, and A. De Guio. 2022. "Clearence Cairnfields Forever: Combining AI and LiDAR Data in the Marcesina Upland (Northern Italy)." *European Journal of Post-Classical Archaeologies* 12: 49–68.

Beven, K. J., and M. J. Kirkby. 1979. "A Physically Based, Variable Contributing Area Model of Basin Hydrology" [Un modèle à base physique de zone d'appel variable de l'hydrologie du bassin versant]" *Hydrological Sciences Bulletin* 24 (1): 43–69. https://doi.org/10.1080/02626667909491834.

Boehner, J., and O. Antonic. 2009. "Land-surface Parameters Specific to Topo-climatology." *Developments in Soil Science* 33: 195–226. https://doi.org/10.1016/S0166-2481(08)00008-1.

Calancha, A. de la. 1638. *Coronica moralizada del orden de San Augustin en el Peru, con sucesos egenplares vistos en esta monarquia*. Barcelona: Pedro Lacavalleria. https://idus.us.es/handle/11441/117502.

Cappai, M., F. Delogu, D. Pozzi-Escot, G. Pacheco Neyra, P. Meloni, and G. Pia. 2023. "Degradation Phenomena of Templo Pintado Painted Plasters." *Construction and Building Materials* 392: 131839. https://doi.org/10.1016/j.conbuildmat.2023.131839.

Chipana, H., J. Abad, and D. Pozzi-Escot. 2020. *Levantamiento con drone arquitectónico del santuario arqueológico de Pachacamac*. Lima: Ministerio de Cultura.

Cobo, B. (1653) 1956. *Historia del nuevo mundo*. Reprint, Madrid: Biblioteca de Autores Españoles.

Conrad, O., B. Bechtel, M. Bock, H. Dietrich, E. Fischer, L. Gerlitz, J. Wehberg, V. Wichmann, and J. Böhner. 2015. "System for Automated Geoscientific Analyses (SAGA) v. 2.1.4." *Geoscientific Model Development* 8: 1991–2007. https://doi.org/10.5194/gmd-8-1991-2015.

Contreras, D. A., and N. Brodie. 2010. "The Utility of Publicly-available Satellite Imagery for Investigating Looting of Archaeological Sites in Jordan." *Journal of Field Archaeology* 35 (1): 101–114. https://doi.org/10.1179/009346910X12707320296838.

Cunliffe, E. 2014. "Archaeological Site Damage in the Cycle of War and Peace: A Syrian Case Study." *Journal of Eastern Mediterranean Archaeology and Heritage Studies* 2 (3): 229–247. https://doi.org/10.5325/jeasmedarcherstu.2.3.0229.

Darvill, T. C., and G. Wainwright. 1994. "The Monuments at Risk Survey: An Introduction." *Antiquity* 68 (261): 820–824. https://doi.org/10.1017/S0003598X00047517.

Delle Rose, M. 2022. "Landscape Modifications Ascribed to El Niño Events in Late Pre-Hispanic Coastal Peru." *Land* 11: 2207. https://doi.org/10.3390/land11122207.

Duviols, P. 1977. "Los nombres quechua de Viracocha, supuesto "Dios Creador" de los evangelizadores." *Allpanchis* 9 (10): 53–63. https://doi.org/10.36901/allpanchis.v9i10.846.

Estete, M. (1535) 1968. "*Noticia del Perú*, vol. 1." In *Biblioteca Peruana: El Peru a traves de los siglos*, edited by Editores Tecnicos Asociados, 345402. Lima: Editores Tecnicos Asociados.

Evans, D. H., R. J. Fletcher, C. Pottier, Jean-Baptiste Chevance, Dominique Soutif, Boun Suy Tan, Sokrithy Im, et al. 2013. "Uncovering Archaeological Landscapes at Angkor Using Lidar." *Proceedings of the National Academy of Sciences* 110 (31): 12595–12600. https://doi.org/10.1073/pnas.1306539110.

Fisher, C. T., A. S. Cohen, J. C. Fernández-Diaz, and S. J. Leisz. 2017. "The Application of Airborne Mapping LiDAR for the Documentation of Ancient Cities and Regions in Tropical Regions." *Quaternary International* 448: 129–138. https://doi.org/10.1016/j.quaint.2016.08.050.

Forti, L., F. Brandolini, V. Oselini, L. Peyronel, A. Pezzotta, A. Vacca, and A. Zerboni. 2023. "Geomorphological Assessment of the Preservation of Archaeological Tell Sites." *Scientific Reports* 13: 7683. https://doi.org/10.1038/s41598-023-34490-4.

Franco, R. 1996. *Ms. El Templo del Sol de Pachacamac. Esplendor y Poder*. Lima: Diseño/ Pre-Prensa/ Impresión.

Franco, R., and P. Paredes. 2000. "El Templo Viejo de Pachacamac: Nuevos aportes al estudio del Horizonte Medio." *Boletín de Arqueología PUCP* 4: 607–630. https://doi.org/10.18800/boletindearqueologiapucp.200001.022.

Fu, P., and P. M. Rich. 1999. "Design and Implementation of the Solar Analyst: An ArcView Extension for Modeling solar Radiation at Landscape Scales." In *Proceedings of the Nineteenth Annual ESRI User Conference, 26–30 July 1999*, 1–31. San Diego, CA. http://professorpaul.org/publications/fu_rich_1999_esri.pdf.

Fu, P., and P. M. Rich. 2000. *The Solar Analyst 1.0 User Manual*. Reston, VA: Helios Environmental Modeling Institute.

Fu, P., and P. M. Rich. 2002. "A Geometric Solar Radiation Model with Applications in Agriculture and Forestry." *Computers and Electronics in Agriculture* 37 (1-3): 25–35. https://doi.org/10.1016/S0168-1699(02)00115-1.

Garrison, T. G., S. Houston, and O. Alcover Firpi. 2019. "Recentering the Rural: Lidar and Articulated Landscapes among the Maya." *Journal of Anthropological Archaeology* 53: 133–146. https://doi.org/10.1016/j.jaa.2018.11.005.

Goubanova, K., V. Echevin, B. Dewitte, F. Codron, K. Takahashi, P. Terray, and M. Vrac. 2011. "Statistical Downscaling of Sea-surface Wind Over the Peru-Chile Upwelling Region: Diagnosing the Impact of Climate Change from the IPSL-CM4 Model." *Climate Dynamics* 36 (7-8): 1365–1378. https://doi.org/10.1007/s00382-010-0824-0.

Guiney, R., E. Santucci, S. Valman, A. Booth, A. Birley, I. Haynes, S. Marsh, and J. Mills. 2021. "Integration and Analysis of Multi-Modal Geospatial Secondary Data to Inform Management of at-Risk Archaeological Sites." *ISPRS International Journal of Geo-Information* 10: 575. https://doi.org/10.3390/ijgi10090575.

Inomata, T., D. Triadan, F. Pinzón, M. Burham, J. L. Ranchos, K. Aoyama, and T. Haraguchi. 2018. "Archaeological Application of Airborne LiDAR to Examine Social Changes in the Ceibal Region of the Maya Lowlands." *PLoS One* 13: e0191619.

Kidd, C., and L. Chapman. 2012. "Derivation of Sky-view Factors from Lidar Data." *International Journal of Remote Sensing* 33 (11): 3640–3652. https://doi.org/10.1080/01431161.2011.635163.

Kincey, M., C. Gerrard, and J. Warburton. 2017. "Quantifying Erosion of 'At Risk' Archaeological Sites Using Repeat Terrestrial Laser Scanning." *Journal of Archaeological Science: Reports* 12: 405–424. https://doi.org/10.1016/j.jasrep.2017.02.003.

Kintigh, K. W., J. H. Altschul, M. C. Beaudry, Robert D. Drennan, Ann P. Kinzig, Timothy A. Kohler, W. Fredrick Limp, et al. 2014. "Grand Challenges for Archaeology." *Proceedings of the National Academy of Sciences* 111 (3): 879–880. https://doi.org/10.1073/pnas.1324000111.

Kirby, A., and M. Kirby. 1976. "Geomorphic Processes and the Surface Survey of Archaeological Sites in Semi-arid Areas." In *Geoarchaeology: Earth Science and the Past*, edited by D. Davidson, and M. Shackley, 229–253. New York: Wiley.

Kopecký, M., M. Macek, and J. Wild. 2021. "Topographic Wetness Index Calculation Guidelines Based on Measured Soil Moisture and Plant Species Composition." *Science of the Total Environment* 757: 143785. https://doi.org/10.1016/j.scitotenv.2020.143785.

Kottek, M., J. Grieser, C. Beck, B. Rudolf, and F. Rubel. 2006. "World Map of the Köppen-Geiger Climate Classification Updated" *Meteorologische Zeitschrift* 15 (3): 259–263. https://doi.org/10.1127/0941-2948/2006/0130.

Lagos, P., Y. Silva, E. Nickl, and K. Mosquera. 2008. "El Niño – Related Precipitation Variability in Perú" *Advances in Geosciences* 14: 231–237. https://doi.org/10.5194/adgeo-14-231-2008.

L'Heureux, M. L., M. K. Tippett, K. Takahashi, Anthony G. Barnston, Emily J. Becker, Gerald D. Bell, Tom E. Di Liberto, et al. 2019. "Strength Outlooks for the El Niño-Southern Oscillation." *Weather and Forecasting* 34 (1): 165–175. https://doi.org/10.1175/WAF-D-18-0126.1.

Magnini, L., and C. Bettineschi. 2019. "Theory and Practice for an Object-based Approach in Archaeological Remote Sensing." *Journal of Archaeological Science* 107: 10–22. https://doi.org/10.1016/j.jas.2019.04.005.

Marsh, A., D. Fleitmann, D. A. M. Al-Manmi, M. Altaweel, D. Wengrow, and R. Carter. 2018. "Mid- to Late-Holocene Archaeology, Environment and Climate in the Northeast Kurdistan Region of Iraq." *The Holocene* 28 (6): 955–967. https://doi.org/10.1177/0959683617752843.

Papageorgiou, N., and D. G. Hadjimitsis. 2021. "Evaluation of Soil Loss by Water in Archaeological Landscapes by Using the (R)USLE Model and GIS: The Case Study of Paphos District, Cyprus." In *Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection*, edited by M. Ioannides, E. Fink, L. Cantoni, and E. Champion, 64–77. Cham: Springer. https://doi.org/10.1007/978-3-030-73043-7_6.

Pardo-Igúzquiza, E., and P. A. Dowd. 2021. "The Mapping of Closed Depressions and its Contribution to the Geodiversity Inventory." *International Journal of Geoheritage and Parks* 9 (4): 480–495. https://doi.org/10.1016/j.ijgeop.2021.11.007.

Pozzi-Escot, D. 2017. *Un espacio sagrado milenario Pachacamac: el oráculo: en el horizonte marino del sol poniente*. Lima: Banco de Crédito del Perú (Colección Arte y Tesoros del Perú).

Quinn, P., K. Beven, P. Chevallier, and O. Planchon. 1991. "The Prediction of Hillslope Flow Paths for Distributed Hydrological Modelling Using Digital Terrain Models." *Hydrological Processes* 5 (1): 59–79. https://doi.org/10.1002/hyp.3360050106.

Risbøl, O., and L. Gustavsen. 2018. "LiDAR from Drones Employed for Mapping Archaeology – Potential, Benefits and Challenges." *Archaeological Prospection* 25 (4): 329–338. https://doi.org/10.1002/arp.1712.

Sandweiss, D. H., K. A. Maasch, R. L. Burger, J. B. Richardson III, H. B. Rollins, and A. Clement. 2001. "Variation in Holocene El Niño Frequencies: Climate Records and Cultural Consequences in Ancient Peru." *Geology* 29 (7): 603–606.

Squier, E. G. 1877. *Peru: Incidents of Travel and Exploration in the Land of the Incas*. New York: Harper & Brothers.

Strong, W. D., G. R. Willey, and J. M. Corbett. 1943. *Archeological Studies in Peru 1941–1942*. New York: Columbia University Press.

Uhle, M. (1903) 1991. *Pachacamac*. Reprint, Philadelphia: University Museum of Archaeology and Anthropology, University of Pennsylvania.

Vieira, M. T., A. V. Vieira, and C. M. V. García. 2019. "Vulnerability Index Elaboration for Climate Change Adaptation in Peru." *European Journal of Sustainable Development* 8 (5): 102–114. https://doi.org/10.14207/ejsd.2019.v8n5p102.

Wang, L., and H. Liu. 2006. "An Efficient Method for Identifying and Filling Surface Depressions in Digital Elevation Models for Hydrologic Analysis and Modelling." *International Journal of Geographical Information Science* 20 (2): 193–213. https://doi.org/10.1080/13658810500433453.

Winsborough, B. M., I. Shimada, L. A. Newsom, J. G. Jones, and R. A. Segura. 2012. "Paleoenvironmental Catastrophies on the Peruvian Coast Revealed in Lagoon Sediment Cores from Pachacamac." *Journal of Archaeological Science* 39 (3): 602–614. https://doi.org/10.1016/j.jas.2011.10.018.

Xiao, W., J. Mills, G. Guidi, P. Rodríguez-Gonzálvez, S. Gonizzi Barsanti, and D. González-Aguilera. 2018. "Geoinformatics for the Conservation and Promotion of Cultural Heritage in Support of the UN Sustainable Development Goals." *ISPRS Journal of Photogrammetry and Remote Sensing* 142: 389–406. https://doi.org/10.1016/j.isprsjprs.2018.01.001.

Zaksek, K., K. Oštir, and Z. Kokalj. 2011. "Sky-View Factor as a Relief Visualization Technique." *Remote Sensing* 3: 398–415. https://doi.org/10.3390/rs3020398.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S291–S297
https://doi.org/10.1080/00393630.2024.2336781

ORIGINAL RESEARCH OR TREATMENT PAPER

From Paper Fibers to Practical Conservation Experiences: The *International Paper Conservation Seminars* in Latin America

Desde las fibras del papel a las experiencias prácticas de conservación: El *Seminario Internacional de Conservación de Papel* en América Latina

Yerko Andrés Quitral

Faculty of Arts, University of Chile, Santiago, Chile

ABSTRACT

The *International Paper Conservation Seminar* has now been held as four face-to-face events and four online events. It is a three-day international event delivered in Spanish and Portugese with keynote talks from national and international conservation professionals from Mexico to Chile presenting projects covering works on paper in diverse formats including documents, photographs historic books, and artworks. Countries such as Argentina, Chile, Bolivia, Peru, Ecuador, Mexico, Paraguay, Uruguay, Colombia, Brazil, Spain and Costa Rica have sent delegates to discuss both the social and cultural aspects of conservation work. The seminar is a completely free event for its attendees. It is intended to be suitable for all, with high-level talks addressing issues of management, preservation, conservation, restoration and disaster recovery among many others. From the third event onwards, training workshops for basic treatments have been developed, with the participation of recognized conservation professionals from universities and international institutes, allowing the number of attendees to remain constant since the Covid-19 pandemic. It creates networks and fosters collaboration for professional and institutional projects. The seminars have generated a connected and active community of paper conservators in the region, aware of our limitations, and capable of solving problems collaboratively and according to local resources.

El *Seminario Internacional de Conservación del Papel* se ha desarrollado en cuatro eventos presenciales y cuatro eventos en línea. Es un evento internacional de tres días, impartido en español y portugués con charlas magistrales de profesionales de la conservación, nacionales e internacionales, desde México hasta Chile presentando proyectos que abarcan trabajos en papel de diversos formatos, incluidos documentos, fotografías, libros históricos y obras de arte. Países como Argentina, Chile, Bolivia, Perú, Ecuador, México, Paraguay, Uruguay, Colombia, Brasil, España y Costa Rica han enviado delegados para discutir los aspectos sociales y culturales del trabajo de conservación. El seminario es un evento completamente gratuito para sus asistentes. Se pretende que sea apto para todos, con charlas de alto nivel que aborden temas de gestión, preservación, conservación, restauración y recuperación de desastres, entre muchos otros. A partir del tercer evento se han desarrollado talleres de capacitación en tratamientos básicos, con la participación de reconocidos profesionales de la conservación de universidades e institutos internacionales, permitiendo que el número de asistentes se mantenga constante desde la pandemia de Covid-19. Crea redes y fomenta la colaboración para proyectos profesionales e institucionales. Los seminarios han generado una comunidad conectada y activa de restauradores de papel en la región, conscientes de nuestras limitaciones, y capaces de resolver problemas de manera colaborativa y de acuerdo con los recursos locales.

ARTICLE HISTORY
Received February 2024
Accepted March 2024

KEYWORDS
Conservation; paper; training; Latin America

Conservación-restauración; papel; formación; América Latina

Introduction

The need to preserve and conserve documents dates back to the invention of writing and the creation of the first libraries. Successive civilizations have used various supports such as clay, wooden boards, papyrus, paper, etc., with parchment standing out for its resistance and durability. Even though digital information prevails today, paper continues to be the safest and most important medium for the transmission of knowledge. Paper conservators aim to guarantee access to documents, while ensuring they survive as long as possible.

The training of paper conservators in both technical and methodological aspects is essential. Constant professional updating about current research is necessary for a complete understanding of heritage assets in an environmental and social context. This includes a complex network of knowledge about the chemistry and physics of materials and their response to biological agents of deterioration in conjunction with their environment and their history (Martínez Justicia, Martínez, and Sánchez-Mesa Martínez 2008; Muñoz 2000). Definitions of the profession exist (Medina-González 2011):

CONTACT Yerko Andrés Quitral yerkoquitral@gmail.com Faculty of Arts, University of Chile, Compañía 1264, 8320000, Santiago, Chile
© The International Institute for Conservation of Historic and Artistic Works 2024

> The conservator/restorer is a professional who has the training, knowledge, skills, experience, and capacity to act to preserve the cultural heritage … by a series of considerations that involve the perception, appreciation, and understanding of cultural heritage concerning its environmental context, its meaning and relevance; the responsibility of carrying out strategic planning, including a diagnostic examination, and the development of a conservation plan.

Since 1975 there have been significant differences between European conservation training and that in Latin America. The training and role of the conservator in museum institutions has been discussed at ICOM and UNESCO meetings (Ruiz-De-Lacanal 1995):

> Training in developing countries, where priorities have not allowed the training of conservators-restorers until today, the problem of training conservators is posed in a particular way. In most cases, the authorities do not understand the need to train a specialist for four years. The sum of theoretical and practical knowledge that must be accumulated to become a qualified restorer is such that a specialist recently stated that training a restorer was as expensive as training a nuclear engineer. All this means that there are geographical areas in which there are practically no qualified conservators.

Given this premise, we have to acknowledge that professional training is not homogeneous throughout Latin America. Training programs began to be developed in Mexico with the National School of Conservation, Restoration and Museography (ENCRyM) in 1968. Subsequently from 1974, Conservation Centers were created in Peru, Brazil, Panama, Colombia, Venezuela, Honduras, Guatemala, Chile, Argentina and Cuba. In 1999, the National Institute of Anthropology and History (INAH) created the Western School of Conservation and Restoration (ECRO) in the city of Guadalajara, Mexico (Pernaut 2002). Thus, successively, technical and undergraduate centers and institutes associated with private and state institutions were created, dedicated to the training of professionals in the conservation of cultural heritage. These have trained academics and researchers, cultural managers and directors of important national and international institutions. Since approximately 2010, there has been a reduction in the number of programs taught in Latin America for conservation of heritage assets in a significant number of countries, with the closure of bachelor degree programs and technical programs in both universities and technology centers. There has also been a decrease in the status of conservators as professionals, leading to lack of recognition not only as specialist practitioners but also as academics and trainers.

Given the lack of paid roles available, a lack of trained and specialized professionals in conservation has been generated. Across Latin America there are structural differences between libraries, archives and museums, and differing budgets within such institutions for activities, whether state, private, or self-funded projects. There is diversity in the spaces in buildings intended for conservation work, technical implementation, training updates, and qualified personnel. On one hand, there are some institutions with admirable capacity to respond to catastrophes, which have already integrated their environmental management with international standards and are equipped for the conservation of artistic or heritage objects; on the other hand, many institutions cannot meet internationally accepted parameters for preventive conservation or conservation treatment due to lack of resources (Quitral 2020).

Today's universities face the challenge of positioning themselves into a complex world, with new demands for professionalism, and emerging competencies associated with the knowledge society. Added to this are new pedagogical tasks and the requirement from institutional management to be accountable and efficient (González and Espinoza 2008). Due to this and other factors, conservation training must be integrated into the social and cultural reality of each country.

According to Angulo Marcial (2009):

> The importance of dialogue is recognized and of course, implicitly, the necessary management of knowledge and information to share what is known and collectively validate new findings. Within the framework of conferences and academic meetings, researchers come into contact with other professionals who work in related fields and can access information not yet available in magazines or books, or information that will never be published.
>
> Direct and personal contact is possible with professionals linked to education, from other disciplinary fields, allowing the establishment of contacts between individuals and groups, as well as the creation of networks and communities of collaborative work. Spaces where they can submit their results, ideas and speculations to their colleagues.

Such issues were discussed in 2015 by professionals and colleagues in the field of paper conservation from several countries. This led to the creation of a seminar targeted at the Latin American region, to present practical and research projects in conservation, involving workers from the worlds of libraries, archives, museums, universities and private and state institutions. It covered both disaster recovery and the conservation of collections.

This interaction is important at a time when training programs in many Latin American countries are nonexistent and opportunities to connect conservation professionals have disappeared. The International Paper Conservation Seminar was formulated as an inter-disciplinary forum for discussion, development and updating of procedures and practices for paper conservation, for professionals from all departments

of museums, archives, libraries and public and private institutions. Its objective was to disseminate knowledge about the conservation of bibliographic, documentary and photographic heritage, according to a representative socioeconomic reality of the region.

The *Seminar* has four main objectives:

- To replace lost academic training both at a technical and mid-career level, that has led to the loss professional development opportunities for existing professionals
- To replace lost connections between conservators at the Latin American level
- To foster discussion on materials and treatment methodologies
- To generate recognition of conservation professionals at a national and international level, and to improve working conditions in conservation workshops and institutions to the standards of national and international laboratories.

To develop these objectives, a seminar and workshop were proposed to share the outcomes from a conservation project for the *First Chilean Prints*, in the Central Archive of the University of Chile, funded by the National Fund for Cultural Development and the Arts (FONDART) by the Ministry of Culture, Arts, and Heritage in Chile.

Results

In 2015 the team consisted of Richard Solis and Yerko Quitral. It was decided to address the community of conservators, archivists and historians, to foster joint decision-making in conservation projects. Likewise, a specialty workshop on paper cleaning was organized, providing basic and advanced knowledge on the treatment of paper, presented in both a practical and theoretical way by the professional conservator for works of art on paper Cecilia Oviedo Bustos from Argentina, on the use of agarose gels. This workshop, which included 22 students from different conservation training programs at that time in Santiago, Chile, was carried out in the Conservation Laboratory of the Andrés Bello Central Archive of the University of Chile. This first *Seminar* was held in the Central House of the University, with a massive attendance, approximately 200 people, and 5 keynote talks given in a single morning (Figure 1).

Evolution of the *Seminars*

Due to the impact generated by the first *Seminar* and the relevance expressed by the attendees and colleagues with the topics presented, it was decided to run such events on a regular basis, preceded by an international call for paper proposals to all



Figure 1. First and second *International Paper Conservation Seminars* of 2016 and 2017, (a) Assistants at the Central House of the University of Chile and (b) First workshop held on cleaning with agarose gels, (c) Gemma Contreras, in the National Museum of Fine Arts of Santiago, Chile. Images: Yerko Quitral.

researchers, staff or students engaged in projects relevant to paper conservation in Latin America, subsequently evaluated by specialists in paper. This has led to improved presentations. The second event in 2017 (Figure 1) was held for two consecutive days with keynote talks and discussion tables at the National Museum of Fine Arts of Chile, bringing together specialists from Argentina, Brazil, Peru and Spain. The participation of Gemma Contreras Zamorano, director of the Valencian Institute of Conservation and Restoration (IVCR+i) and specialist in paper restoration, with extensive international experience in courses, projects and talks in the field of research into ferrogallic inks and paper conservation, was notable. This occasion included 11 presentations from professional conservators in Argentina, Brazil and Chile, attracting an audience of approximately 300 attendees. That year saw the inauguration of the seminar's Facebook page with a reach of 5–10,000 people throughout Latin America.

The third event in 2018 was held at the San Francisco Museum of Colonial Art, with keynote talks and roundtable discussions covering research, collection rescue projects, and historical documents. The first day covered preservation, the second conservation, and the third dealt with photography conservation and digitization, with an audience that was around 800 people. In parallel, updating of professional knowledge was delivered through four theoretical and practical workshops reaching 160 people on: conservation of photography; conservation of parchment led by Susana Brandariz, Head of the Conservation Laboratory of the Ancient Fund of the Society of Jesus of Buenos Aires; conservation of works on paper led again by Cecilia Oviedo Bustos; and biological deterioration of paper led by the researcher and academic Yerko Quitral from Chile (Figure 2).

Since that time, the workshops have been organized to fully finance the attendance of some professionals at the *Seminar* and the full attendance of professionals for specialty workshops. It should be emphasized that the events held are not sponsored by public or private entities, and have been managed autonomously. The travel and living expenses of the trainers are their own responsibility, and have always been given freely by them, to develop the conservation profession.

For 2019, the fourth *Seminar* was organized with the support of the National Library of Chile, delivering a program with six keynote talks and nine roundtables, achieving an attendance of approximately 370 people over 3 days. On this occasion, four workshops were held: conservation of photography led Amanda Chamorro, National Library of Peru; making conservation covers for documents, led by conservator Andrea Fabianna Saval from Argentina; risk



Figure 2. Workshops given at the *International Paper Conservation Seminars* in 2018 and 2019, at (a) Paper biodeterioration, (b) Parchment conservation and (c) Chromatic reintegration. Images: Yerko Quitral.

management for archives and libraries; and color theory and chromatic reintegration on paper, led by Daniela Sierra Poblete and Carla Salas from Chile.

Access through online delivery

At the beginning of 2020 and due to the Covid-19 pandemic, the *Seminar* and its workshops had to be canceled. Therefore, it was proposed to hold the meeting completely online. With this change, an international call for Spanish-speaking or Portugese-speaking participants was made, increasing impact by increasing attendance and enabling international speakers to take part without traveling to Latin America. For the first event Zoom was used, with a maximum capacity of 500 people, as in previous years. Online registration through the seminar website www.sicp.cl, Facebook, and Instagram reached more than 1500 people on that occasion, however the real attendance on seminar days was 500 people daily (Figure 3).

The virtual format has allowed us to have the participation of international conservation professionals, leaders in their respective fields, such as Nieves Valentín, a prominent Spanish researcher in biodeterioration of heritage assets. With all his experience and training in paper conservation, Luis Crespo Arca from the National Library of Spain spoke to us about oriental methods of treating paper, the use of adhesives and their preparation. From the National Autonomous University of Mexico (UNAM) and the National School of Conservation and Restoration, Mexico, we listened to the conservator Ricardo Paquini, with a timely topic, the reorganization of the library system around a pandemic with no end date in sight. Fernando Osorio González presented problems of photographic management beyond the technical and methodological, added to the economic limitations existing in the region. Gemma Contreras Zamorano gave talks on research into ferrogallic inks, and the relevance of paper conservation, history, art and document management. Marie Vander Meeren, who leads the conservation laboratory for the archival Collections of INAH, as well as the only course on paper conservation in Latin America, presented her work.

It was observed that the virtual format brought with it a considerable increase in attendance (Figure 4), almost 7 times the number of attendees compared to the first face-to-face seminar. This increase is due to the greatly improved connectivity that the pandemic has provided, and the online platforms that have been developed in consequence. Although connectivity of countries varies, it has proved possible to achieve continuous online attendance at the *Seminar* in the years that it has been virtual. It has made it possible for all attendees to see important personalities from the world of conservation, generating crucial debate.

We have also seen an increase in the number of countries participating. However, once the pandemic was over, the format had to be updated to enable a roundtable discussion. In 2023, the event took place over two days, with four roundtables: training and professional conservation criteria; biodeterioration and current treatment methods in heritage; antique book binding and conservation; and criteria for the restoration of artworks. Practical work was presented for the collective development and interpretation of criteria, which generated a significant number of questions from attendees. This interactive methodology has been very well received by attendees and has now been incorporated into the *Seminar* for the future.

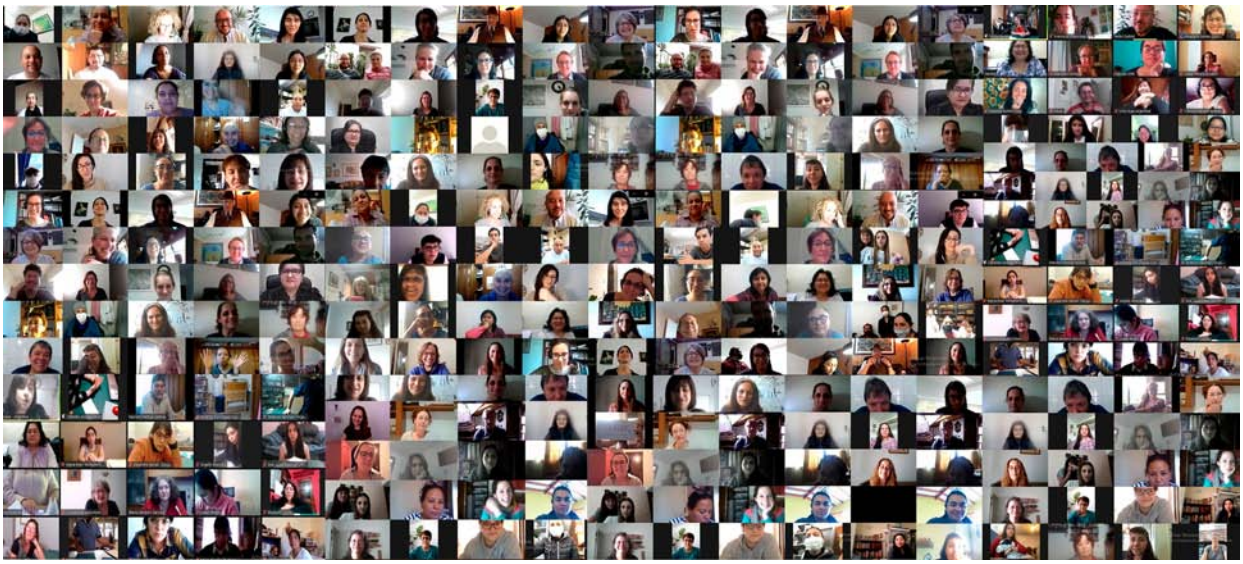


Figure 3. Attendees at the first online-only *Seminar* during the pandemic in 2020, with a total attendance of 1500 and registration exceeding 4000.

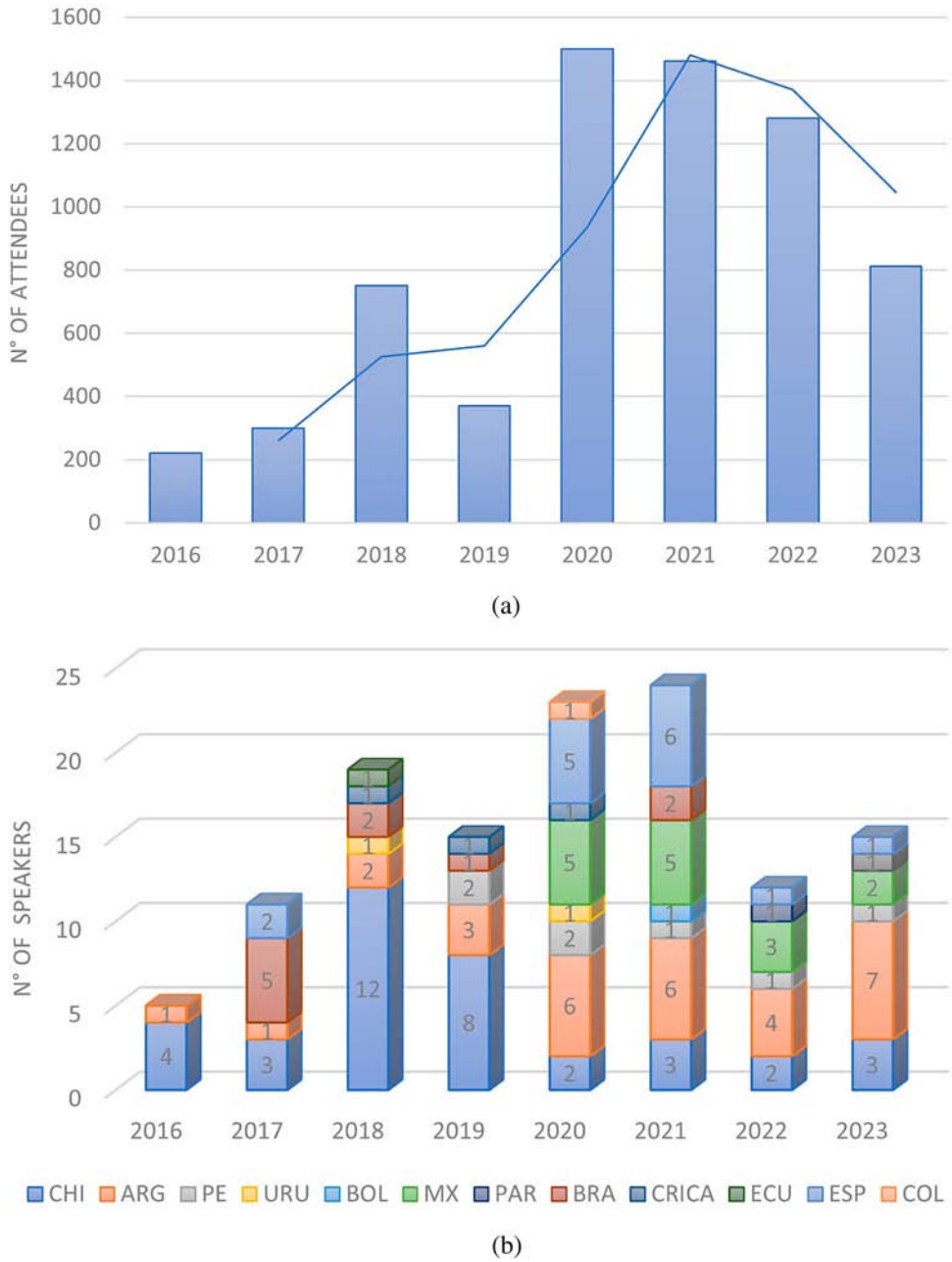


Figure 4. (a) Attendance over time. (b) Breakdown of delegates' countries.

Conclusion

At the first *Seminars*, it was difficult to deliver conservation training to such a heterogeneous audience, and also challenging for the audience to appreciate both technical and economic differences. Such understanding has developed over time. The presentation of case studies from each country has highlighted both practical conservation techniques and substitutions for conservation materials when these are scarce or simply cannot be obtained. In many cases the solutions are appropriate, but in others not, whereupon the discussion becomes very interesting. The showcasing of such topics has led to the recognition of a heterogeneous sector dedicated to paper conservation, and of the transdisciplinary nature of its training. We have had archivists, museologists, historians, biologists, chemists, writers, artists, and librarians attend. The subjects presented over the eight years have generated 10 main themes (Figure 5).

Although training problems in most countries have not been solved and in many of them have even increased, today there is more awareness of such shortcomings, and training support is sought from recognized international institutions, as well as funding for individuals to attend conservation meetings to increase and update their knowledge.

The *International Paper Conservation Seminar* has generated a recognizable community of conservators, connected and active over time, aware of our limitations, but capable of solving the work according to our capabilities, both personal, institutional regional. All of these experiences have led us to achieve

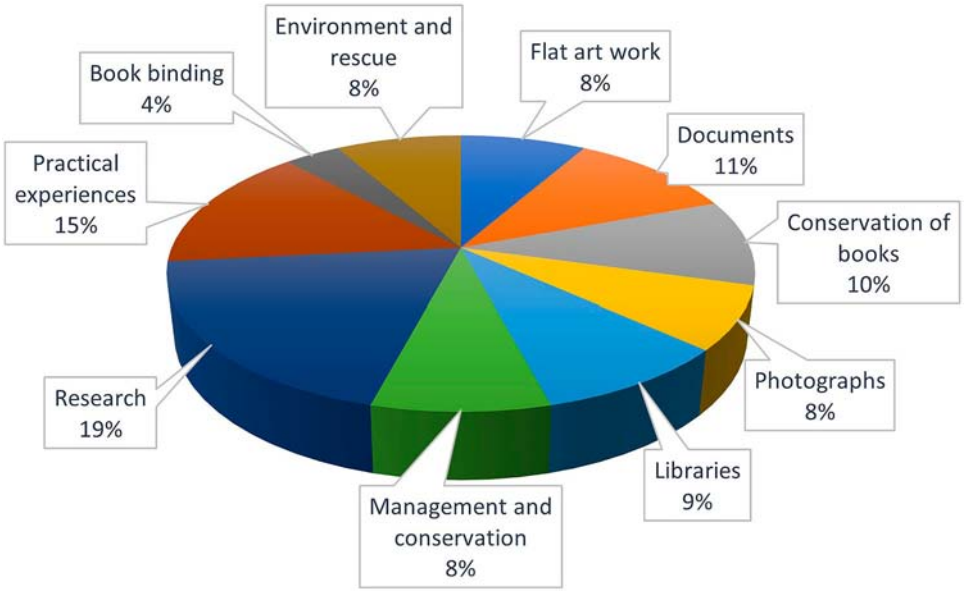


Figure 5. Topics presented over the years.

collaborative work to advance training in paper conservation in Latin America.

Acknowledgements

I thank each of the institutions that have selflessly collaborated in the development of the *Seminar*'s activities, helping to recognize and disseminate conservation studies. Special thanks to my friends Richard Solís, Cecilia Oviedo Bustos, Gemma Contreras and Susana Brandariz, who have provided not only their knowledge, but also their important personal support from the beginning. And an eternal thank you to each of the friends and colleagues of paper conservation, Andrea Fabiana Savall, Daniela Sierra Poblete, Paula Fiori, Fermina Ziaurriz, Alejandra Odor, María Pardo and Lucrecia Vélez, they have given their time and knowledge to the program on many occasions. Thank you to all those I have not named who have participated in this paper conservation education/training project.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Angulo Marcial, N. 2009. "La importancia de los congresos y reuniones académicas como fuente de información para la innovación y la generación del conocimiento." *Congreso Internacional de Innovación Educativa* 453:462.

González, L. E., and Ó. Espinoza. 2008. "Calidad en la educación superior: concepto y modelos." *Calidad en la educación* 28:248. https://doi.org/10.31619/caledu.n28.210.

Martínez Justicia, M. J., D. Martínez, and L. Sánchez-Mesa Martínez. 2008. *Historia y Teoría de la Conservación y Restauración artística*. Madrid: Tecnos.

Medina-González, I. 2011. "Hacia un nuevo centro de gravedad: el proceso de toma de decisiones en la definición y formación de conservadores-restauradores profesionales." *Revista del Centro Nacional de Conservación y Restauración* 16:5–15.

Muñoz, R. F. 2000. "Fuentes de conocimiento para nuevas tecnologías aplicadas a la educación." *Docencia e Investigación: revista de la Escuela Universitaria de Magisterio de Toledo* 25 (10): 17–61.

Pernaut, C. 2002. *La formación para la conservación del patrimonio cultural en América Latina*. Madrid: Comité Nacional Español del ICOMOS. 287–289.

Quitral, Y. A. 2020. "Bibliotecas frente a la pandemia COVID-19: fundamentos y acciones en Latinoamérica." *Biblioteca Universitaria* 23 (1): 119–131. https://doi.org/10.22201/dgb.0187750xp.0.0.992.

Ruiz-De-Lacanal, M.-D. 1995. "El Instituto de Conservación y Restauración de Bienes Culturales y la formación del conservador-restaurado." *PH: Boletin del Instituto Andaluz del Patrimonio* 10:38–45.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S298–S304
https://doi.org/10.1080/00393630.2024.2350280

ORIGINAL RESEARCH OR TREATMENT PAPER

Development of Starch Nanoparticles as a Green Consolidant for Paper-based Objects: Synthesis and Design

Desarrollo de Nanopartículas de Almidón como Consolidante Verde para Objetos de Papel: Síntesis y Diseño

Ashna Rawat and Satish C. Pandey

Department of Conservation, Indian Institute of Heritage, Noida, UP, India

ABSTRACT

Starch is one of the oldest adhesives, and has been utilised for a variety of applications, including as a consolidant for artworks and archives, after cooking. Although widely available, cost-effective, and versatile it has limitations such as large particle size, which makes it challenging for the adhesive to penetrate deeply into objects. Attempts to increase the concentration of starch adhesives for enhanced strength often lead to increased viscosity, hindering penetration and causing an undesirable film on the surface. Achieving a workable consistency often leads to reduced adhesive power. An approach to using nanosized starch as a binder for paper and cellulose-based objects is presented. Starch nanoparticles (SNPs) from wheat, rice, maize and waxy maize were successfully synthesised using a 'top-down' approach that is facile as well as energy efficient. Size distribution measurements indicate most particles to be less than 50 nm, smaller than the pore size of most historic papers. SNPs could make a better sizing adhesive than traditionally-made starch paste, and they are also a green alternative to a variety of chemically formulated, organic solvent-based adhesives. The compatibility, non-toxicity, and biodegradability of starch remained uncompromised during the modification.

El almidón es uno de los adhesivos más antiguos y se ha utilizado para una variedad de aplicaciones, incluso como consolidante para obras de arte y archivos, después de la cocción. Aunque está ampliamente disponible, es rentable y versátil, tiene limitaciones como el gran tamaño de las partículas, lo que dificulta que el adhesivo penetre profundamente en los objetos. Los intentos de aumentar la concentración de adhesivos de almidón para mejorar la resistencia a menudo conducen a una mayor viscosidad, lo que dificulta la penetración y provoca una película indeseable en la superficie. Lograr una consistencia trabajable a menudo conduce a una reducción del poder adhesivo. Se presenta un método para utilizar almidón nanométrico como aglutinante para papel y objetos a base de celulosa. Se sintetizaron con éxito nanopartículas de almidón (SNP) de trigo, arroz, maíz y maíz ceroso utilizando un enfoque 'de arriba hacia abajo' que es sencillo y energéticamente eficiente. Las mediciones de distribución de tamaño indican que la mayoría de las partículas tienen menos de 50 nm, más pequeñas que el tamaño de poro de la mayoría de los papeles históricos. Los SNP podrían producir un adhesivo de mejor tamaño que la pasta de almidón fabricada tradicionalmente, y también son una alternativa ecológica a una variedad de adhesivos a base de solventes orgánicos formulados químicamente. La compatibilidad, la no toxicidad y la biodegradabilidad del almidón no se vieron comprometidas durante la modificación.

ARTICLE HISTORY
Received November 2023
Accepted April 2024

KEYWORDS
Consolidation; paper conservation; adhesive; starch; nanoparticles

Consolidación; conservación de papel; adhesivo; almidón; nanopartículas

Introduction: starch and its structure

Starch is one of the most abundant biopolymers, available as an energy reserve in various plant roots, staple crops and cereals such as tapioca, potato, rice, maize, wheat, barley, corn, etc. (Ahmad et al. 2020; Kim, Park, and Lim 2015). It is a biocompatible, biodegradable, non-toxic polymer, with a multitude of advantages over other available biopolymers. Apart from its bountiful supply, its cost-effectiveness, low density and greenness are some of the other advantages (Le Corre, Bras, and Dufresne 2010; Oladebeye et al. 2015). It finds application in major industries such as food production, paper-making, fine chemicals, pharmaceuticals, packaging, it is used with rubber and plastic products (Oladebeye et al. 2015), and in drugs and bioactive delivery systems (Ahmad et al. 2020). A major component of our daily diet, it has been extensively used as a thickening, gelling, stabilising agent in a wide range of food and non-food products (Ahmad

CONTACT Satish C. Pandey satish.pandey.nmi@gov.in Department of Conservation, Indian Institute of Heritage, A-19, A Block, Institutional Area, Sector 62, Noida, Uttar Pradesh 201309, India

© The International Institute for Conservation of Historic and Artistic Works 2024

et al. 2020; Campelo, Sant'Ana, and Pedrosa Silva Clerici 2020). The major sources available to us are maize (82%), wheat (8%), potatoes (5%), and cassava (5%) (Le Corre, Bras, and Dufresne 2010).

Starch is synthesised in the amyloplasts of plants during photosynthesis (Kim, Park, and Lim 2015). It is extracted from the seeds, roots or stalks of the plant and is refined by wet grinding, sieving, and finally drying (Le Corre, Bras, and Dufresne 2010), and made available as a flour-like white powder insoluble in cold water. This has a particle size diameter ranging from 2 to 100 μm, depending on the botanical origin, and a density of approximately 1.5 g/cm^3 (Le Corre, Bras, and Dufresne 2010). Structurally, starch is made of a glucose monomer called α-D-glucopyranose (or α-D-glucose) which can be linear or branched, and hence the chemical formula of the carbohydrate polymer also known as amylum $(C_6H_{10}O_5)_n$ (Le Corre, Bras, and Dufresne 2010a; Safari and Sadeghi 2017; Golińska 2021). Amylose is a linear arrangement of molecules of anhydrous glucose units connected to each other through α (1–4) glycosidic bonds (Horie 2005; Safari and Sadeghi 2017). Only c.1.6% of the glucose units are connected by α (1–6) linkage which are attached to the main amylose structure and hence lead to branching (Safari and Sadeghi 2017), when the molecule is called amylopectin (Safari and Sadeghi 2017). Figure 1 shows both structures. Starch extracted directly from the plant is called 'native starch', and when this undergoes one or more treatments to confer desired properties, it is 'modified starch' (Le Corre and Dufresne 2013). The native form however has many limitations such as poor solubility, retrogradation, limited digestibility and poor functional properties (Masina et al. 2017). Various physical, chemical and enzymatic methods have been employed to modify and minimise these limitations or to add new attributes (Ahmad et al. 2020). Currently, starch nanoparticles are gaining popularity for improved quality and a wide range of applications (Le Corre, Bras, and Dufresne 2010).

Starch nanoparticles

Properties of materials change with size, i.e. a bulk particle can behave totally differently from its nano-sized counterpart (Guisbiers, Mejía-Rosales, and Deepak 2012). Starch granules are naturally of micro dimensions (Alcázar-Alay and Meireles 2015) which can be broken down to nano-sized dimensions with new properties using various methods (Lin et al. 2011; Masina et al. 2017). Starch nanoparticles (SNPs) are mostly safe for human health and are increasingly utilised by various industries (El-Naggar et al. 2015; Sandhu and Nain 2017) such as biomedicine, where SNPs were recently found to be suitable drug carriers (El-Naggar et al. 2015; Kim, Park, and Lim 2015; Le Corre, Bras, and Dufresne 2010). SNPs have fascinating barrier properties useful in packaging materials (Kim, Park, and Lim 2015; Le Corre, Bras, and Dufresne 2010; Sandhu and Nain 2017).

Starch as a conservation adhesive

Starch is one of the oldest adhesives used by mankind (van Steene and Masschelein-Kleiner 1980). Pliny the Elder described the manufacture of papyrus using wheat flour paste in the first century CE (AIC 2023). It has traditionally been used for the consolidation and repair of manuscripts, textiles, paintings and other composite objects, and is still used by many paper conservators for consolidation, tear mending, lining, reintegration and strengthening (CCI 2015). These treatments require adhesives and consolidants that

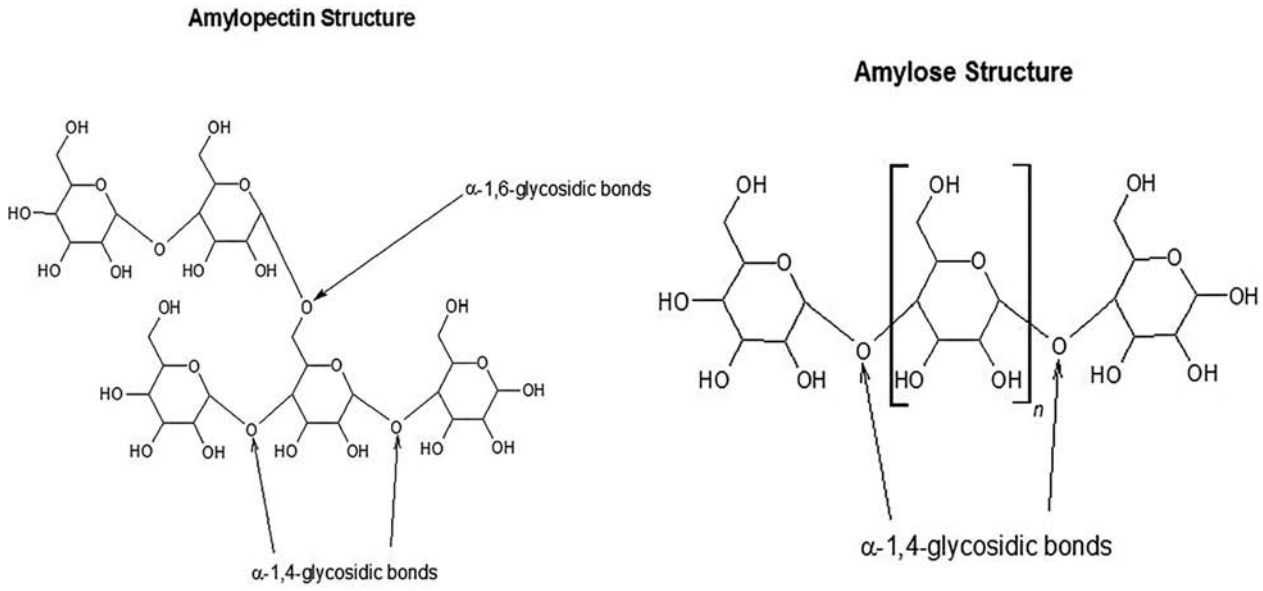


Figure 1. Starch amylopectin branched structure (left) and starch amylose linear structure (right), after Pawar et al. (2008).

are compatible with the substrate, reversible, and provide the required strength. SNPs with enhanced rheological and adhesion properties (Kim, Park, and Lim 2015), have the potential to be used in conservation but have not yet been explored. Nanomaterials are not new to conservation: nanoparticles of calcium hydroxide as a consolidant for mural paintings have been used (Baglioni and Giorgi 2011), and they have found application in cleaning, de-acidification (Altavilla and Ciliberto 2011), and to block ultraviolet radiation (Rawat et al. 2018). Nanoemulsions are being used to clean unvarnished paint, and to remove varnishes from paint (Stoveland et al. 2021; Weththimuni et al. 2023).

SNPs have been synthesised by acid hydrolysis, enzymatic hydrolysis, nanoprecipitation, emulsion crosslinking physical treatments like ultrasonication, reactive extrusion, and gamma irradiation, or a combination such as hydrolysis with ultrasonication, or enzymatic hydrolysis and recrystallization, or complex formation followed by enzymatic hydrolysis (Kim, Park, and Lim 2015). Researchers at EcoSynthetix Inc. were perhaps the first to develop a biopolymer adhesive made from nanostarch powder with a particle size of 50–100 nm for the manufacture of corrugated boards, at lower water content than conventional starch adhesives, implying less energy and shorter time required for drying (Yam 2010). SNP-based adhesives can be a good alternative to petroleum-based synthetic adhesives, do not interfere when paper products are recycled (Bloembergen 2005), and have been used in the papermaking industry as adhesives, binders and coatings (Kim, Park, and Lim 2015; Chen et al. 2017; Sandhu and Nain 2017).

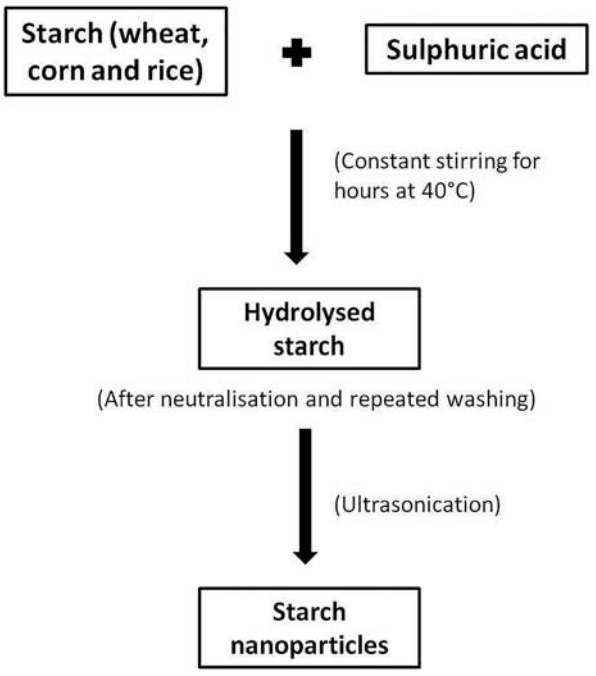


Figure 2. Protocol for the synthesis of starch nanoparticles.

Cooked starch has long been widely used as a papermaking additive: however, its retention is limited by absorption on the cellulose substrate (Maurer 2009). Another problem is the high viscosity of cooked starch paste. SNPs perform better than cooked native starch and the viscosity of the cooked paste can be substantially lowered (Kim, Park, and Lim 2015).

The compatible adhesives/consolidants presently used in conservation are wheat/rice starch paste and some of the cellulose derivatives (Rodgers 1988). One issue is similar to that of the papermaking industry: today we can manufacture papers with uniform porosity and a specific pore size, but papers of historic significance show a wide range of pore sizes. One of the methods to determine porosity claimed that most papers, unless coated, had an average pore radius of 0.2–1.2 µm (Carson 1940). The particle size of a native starch granule is much larger, namely 1–100 µm depending on botanical origin (Fuentes et al. 2019). The starch granule cannot penetrate the paper matrix and hence is left on the surface, forming a film and giving an undesirable sheen (Ream 1995). Also, increasing the concentration of the starch in order to increase adhesive strength compounds the problem. To deeply strengthen the paper matrix we need something like SNPs that can enter the pores of the paper.

Also, SNPs have significantly lower viscosity at similar concentrations (Kim, Park, and Lim 2015; Le Corre, Bras, and Dufresne 2010), which would provide better workability and enable more uniform application. The biodegradability and hydrophilicity of SNPs is reported to be better than native starch, making it more reversible, or more realistically, more re-treatable (Kim, Park, and Lim 2015; Torres et al. 2015). The other properties of starch like non-toxicity and compatibility with cellulose-based objects remain unaltered in SNPs (Sandhu and Nain 2017).

Synthesis of starch nanoparticles

Different shapes and sizes of SNPs can be synthesised (Guisbiers, Mejía-Rosales, and Deepak 2012). These methods may be classified as 'top-down' and 'bottom-up' processes (Kim, Park, and Lim 2015). In the 'top-down' process bulk particles are broken down by refining structure and shape using physical and chemical means until the desired size is obtained (Kim, Park, and Lim 2015). In the 'bottom-up' approach, nanoparticles are built up from atoms or molecules under regulated conditions by thermodynamic means such as self-assembly (Tan et al. 2009). More commonly, the 'top-down' method is employed for the synthesis of SNPs (Kim, Park, and Lim 2015). Top-down methods are easy to use, but do not produce particles with a specific size or shape, while bottom-up methods do, although they require specific

chemical reagents and advanced equipment, and give only low yields (Marta et al. 2023; Pattekari et al. 2011). While hydrolysis and physical techniques are top-down approaches, nanoprecipitation or self-assembly are bottom-up (Marta et al. 2023).

Acid hydrolysis with ultrasonication was found to be the most suitable choice, in respect of by-products, particle size, percentage yield and ease of preparation. Nanoparticles of wheat, rice, maize and waxy maize starches were synthesised using this top-down approach. Figure 2 shows a diagrammatic protocol of the methods followed during synthesis, optimised from Kim et al. (2013) to maximise yield and minimise energy consumption. Nanoparticles of all the starches were prepared following the same procedure but with slight alterations in time and temperature, as all these starches differ in their amylose and amylopectin composition.

Material and methods

Rice, wheat, maize and waxy maize starches were obtained from Merck. Concentrated sulphuric acid and sodium hydroxide pellets were purchased from Fisher Scientific.

Each of the native starches (30 g dry solid) was dispersed in 200 mL of 3M sulphuric acid using a magnetic stirrer set at 500 rpm at 40°C for 48 hours continuously. The hydrolyzates were then immediately neutralised using 1M sodium hydroxide. The neutralised suspension was then centrifuged at 12000rpm for 15 min and the precipitate was redispersed in distilled water. The residual sodium sulphate salt was washed away by repeating the precipitation and redispersion thrice.

The aqueous dispersions of starch hydrolyzates were next subjected to ultrasonic vibrations (Oscar ultrasonics, sonapros PR-250MP) using a probe-type sonicator. Ultrasonication was performed at an amplitude of 60% with an on/off pulse of 30/10 s. Each of the starch hydrolyzates had different susceptibilities, so wheat starch was treated for 10 min, rice starch for 20 min, maize starch for 40 min and waxy maize for 30 min.

The recovery yield of SNPs was calculated by drying 1 mL of the product and comparing it with the original weight of dry solids.

The hydrodynamic particle size distribution was measured using a dynamic light scattering (DLS) detector (DynaPro Nanostar, Wyatt system).

SNPs as a green consolidant

Efficient synthesis

Successful optimisation of a synthesis protocol for all SNPs was done by considering all the requirements

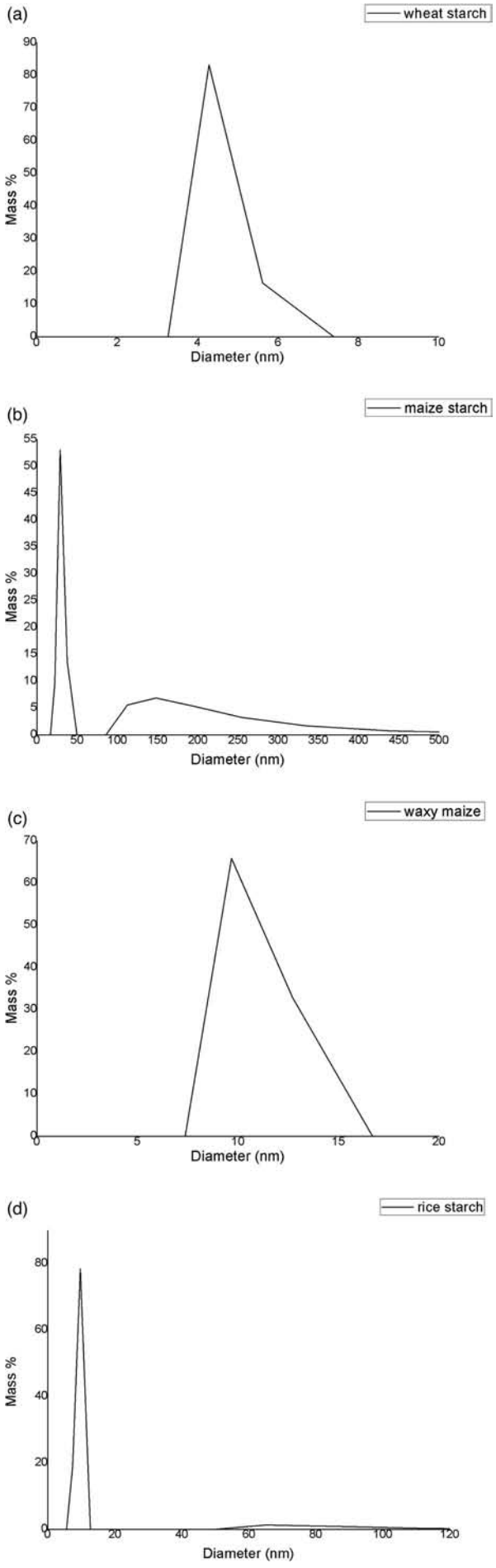


Figure 3. Size distribution for SNPs made from (a) wheat (b) maize (c) waxy maize and (d) rice starch.

of a potential consolidant. The method is simple, economical and scalable to an industrial level. The technique with minimum energy consumption, no residue on the artefact after application and maximum yield was chosen. The recovery yield for each of the SNPs was greater than 80%, which ensures minimum wastage of energy and resources.

Particle size and porosity

Figure 3 shows the particle size distribution of the SNPs. The average particles size of the wheat SNP (Figure 3a) was 4.5 nm, with a narrow peak showing that 99.6% of the particles were in the size range of 3–8 nm. Two size ranges (Figure 3b) were observed for the maize SNPs, with 76.2% of particles formed within the range 20–50 nm with a mean of 30 nm, while the remaining particles spanned 80–500 nm with a mean of 196 nm. The waxy maize SNPs size distribution pattern (Figure 3c) is similar to that of wheat: the majority of the particles were 7–17 nm with a mean of 11 nm. The rice SNPs showed a pronounced peak at 9.2 nm encompassing 97% of the particles formed, with the remainder in the range 50–100 nm as seen in Figure 3d, showing a slight curve in that area.

Each sample was sonicated at intervals of 10 minutes, and particle sizes were measured. The ones which gave the most uniform size distribution pattern and smallest particles were chosen and noted. It is worth noticing that the maize SNPs are the largest in size and do not give a prominent peak like the others. Upon sonication, it was observed that maize starch was the most difficult to break up. It took 40 minutes of sonication to break it to this size distribution and on further sonication no significant changes were seen. This is probably because of the high amylose content in maize starch (Zakaria, Muhammad, and Abdullah 2017).

Viscosity and distribution

Starch is cooked to form a paste, using different concentrations according to the requirements of the conservation task. This process of heating the starch in excess water is called gelatinisation (Zobel 1984): the starch granules swell up, leading to an increase in viscosity of the suspended starch particles as they form a paste (Eliasson 1986). The SNPs were gelatinised along with their native counterparts at the same concentration. Their rheological properties are not reported here, but it is known that the viscosity of gelatinised SNPs is less than that of gelatinised bulk starch. Traditionally cooked starch paste at a low concentration of 3% showed much higher viscosity at the same shear rate of $1000s^{-1}$ than an SNP suspension at a higher concentration of 9%, according to Kim, Park, and Lim (2015). This indicates that SNPs produce suspensions of much higher solid content at lower viscosity. The high solid content would increase adhesive strength, while the low viscosity would increase the absorption of starch on the cellulose substrate (Kim, Park, and Lim 2015).

A low viscosity at the same concentration also enables the consolidant be uniformly distributed within the cellulose matrix. High concentrations of starch can be applied with ease to the object using this method. Increasing the concentration of bulk starch increases the viscosity of the starch paste which in turn makes it undesirable to work with. SNPs provide us with a workable consistency at high concentrations as well. Figure 4 shows both gelatinised bulk and nano-starch at the same concentration. It can be very clearly seen how uniform and workable the nano-starches are. This also means that even at higher concentrations the starch suspension can be sprayed on friable objects because of its low viscosity.

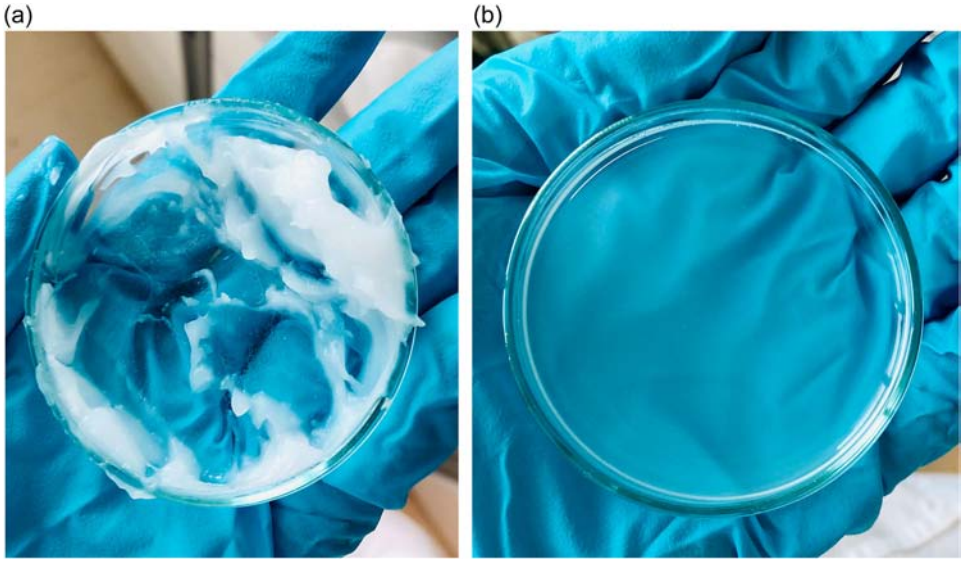


Figure 4. Bulk starch paste (a) nano-starch paste (b) at the same concentration.

Conclusion

This work aims to develop a natural, green and efficient consolidant for the conservation of cellulose-based objects of art. Not all parameters have not been tested yet but the theory and the practical work performed to date have been favourable. The synthesised SNPs were below 50 nm in size, which is much less than the pore sizes of most of historic papers, thus bypassing the complication of consolidants forming films on the surface of the object, as well as providing improved adhesive strength. This study reflects a dynamic and evolving area where efforts can be made to optimise conservation techniques and materials for better outcomes in preserving cultural heritage.

It would be interesting to compare all the starches from different sources and test them individually as a consolidant and an adhesive too. These SNPs have already found use in the food and papermaking industries and should be developed further for conservation use.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Ahmad, M., A. Gani, I. Hassan, Q. Huang, and H. Shabbir. 2020. "Production and Characterization of Starch Nanoparticles by Mild Alkali Hydrolysis and Ultra-Sonication Process." *Scientific Reports* 10: 3533. https://doi.org/10.1038/s41598-020-60380-0.

AIC. 2023. "BPG Adhesives". American Institute for Conservation Wiki. http://www.conservation-wiki.com/wiki/Adhesives_for_Paper (accessed 2.2.24).

Alcázar-Alay, S. C., and M. A. A. Meireles. 2015. "Physicochemical Properties, Modifications and Applications of Starches from Different Botanical Sources." *Food Science and Technology (Campinas)* 35: 215–236. https://doi.org/10.1590/1678-457X.6749.

Altavilla, C., and E. Ciliberto. 2011. *Inorganic Nanoparticles: Synthesis, Applications, and Perspectives, Nanomaterials and Their Applications*. Boca Raton: CRC Press.

Baglioni, P., and R. Giorgi. 2011. "Inorganic Nanoparticles for the Conservation of Works of Art." In *Inorganic Nanoparticles: Synthesis, Applications, and Perspectives, Nanomaterials and Their Applications*, edited by C. Altavilla, and E. Ciliberto, 17–33. Boca Raton: CRC Press.

Bloembergen, S. 2005. "Ecosynthetix Starch Nanoparticle Bioadhesive." *Journal Title* 27: 4–5. https://www.researchgate.net/publication/298623511_Ecosynthetix_starch_nanoparticle_bioadhesive/comments

Campelo, P. H., A. S. Sant'Ana, and M. T. Pedrosa Silva Clerici. 2020. "Starch Nanoparticles: Production Methods, Structure, and Properties for Food Applications." *Current Opinion in Food Science* 33: 136–140. https://doi.org/10.1016/j.cofs.2020.04.007.

Carson, F. T. 1940. "Some Observations on Determining the Size of Pores in Paper." *Journal of Research of the National Bureau of Standards* 24: 435–442. https://doi.org/10.6028/jres.024.025.

CCI. 2015. "Wheat Starch Paste." Canadian Conservation Institute Notes 11/4 http://canada.pch.gc.ca/eng/1439925170645 (accessed 7.16.17).

Chen, Q., X. Dong, L. Zhou, X. Zheng, J. Wang, and P. Wang. 2017. "Nanostarch Surface Coating of Lightweight Coated Paper." *BioResources* 13: 729–739. https://doi.org/10.15376/biores.13.1.729-739.

El-Naggar, M. E., M. H. El-Rafie, M. A. El-sheikh, G. S. El-Feky, and A. Hebeish. 2015. "Synthesis, Characterization, Release Kinetics and Toxicity Profile of Drug-Loaded Starch Nanoparticles." *International Journal of Biological Macromolecules* 81: 718–729. https://doi.org/10.1016/j.ijbiomac.2015.09.005.

Eliasson, A.-C. 1986. "Viscoelastic Behaviour During the Gelatinization of Starch i. Comparison of Wheat, Maize, Potato and Waxy-Barley Starches." *Journal of Texture Studies* 17: 253–265. https://doi.org/10.1111/j.1745-4603.1986.tb00551.x.

Fuentes, C., I. Kang, J. Lee, D. Song, M. Sjöö, J. Choi, S. Lee, and L. Nilsson. 2019. "Fractionation and Characterization of Starch Granules Using Field-Flow Fractionation (FFF) and Differential Scanning Calorimetry (DSC)." *Analytical and Bioanalytical Chemistry* 411: 3665–3674. https://doi.org/10.1007/s00216-019-01852-9.

Golińska, P. 2021. "Biopolymer-Based Nanofilms: Utility and Toxicity." In *Biopolymer-Based Nano Films*, 353–385. New York: Elsevier. https://doi.org/10.1016/B978-0-12-823381-8.00014-4.

Guisbiers, G., S. Mejía-Rosales, and F. L. Deepak. 2012. "Nanomaterial Properties: Size and Shape Dependencies." *Journal of Nanomaterials* 2012: 1–2. https://doi.org/10.1155/2012/180976.

Horie, C. V. 2005. *Materials for Conservation: Organic Consolidants, Adhesives and Coatings*. Oxford: Butterworth-Heinemann. [Reprinted Routledge 2010].

Kim, H.-Y., D. J. Park, J.-Y. Kim, and S.-T. Lim. 2013. "Preparation of Crystalline Starch Nanoparticles Using Cold Acid Hydrolysis and Ultrasonication." *Carbohydrate Polymers* 98: 295–301. https://doi.org/10.1016/j.carbpol.2013.05.085.

Kim, H.-Y., S. S. Park, and S.-T. Lim. 2015. "Preparation, Characterization and Utilization of Starch Nanoparticles." *Colloids and Surfaces B: Biointerfaces* 126: 607–620. https://doi.org/10.1016/j.colsurfb.2014.11.011.

Le Corre, D., J. Bras, and A. Dufresne. 2010. "Starch Nanoparticles: A Review." *Biomacromolecules* 11: 1139–1153. https://doi.org/10.1021/bm901428y.

Le Corre, D., and A. Dufresne. 2013. "Preparation of Starch Nanoparticles." In *Biopolymer Nanocomposites*, edited by A. Dufresne, S. Thomas, and L. A. Pothen, 153–180. Hoboken: John Wiley and Sons. https://doi.org/10.1002/9781118609958.ch8

Lin, N., J. Huang, P. R. Chang, D. P. Anderson, and J. Yu. 2011. "Preparation, Modification, and Application of Starch Nanocrystals in Nanomaterials: A Review." *Journal of Nanomaterials*, 1–13. https://doi.org/10.1155/2011/573687.

Marta, H., D. I. Rizki, E. Mardawati, M. Djali, M. Mohammad, and Y. Cahyana. 2023. "Starch Nanoparticles: Preparation, Properties and Applications." *Polymers* 15: 1167. https://doi.org/10.3390/polym15051167.

Masina, N., Y. E. Choonara, P. Kumar, L. C. du Toit, M. Govender, S. Indermun, and V. Pillay. 2017. "A Review of the Chemical Modification Techniques of Starch." *Carbohydrate Polymers* 157: 1226–1236. https://doi.org/10.1016/j.carbpol.2016.09.094.

Maurer, H. W. 2009. "Starch in the Paper Industry." In *Starch*, 657–713. New York: Elsevier. https://doi.org/10.1016/B978-0-12-746275-2.00018-5.

Oladebeye, A. O., A. A. Oshodi, I. A. Amoo, and A. A. Karim. 2015. "Selective Comparison of Native and Nanocrystals of White and Yellow Yam Starches." *Walailak Journal of Science and Technology* 12: 12. https://doi.org/10.14456/WJST.2015.95.

Pattekari, P., Z. Zheng, X. Zhang, T. Levchenko, V. Torchilin, and Y. Lvov. 2011. "Top-down and Bottom-Up Approaches in Production of Aqueous Nanocolloids of Low Solubility Drug Paclitaxel." *Physical Chemistry Chemical Physics* 13: 9014. https://doi.org/10.1039/c0cp02549f.

Pawar, R., W. Jadhav, S. Bhusare, R. Borade, S. Farber, D. Itzkowitz, and A. Domb. 2008. "Polysaccharides as Carriers of Bioactive Agents for Medical Applications." In *Natural-Based Polymers for Biomedical Applications*, 3–53. New York: Elsevier. https://doi.org/10.1533/9781845694814.1.3.

Rawat, A., U. Soni, R. S. Malik, and S. C. Pandey. 2018. "Facile Synthesis of UV Blocking Nano-Sized Zinc Oxide and Polymethyl-Methacrylate Polymer Nanocomposite Coating Material." *Nano-Structures & Nano-Objects* 16: 371–380. https://doi.org/10.1016/j.nanoso.2018.09.002.

Ream, J. D. 1995. "Observations on the Penetration of Two Consolidants Applied to Insecure Gouache on Paper." *Book and Paper Group Annual* 14: 27–40.

Rodgers, S. M., ed. 1988. "Consolidation/Fixing/Facing." In *The Paper Conservation Catalog*, 1–20. Washington D.C.: AIC.

Safari, J., and M. Sadeghi. 2017. "Nanostarch: A Novel and Green Catalyst for Synthesis of 2-Aminothiazoles." *Monatshefte für Chemie - Chemical Monthly* 148: 745–749. https://doi.org/10.1007/s00706-016-1805-8.

Sandhu, K. S., and V. Nain. 2017. "Starch Nanoparticles: Their Preparation and Applications." In *In Plant Biotechnology: Recent Advancements and Developments*, edited by S. K. Gahlawat, R. K. Salar, P. Siwach, J. S. Duhan, S. Kumar, and P. Kaur, 213–232. Singapore: Springer. https://doi.org/10.1007/978-981-10-4732-9_11.

Stoveland, L. P., T. Frøysaker, M. Stols-Witlox, T. Grøntoft, C. C. Steindal, O. Madden, and B. Ormsby. 2021. "Evaluation of Novel Cleaning Systems on Mock-Ups of Unvarnished Oil Paint and Chalk-Glue Ground Within the Munch Aula Paintings Project." *Heritage Science* 9: 144. https://doi.org/10.1186/s40494-021-00599-w.

Tan, Y., K. Xu, L. Li, C. Liu, C. Song, and P. Wang. 2009. "Fabrication of Size-Controlled Starch-Based Nanospheres by Nanoprecipitation." *ACS Applied Materials & Interfaces* 1: 956–959. https://doi.org/10.1021/am900054f.

Torres, F. G., O. P. Troncoso, J. Vega, and M. Wong. 2015. "Influence of Botanic Origin on the Morphology and Size of Starch Nanoparticles from Andean Native Starch Sources." *Polymer Renewable Resources* 6: 91–104.

van Steene, G., and L. Masschelein-Kleiner. 1980. "Modified Starch for Conservation Purposes." *Studies in Conservation* 25: 64–70. https://doi.org/10.1179/sic.1980.25.2.64.

Weththimuni, M. L., A. Girella, M. Ferretti, D. Sacchi, and M. Licchelli. 2023. "Nanostructured Emulsions as Smart Cleaning Materials for Removing Aged Polymer Coatings from Stone Substrates." *Sustainability* 15: 8117. https://doi.org/10.3390/su15108117.

Yam, K. L. 2010. *The Wiley Encyclopedia of Packaging Technology*. New York: John Wiley and Sons.

Zakaria, N. H., N. Muhammad, and M. M. A. B. Abdullah. 2017. "Potential of Starch Nanocomposites for Biomedical Applications." *IOP Conference Series: Materials Science and Engineering* 209: 012087. https://doi.org/10.1088/1757-899X/209/1/012087.

Zobel, H. F. 1984. "Gelatinisation of Starch and Mechanical Properties of Starch Pastes." In *Starch: Chemistry and Technology*, 285–309. New York: Elsevier.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S305–S313
https://doi.org/10.1080/00393630.2024.2364993

Check for updates

Interrogating Pollutants in Collecting Institutions During the Implementation of HVAC Energy-Saving Strategies: Lessons Learned and Practical Implications for Optimizing Sustainable Environmental Control

Interrogación de Contaminantes en Instituciones Recolectoras durante la Implementación de Estrategias de Ahorro de Energía en HVAC: Lecciones Aprendidas e Implicaciones Prácticas para Optimizar el Control Ambiental Sostenible

Emma Richardson [1], Kelly McCauley Krish[2], Marvin Cummings[1], Martin Schooping[3], Philip Hopke[4] and Jean Tétreault[5]

[1]Image Permanence Institute, Rochester Institute of Technology, Rochester, NY, USA; [2]Colonial Williamsburg Foundation, Williamsburg VA, USA; [3]Golisano Institute of Sustainability, Rochester Institute of Technology, Rochester, NY, USA; [4]Independent consultant, Rochester, NY, USA; [5]Canadian Conservation Institute, Ottawa, Canada

ABSTRACT

Strategies of outside air reduction, fan speed adjustments, and temporary system shutdowns can be effective ways to maintain or improve the preservation quality of a collection environment while reducing the financial burden and carbon footprint of a collecting institution. However, current criteria guiding safe implementation of energy-saving strategies focus on temperature and RH alone, which ignores risks posed by pollutants. This research aims to address this by monitoring indoor and outdoor-generated pollutants at four collecting institutions before and during implementing energy-saving strategies. Alongside temperature and RH loggers, continuous pollution monitors were located within the mechanical system and collection spaces. Additionally, energy monitors were installed on the mechanical systems serving the collection spaces to quantify the energy consumption prior to and during operation modifications. Initial results indicate pollutant levels remain stable during the test periods, and did not exceed baseline concentrations. In this paper, the lessons learned from this field research are addressed and practical implications for optimizing sustainable environmental controls are given.

Las estrategias de reducción del aire exterior, ajustes de la velocidad de los ventiladores y apagados temporales del sistema pueden ser formas efectivas de mantener o mejorar la calidad de preservación de un entorno de recolección y, al mismo tiempo, reducir la carga financiera y la huella de carbono de una institución recolectora. Sin embargo, los criterios actuales que guían la implementación segura de estrategias de ahorro de energía se centran únicamente en la temperatura y la humedad relativa, ignorando así los riesgos que plantean los contaminantes. Esta investigación tiene como objetivo abordar este tema mediante el monitoreo de contaminantes generados en interiores y exteriores en cuatro instituciones recolectoras antes y durante la implementación de estrategias de ahorro de energía. Además de los registradores de temperatura y humedad relativa, se ubicaron monitores continuos de contaminación dentro del sistema mecánico y los espacios de recolección. Además, se instalaron monitores de energía en los sistemas mecánicos que dan servicio a los espacios de recolección para cuantificar el consumo de energía antes y durante las modificaciones de operación. Los resultados iniciales indican que los niveles de contaminantes permanecieron estables durante los períodos de prueba y no excedieron las concentraciones iniciales. En este artículo, se abordan las lecciones aprendidas en esta investigación de campo y se dan implicaciones prácticas para optimizar los controles ambientales sostenibles.

ARTICLE HISTORY
Received November 2023
Accepted June 2024

KEYWORDS
Energy-saving strategies; HVAC; indoor air quality; pollutants; sustainability

Estrategias de ahorro de energía; climatización; calidad del aire interior; contaminantes; sostenibilidad

Introduction

As our understanding of the material science of collections has developed over the decades, it is recognized that the majority of museum and archive collections can safely be exposed to some degree of dynamic change to their immediate environment (Erhardt and Mecklenburg 1994; Michalski 2018; Kompatscher et al. 2019), broadening the recommended range of temperature and relative humidities while continuing to meet preservation aims. Over the past decade, the Image Permanence Institute (IPI) has worked with collecting institutions across the U.S.A. to apply this

CONTACT Emma Richardson ejrpph@rit.edu Image Permanence Institute, Rochester Institute of Technology, Rochester, NY 14623, USA
© The International Institute for Conservation of Historic and Artistic Works 2024

knowledge to collections environments. IPI's *Methodology for Implementing Sustainable Energy-Saving Strategies* (Image Permanence Institute 2017) outlines procedures used for mitigating risk during the implementation of six different energy-saving strategies, namely light reduction, seasonal set points, outside air reduction, fan speed adjustments, system shutdowns, and system setbacks.

Notably though, several of these involve reduced airflow and ventilation in collection storage spaces, and studies have shown the significance of air exchange in determining indoor pollutant levels. However, it is currently uncommon for pollutants to be regularly monitored in collecting institutions. A 2010 survey by Prosek et al. (2010), suggests that only 3% of heritage sites in Europe and North America monitor air quality parameters other than temperature and relative humidity (RH) (Agbota, Young, and Strlič 2013). Assessing the potential impact sustainable mechanical operations have on indoor pollutant levels will inform decisions regarding safe, sustainable management of collections, balancing both benefits and risks.

The potential cost-benefits are significant. Heating, ventilation, and air-conditoning (HVAC) systems that maintain storage and display conditions represent a sizable portion of energy consumption and operational costs for a collecting institution. According to the International Energy Agency, the operation of buildings accounts for 30% of global energy consumption and 26% of direct and indirect energy-related emissions (International Energy Agency 2023). With over 30,000 museums across the U.S.A. alone (Frehill and Pelczar 2018), many of which are housed in large, historic buildings, the museum sector has the potential to play a significant part in improving energy efficiency and reducing the associated carbon footprint alongside caring for our cultural heritage.

Challenges posed by Covid-19 pandemic closures further increased our need to understand the effects of implementing strategic mechanical system modifications that result in reduced air exchanges in collections spaces. In 2020, the American Association of Museums newsletter recommended closing air dampers to save energy and reduce costs during periods of institutional closure (Lee 2020), and ASHRAE's *Guidance for Re-opening Buildings* recommended running mechanical systems with the minimum amount of outside air during reduced occupancy periods (ASHRAE 2021). However, higher air ventilation is important to help prevent the transmission of airborne viruses or harmful accumlations of carbon dioxide (CO_2) (Franco and Leccese 2020), highlighting the need for a balance between indoor air quality and energy efficiency. Emergency guidance, such as during the pandemic and during increasingly intense wildfires, usually direct attention to the amount and timing of outside air usage. Understanding the implications of this course of action on outdoor and indoor generated pollutants in collections is important to ensure safe environments for people and objects.

In 2016, the National Archives and Records Administration (NARA) estimated that the mechanical system in one of their buildings was costing approximately $1.5 million per year in electricity (Ormsby 2016). In an effort to reduce those energy costs, NARA tested the potential of shutting down redundant air handling units (AHUs) and reduced air exchange rates in collections storage spaces in the building. The study found no significant difference in the acetic acid and formaldehyde levels in the spaces after implementing changes. They then applied further pollutant monitoring to inform decisions about filtration on the AHUs. This work demonstrated the successful integration of pollutant monitoring into institutions for sustainability purposes.

Working in collaboration with four collecting institutions on the east coast of the U.S.A., we have expanded upon the work of Ormsby (2016) to assess changes in room-level pollutant concentrations during the implementation of outside air reduction (OAR), fan speed adjustments (FSA), and system shutdowns (SS). These three strategies have formed the focus of our current research due to their direct impact on air exchange at the room level.

Methodology and instrumentation

Partner identification

Four collecting institutions were identified as collaborative partners following an open call for applications through IPI's quarterly newsletter, and the American Institute of Conservation's online membership community. Each successful institution needed to: identify a collection space where the mechanical system did not serve other spaces; demonstrate the mechanical system was capable of operational modification; and commit staff time over the course of two years. Following this process, two museums and two archives were identified as suitable partners. Collections included furniture, sculpture, natural history specimens, and paper-based materials, including photographs. All four institutions are located in east coast U.S.A. urban environments. In this publication, the data from each institution has been anonymized.

Continuous monitoring systems

Wireless South Coast Science (SCS) Praxis/Urban monitors were installed at the outside air (OA) inlet, the supply air (SA) to the collection space, and the return air (RA) of the air-handling unit at all four partner

institutions (Figure 1), allowing the movement of pollutants to be tracked through the mechanical system. The SCS monitors use Alphasense sensors that measure particulate matter up to 1, 2.5 and 10 µm in diameter (PM_1, $PM_{2.5}$ and PM_{10}, respectively, the last being the combination of all three measurements) at the µg/m^3 level, total volatile organic compounds (tVOCs, with reference gas isobutylene), nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2) at the parts per billion (ppb) level and CO_2 at the parts per million (ppm) level. (The conversion factors at 25°C are: NO_2 1ppb = 1.88 µg/m^3; O_3 1ppb = 1.96 µg/m^3; SO_2 1ppb = 2.62 µg/m^3, and CO_2 1 ppm = 1.80 mg/m^3). The SCS monitors also incorporate temperature, RH, and barometric pressure sensors. Where safe access within the air handling units was possible, additional Preservation Environment Monitor (PEM2®) temperature and RH loggers were installed at the mixed air, cooling coil, and heating coil components. IPI PEM2® loggers were also located within the collection spaces to monitor the impact of the energy-saving strategies on the indoor environment at the collection level. Energy consumption of the mechanical system was monitored at each institution using Dent ElitePro™ Power Data Loggers connected remotely via the instiution's virtual private network (VPN). The sampling resolutions of the South Coast Science and Dent ElitePro™ Power loggers were 15 min and the PEM2® loggers sampled every 5 min and averaged over six readings (30 min).

Discrete monitoring system

Specific indoor generated pollutants, namely formic acid and acetic acid, were monitored at the collection level using diffusion dosimeters from IVL Swedish Environmental Research Institute. Dosimeters were deployed within each collection for two weeks during each season of the baseline year of data collection and during testing of each individual energy-saving strategy (see below). The detection limits are inversely proportional to the exposure time, calculated for each sampling period relative to equivalent diffusive sampling for one month, giving measuring ranges of 5–500 µg/m^3 and 7–833 µg/m^3 for formic acid and acetic acid, respectively.

Baseline conditions and optimization

Prior to assessing the impact of the energy-saving strategies on the indoor environment, pollutant levels, and energy consumption, the baseline conditions were determined for each of the four partners. Baseline data was collected over a 12-month period to assess seasonal variations during standard operation and highlight opportunities for future optimization of the mechanical system and the associated collections environment.

Sustainable environmental management strategies

Once baseline data was reviewed in collaboration with the collections care and facilities teams at each institution, individual energy-saving strategies were implemented: outside air reduction, fan speed adjustments, and system shutdown.

Following IPI's protocol, individual strategies were implemented for two-week periods during different seasons, which can inform implementation over longer timeframes. While there is an energy cost associated with restarting the mechanical system following a shutdown, where a mechanical system has approximately 30% redundancy in heating and cooling capacity, an economical recovery is possible following a nightly setback or shutdown, assuming that the temperature in the space does not change by more than 4°C.

The indoor environment, pollutant levels, and energy consumption were monitored on a daily basis during the course of the test period. An individual energy-saving strategy was considered successful if the environmental data within the collection spaces met the following criteria:

- Temperature and RH did not rise significantly.
- Changes in RH did not exceed the safe range for collection type (as defined by the collecting institution).
- Temperature and RH fluctuations were not greater than those seen during standard operation.
- There were no cumulative temperature and RH gains after the testing period(s).
- Pollutant levels never increased to levels statistically higher than those seen prior to energy-saving implementation (average baseline values).
- Pollutant levels returned to average baseline levels consistently following testing (i.e. the mechanical system is able to recover fully and remove build-up).

Key results and discussion (lessons learned)

Quantifying pollutant levels during energy-saving modifications

During 2023, the energy-saving strategies were tested while monitoring for statistically significant changes in pollutants and assessing potential energy savings. Data acquisition and analysis is still underway and will be published in due course, but initial results indicate that pollutant levels remained stable during the two-week testing periods, not exceeding those measured during the baseline year of monitoring.

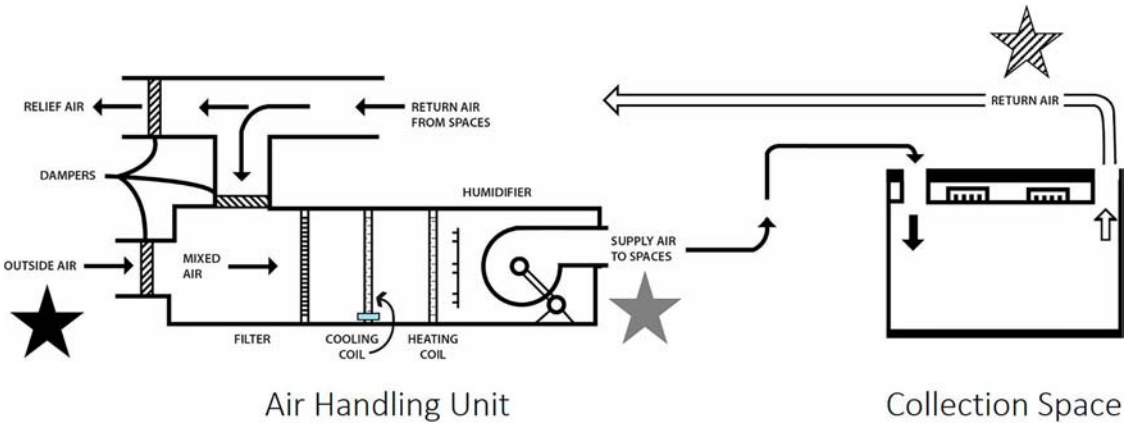


Figure 1. Generalized schematic of an air handling unit and collection space, showing the location of the South Coast Science pollutant monitors at the OA inlet (black star), SA to the collection space (gray star), and the RA to the air handling unit (striped star).

As an illustration, Institute I implemented a FSA during the winter of 2023, which encompased a total shutdown of the SA fan while continuing the use of the RA fan, essentially resulting in a 50% reduction in energy usage (Its collections are housed in the interior spaces of an early twentieth-century building, maintained at 19 ± 0.5°C and 46 ± 3% RH during standard operation.). The mechanical system maintained this operation continuously throughout the test, including during periods of occupancy by collections care staff. Concentrations of CO_2 measured at the RA from the collection space did not significantly increase during testing, with baseline winter levels averaging 515.2 ± 84 ppm compared to 472.6 ± 25 ppm during the winter FSA. Typical levels in occupied spaces range from 600–1,000 ppm (E. N. 2007). While diurnal effects were apparent in the data, with levels increasing during the daytime and falling during the evening, reducing air flow within the air handing unit did not constitute a degradation in indoor air quality.

Monitoring the performance of the mechanical system during natural events

During the course of the environmental monitoring campaign in the summer of 2023, Canada experienced a number of extensive wildfires covering approximately 13.5 million hectares of land (Voiland 2023), which had a significant, negative impact on the outdoor air quality across eastern North America. The continuous monitors located within the mechanical systems at each partner institution enabled the outdoor particle concentrations from the wildfires to be assessed and to track the performance of the filtration systems in the air handling units. Figure 2 shows the concentrations of PM_1, $PM_{2.5}$ and PM_{10} measured at the OA inlet and the SA at Institute II during the wildfires in June 2023 (Its collections are housed in the interior spaces of an early twentieth-century building, maintained at 19 ± 0.5°C and 46 ± 3% RH during standard operation.). Over a period of four days, OA particulates increased by a factor of 2–3 during the wildfires, while indoor particulates did not increase signifiantly compared to baseline levels.

During the time of the wildfires, the mechanical system at Institute II was running with reduced outside air and the air handling unit was equipped with filters that had minimum efficiency reporting values (MERV) of 8 and 16 positioned immediately after the outside air damper; MERV 13 filtration or higher are recommended by ASHRAE during smoke events (Javins et al. 2021). In combination, these two factors helped prevent increased levels of particulates entering the collection space. Tétreault (2021) has proposed limits for increased risk to collection objects due to fine particles ($\leq PM_{2.5}$) to be in the region of 10 µg/m^3, and this goal was met.

Following careful protocols, outside air reduction not only serves to maintain appropriate temperature and RH levels within collection spaces by reducing the load placed on the mechanical systems, but can also prove an effective response to external environmental events (Javins et al. 2021). As extreme natural events are set to increase with climate change, integrating such strategies as part of normal operational controls can reduce costs and the associated carbon footprint, alongside a reduction in the potential risk to collections when natural disasters occur.

Identifying and addressing existing limitations

At Institute III, it became apparent early in the project that the mechanical system presented complications for effective summer operation. (Its collections are housed in a late nineteenth-century building, with one exterior wall, and approximating 300 m^2, maintained at 24 ± 1.2°C and 47 ± 12% RH during standard operation.) The cooling coil was positioned

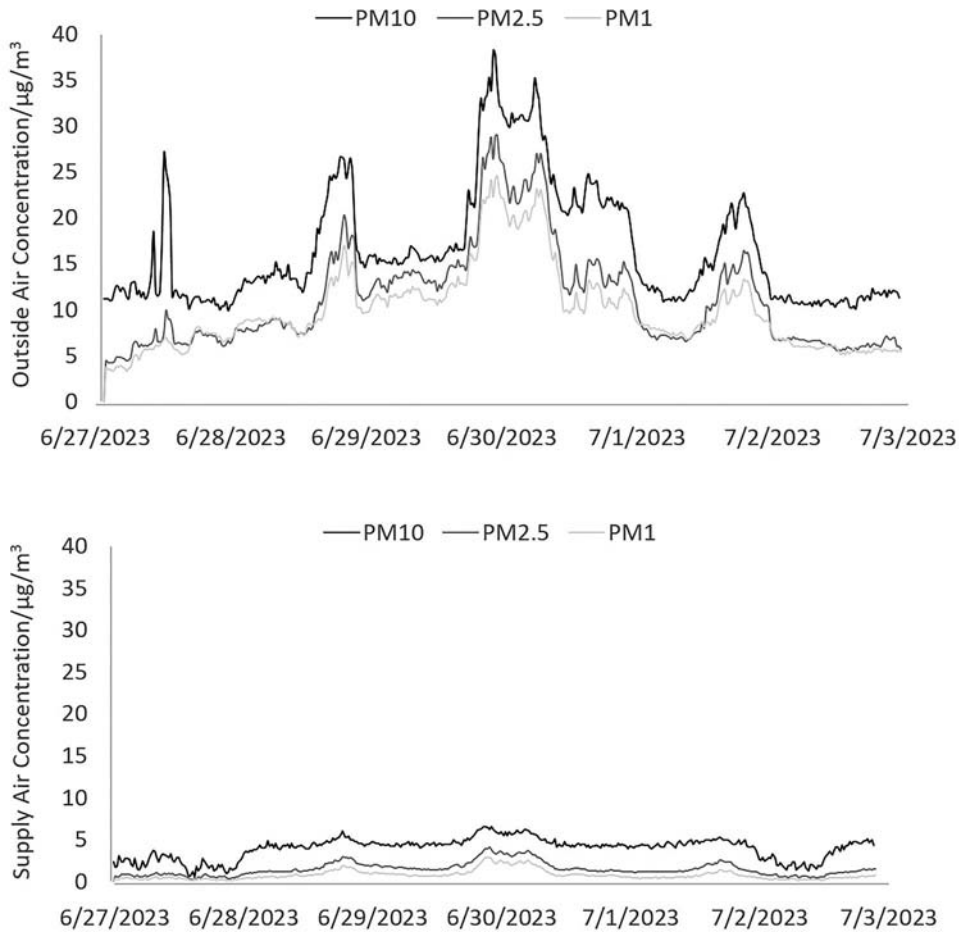


Figure 2. Particle concentrations in µg/m^3 of PM_1, $PM_{2.5}$ and PM_{10} measured at the OA inlet (upper) and the SA (lower) at Institute II during the wildfires in June 2023. Note: PM_{10} concentrations are a combination of PM_1, $PM_{2.5}$ and PM_{10} measurements.

downstream from the heating coil, which meant moisture could not be condensed out of the air during the summer without subsequently passing cold, saturated air into the collection space. The risk to the collection is demonstrated in Figure 3 by the high dew point at the heating coil and SA, and the corresponding eClimate-Notebook Mold Risk Factor metric (Nishimura 2011). Adjustments in fan speed result in local reductions in air movement within the mechanical system, potentially increasing the risk of mold and the presence of moist air. Additionally, the potential benefits offered by these strategies are diminished by the cost of inefficiencies associated with other aspects of the poorly optimized mechanical systems. Therefore, following discussion with the Institute's collections care and facilities teams, it was decided that energy-saving strategies would not be implemented until alterations could be made to their mechanical system. The existing limitations of the system not only pose challenges for preservation, but also limit the potential for adaption of energy-saving strategies to meet sustainability goals.

While we were unable to meet all project goals with this partner, the environmental monitoring and review process will inform changes that enable the institution to enhance optimization of the HVAC system serving the collections space. The result demonstrates the value of monitoring mechanical system performance and understanding system capabilities to guide sustainable environmental management for preservation.

Understanding the capabilities of the monitoring systems

Quantification of indoor and outdoor generated VOCs, and the identification of their source, is an important aspect of preventive conservation, given low levels of pollutants can have a detrimental impact on certain collection materials (Grzywacz 2006; Kraševec et al. 2021). They are not fully integrated into collection monitoring strategies, in part due to the relatively high cost of monitoring systems (Breitung et al. 2020), but also the capabilities of discrete and continuous pollutant monitors for indoor applications. The project team were unable to identify a continuous monitoring system capable of detecting ppb levels of the indoor generated pollutants formic acid and acetic acid. Therefore, organic acid diffusion dosimeters were deployed within the collections.

As outlined, protocols for assessing energy-saving strategies require testing over relatively short periods to determine cumulative effects, while also minimizing

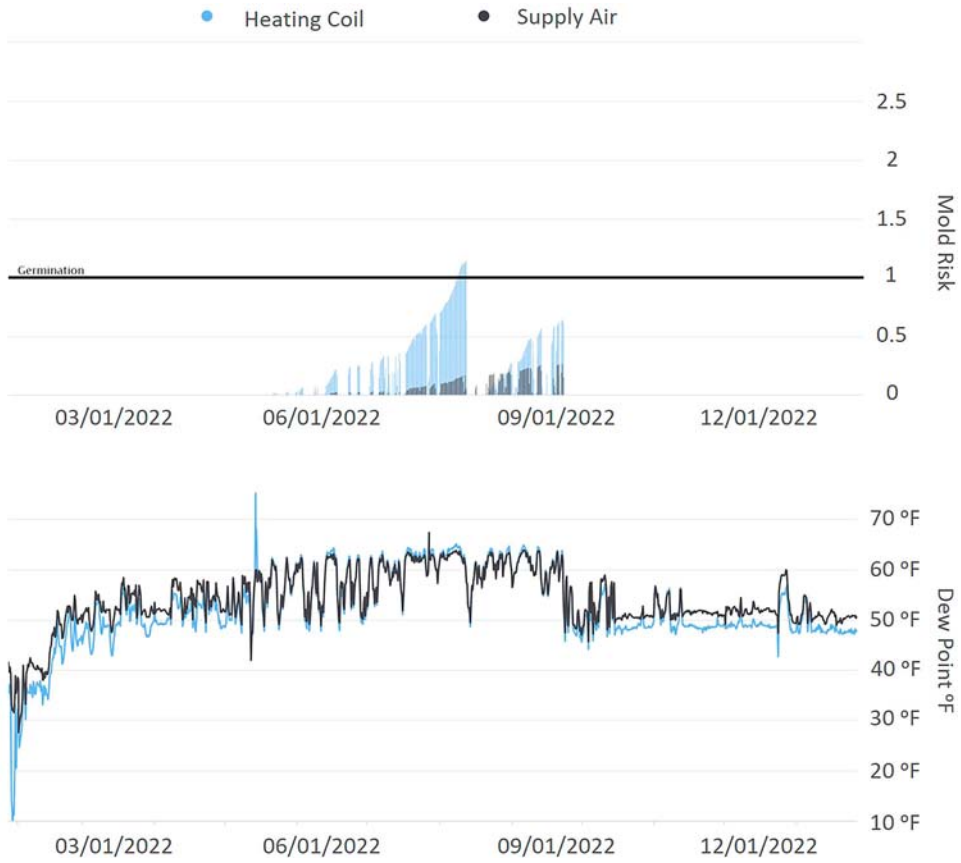


Figure 3. Baseline dew point (°F) meaured at the heating coil (blue) and the supply air (black) between February 2022 and January 2023 at Institute III (lower), and the corresponding eClimateNotebook Mold Risk Factor metric (upper) for the same time period. Horizontal line denotes MRF = 1.0, which indicates that conditions are favorable for active mold growth if spores are present.

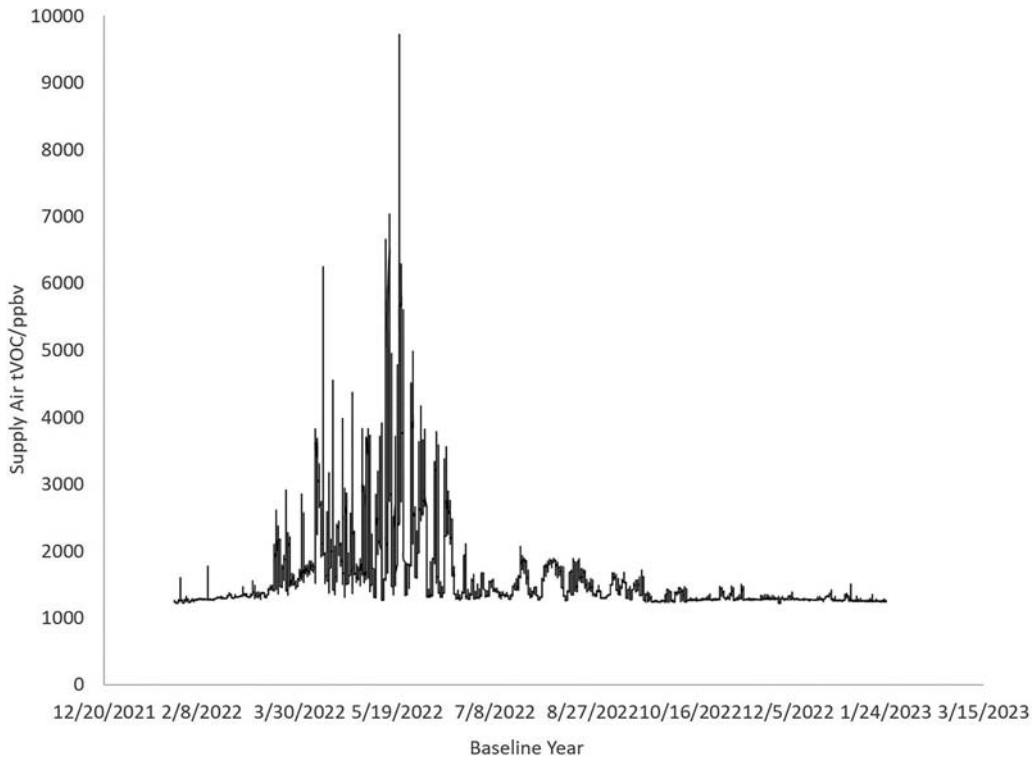


Figure 4. Baseline tVOC (ppbv) measured at the supply air between February 2022 and January 2023 at Institute III, showing the constant baseline offset at the detection limit of the sensor, and the high concentrations of volatiles during spring 2022.

Table 1. Baseline concentrations (μg/m^3) of formic acid and acetic acid measured using IVL diffusion dosimeters in the collection space of Institute III, showing increased local concentrations for formic acid during spring 2022.

			Spring 2022		Summer 2022		Fall 2022		Winter 2023	
Baseline 2022/23	Institution	Location	Formic	Acetic	Formic	Acetic	Formic	Acetic	Formic	Acetic
	Institute III	Outside Cabinet IA	18.6	<7.0	8.1	<5.0	9.3	<6.0	9.9	<10.0
	Institute III	Outside Cabinet IB	<5.0	<7.0	6.5	<5.0	13	<6.0	<8.0	<10.0

potential risk to collections during the optimization process. However, detection limits of diffusion dosimeters are inversely proportional to the exposure time, having the effect of increasing the detection limits during short test periods. Therefore, careful consideration needs to be given to the lowest observable adverse effect dose (LOAED) for a given pollutant, the associated collection material (Breitung et al. 2020), and length of deployment within the field, to ensure the dosimeters are capable of detecting potentially damaging pollutant levels.

Additional challenges were posed by the capabilities of the continuous tVOC monitors. Figure 4 shows the baseline data for tVOC concentrations at the supply air of Institute III. While the sensitivity to VOCs is reported to be in the ppb, the offset to the y-axis demonstrates the lower limit of detection for this sensor, which was 1,200 ppb. Under normal circumstances, these sensors would not provide the level of sensitivity to guide collections management decisions (Menart, de Bruin, and Strlič 2014). However, in this particular case, the level of tVOCs detected in the air handling unit were unusually high during the spring of 2022, reaching a maximum of 9,720 ppb in May 2022. These high VOCs were attributed to an exhibition workshop located close to the collection space preparing for an installation. The diffusion dosimeters deployed in the collection also saw a higher concentration in formic acid than during the remainder of the baseline year (Table 1). The direct correlation between increasing pollutant levels and the activity within the exhibitions workshop helped inform building management priorities for improved collections care and supported the collections care team in advocating for additional measures that restrict organic vapor infiltration.

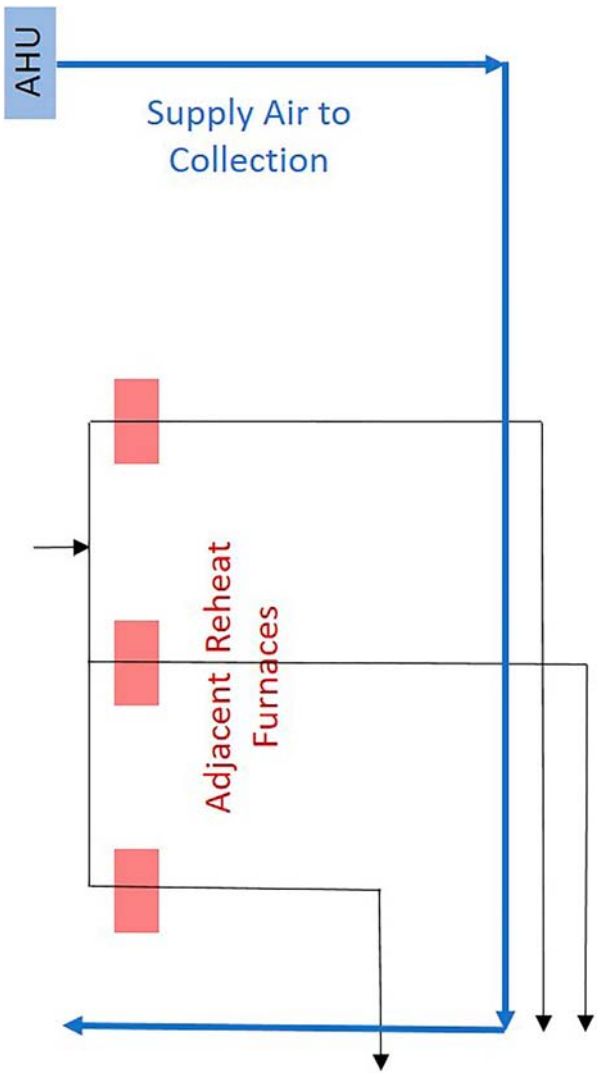


Figure 5. Schematic of the supply air ductwork crossing adjacent furnaces from an adjacent air handling unit, one of the potential heat sources increasing the air temperature of the SA.

Investigating the impact of adjacent spaces and mechanical systems

The successful implementation of energy-saving strategies in collecting institutions are dependent on a number of factors beyond the capabilities of the mechanical system, such as the needs of the collection, human comfort expectations, and the building envelope (Ankersmit and Stappers 2017). Similarly, the impact of adjacent spaces on air quality are also important as was demonstrated at Institute IV during the implementation of a system shutdown (Its collections are housed in a late nineteenth-century building, with one exterior wall, and approximating 300 m^2, maintained at 24 ± 1.2°C and 47 ± 12% RH during standard operation.). This Institute had successfully employed an outside air reduction (OSR) approximating 70%, and a fan speed adjustment (FSA) serving the collection, without compromising the preservation quality of the environment. Given the success of the OSR and FSA, a system shutdown comprising: closure of the OA dampers; closure of the cooling and heating valves; shutdown of the humidifier; and the shutdown of the fan, was tested during the winter of 2023.

During the initial four-hour period of the shutdown, the air temperature at the mixed air and SA in the AHU

increased. The supply air increased from an average baseline of 10.2 ± 0.8°C to a maximum temperature of 21.6°C, and was accompanied by an increase in the dew point, which indicated a moisture source. The collection space experienced only a minor increase in temperature of 3 °C during this time.

Changes in air temperature and dew point were unexpected and conclusive identification of the heat and moisture source has proven challenging. The range of possibilities include diffusion through the room envelope from the neighboring mechanical room, gains in the supply air ductwork due to neighboring furnaces (Figure 5), moisture gains attributable to the basement location, or mechanical component(s) that remained switched on. While the collections were not at risk, the source must be identified prior to implementing further system shutdowns to avoid warm, moist air moving into the collection space.

This example illustrates that successful implementation of sustainable strategies is not always a straightforward task and is dependent on multiple factors. It requires commitment and collaboration to establish a good working knowledge of the mechanical system, to identify the potential impact of adjacent spaces or equipment, and to carefully test protocols prior to longer integration into HVAC operation.

Conclusions

The cultural heritage sector has the potential to play a significant part in improving energy efficiency and reducing the associated carbon footprint alongside caring for our cultural heritage. Strategies of temporary system shutdowns, fan speed adjustments, and outside air reduction are effective ways to maintain or improve the preservation quality of a collection environment while reducing the financial burden and carbon footprint of a collecting institution. However, the current criteria guiding safe implementation of energy-saving strategies focuses on temperature and RH alone, which ignores risks posed by pollutants. The current research aims to address this gap and develop new recommendations for safe implementation.

While there were measurement limitations posed by the pollutant monitoring systems employed for *in situ* analysis, initial results indicate that energy-saving modifications can be safely implemented without significantly increasing collection-level pollutants, so long as methodologies for optimization are carefully followed. Stratagies that reduce the amount of outside air not only reduces the load placed on the mechanical system but also reduces infiltration of damaging particles during wildfires. As illustrated, testing is necessary prior to full implementation of HVAC modifications to highlight potential limitations, which may include inherent limitations posed by the mechanical system's capabilities, or the influence of adjacent spaces and equipment. Safely implementing modifications to the operation of mechancial systems serving collection spaces nessitates cross-disciplinary collaboration and a commitment to methodical testing and optimization. Successful sustainable collections environmental management requires a systematic understanding of the different influences on the indoor environment in order to identify opportunities for improvement, and address energy redundency in the system.

Acknowledgements

The authors would like to acknowledge the time and enthusiasm of the collections care and facilities teams at each partner institution, namely the Carnegie Museum of Art and the Carnegie Museum of Natural History; the George Eastman Museum; the Metropolitan Museum of Art (Department of Scientific Research, European Sculpture and Decorative Arts Department, and Buildings Department); and the U.S.A. National Archives and Records Administration Heritage Science Research and Testing. We are also grateful to our colleagues, Christopher Cameron and Daniel Burge, who supported the development of this research project.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This research was supported by the National Endowment for the Humanities, Division of Preservation and Access, [grant number PR-276878-21].

ORCID

Emma Richardson http://orcid.org/0000-0001-9346-2391

References

Agbota, H., C. Young, and M. Strlič. 2013. "Pollution Monitoring at Heritage Sites in Developing and Emerging Economies." *Studies in Conservation* 58 (2): 129–144. https://doi.org/10.1179/2047058413Y.0000000083.

Ankersmit, B., and M. H. L. Stappers. 2017. *Managing Indoor Climate Risks in Museums*. Cham: Springer International Publishing.

ASHRAE. 2021. *Guidance for Re-opening Buildings*. Accessed October 2023. https://www.ashrae.org/file%20library/technical%20resources/covid-19/guidance-for-re-opening-buildings.pdf.

Breitung, E., J. de Gouw, P. Hatchfield, F. McNeill, and D. Thickett. 2020. *Indoor Air Quality in the Museum Environment*. Accessed February 2023. https://www.metmuseum.org/-/media/files/about-the-met/conservation-and-scientific-research/department-of-scientific-research/2020_iaq_museum_workshop.pdf.

BSI. 2007. EN 13779: *Ventilation for Non-Residential Buildings-Performance Requirements for Ventilation and Room-Conditioning Systems*. London: British Standards Institution.

Erhardt, D., and M. Mecklenburg. 1994. "Relative Humidity re-Examined." *Studies in Conservation* 39 (sup2): 32–38. https://doi.org/10.1179/sic.1994.39.Supplement-2.32.

Franco, A., and F. Leccese. 2020. "Measurement of CO_2 Concentration for Occupancy Estimation in Educational Buildings with Energy Efficiency Purposes." *Journal of Building Engineering* 32: 101714. https://www.sciencedirect.com/science/article/pii/S2352710219316912.

Frehill, L., and M. Pelczar. 2018. *Data File Documentation: Museum Data Files, FY 2018 Release*. Washington, D. C.: Institute of Museum and Library Services.

Grzywacz, C. 2006. *Monitoring for Gaseous Pollutants in Museum Environments*. Los Angeles: Getty Publications.

Image Permanence Institute. 2017. *Methodology for Implementing Sustainable Energy-Saving Strategies*. Rochester, NY: Image Permanence Institute.

International Energy Agency. 2023. *Energy System: Buildings*. Accessed February 2023. https://www.iea.org/energy-system.

Javins, T., G. Robarge, E. G. Snyder, G. Nilsson, and S. Emmerich. 2021. "IEQ Applications: Protecting Building Occupants from Smoke During Wildfire and Prescribed Burning Events." *ASHRAE Journal March*, 38–43. https://store.accuristech.com/ashrae/standards/ieq-applications-protecting-building-occupants-from-smoke-during-wildfire-and-prescribed-burn-events?gateway_code = ashrae&product_id = 2210637.

Kompatscher, K., R. P. Kramer, B. Ankersmit, and H. L. Schellen. 2019. "Intermittent Conditioning of Library Archives: Microclimate Analysis and Energy Impact." *Building and Environment* 147: 50–66. https://store.accuristech.com/ashrae/standards/ieq-applications-protecting-building-occupants-from-smoke-during-wildfire-and-prescribed-burn-events?gateway_code = ashrae&product_id = 2210637.

Kraševec, I., E. Menart, M. Strlič, and I. Kralj Cigić. 2021. "Validation of Passive Samplers for Monitoring of Acetic and Formic Acid in Museum Environments." *Heritage Science* 9 (1): 19. https://heritagesciencejournal.springeropen.com/articles/10.1186s40494-021-00495-3.

Lee, J. S. 2020. *Earth Day during COVID-19: Green Tips for Closed Museums*. American Alliance of Museums. Accessed September 2023. https://www.aam-us.org/2020/04/22/earth-day-during-covid-19-green-tips-for-closed-museums.

Menart, E., G. de Bruin, and M. Strlič. 2014. "Effects of NO2 and Acetic Acid on the Stability of Historic Paper." *Cellulose* 21 (5): 3701–3713. https://doi.org/10.1007/s10570-014-0374-4.

Michalski, S. 2018. *Agent of Deterioration: Incorrect Temperature. Preventive Conservation and Risks*. Accessed February 10, 2023. https://www.canada.ca/en/conservation-institute/services/agents-deterioration/temperature.html.

Nishimura, D. 2011. *Understanding Preservation Metrics*. Rochester, NY: Image Permanence Institute.

Ormsby, M. 2016. "Experiments with Reducing Energy use at the National Archives and Records Administration." Presented at the 12th Indoor Air Quality Conference *Heritage Research to Conservation Practice*, Birmingham, UK. http://iaq.dk/iap/iaq2016/Ormsby_IAQ2016.pdf.

Prosek, T., M. Taube, M. Dubus, M. Kouril, V. Hubet, Y. Degres, B. Scheffel, and D. Thierry. 2010. "Survey on Air Quality Control in Culutral Heritage Institutions and Development of Automated Corrosion Sensors for Real Time Monitoring." Presented at the 9th Indoor Air Quality Conference, Chalon-sur-Saone, France. http://www.iaq.dk/iap/iaq2010/iaq2010_prosek.pdf.

Tétreault, J. 2021. *Control of Pollutants in Museums and Archives*, Technical Bulletin 37. Ottawa: Canadian Conservation Institute. https://www.canada.ca/en/conservation-institute/services/conservation-preservation-publications/technical-bulletins/pollutants-museums-archives.html.

Voiland, A. 2023. *Relentless Wildfires in Canada*. NASA Earth Observatory. https://earthobservatory.nasa.gov/images/151696/relentless-wildfires-in-canada.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S314–S322
https://doi.org/10.1080/00393630.2024.2356920

ORIGINAL RESEARCH OR TREATMENT PAPER

Defining Sustainable Priorities and Actions for Storage of a Public Archive: A UK Case Study

Defin ición de Prioridades y Acciones Sostenibles para el Almacenamiento de un Archivo Público: un Studio de Caso en el Reino Unido

Yuki Russell

Collection Care, Norfolk Record Office, The Archive Centre, Norwich, UK

ABSTRACT

Storage facilities often comprise the most energy-intensive burden within archives. One green solution is a passive building with high thermal inertia and airtightness, to create stable environmental conditions without mechanical intervention, and provide appropriate temperature and RH ranges and good air quality for preservation. However, where airtightness is concerned, there is potential for accumulation of pollutants within densely occupied repositories such as library and archive stores. This risk is not addressed by current requirements for greener operation, because operational conflicts arise when balancing these three environmental parameters. This article discusses air quality and its effects on archive materials. It contributes to better understanding of green operation for archives. It presents a preliminary study carried out at Norfolk Record Office in the UK on options to increase archives storage capacity whilst improving both public access and preservation. This concluded that an initial programme to replace low-quality packaging which is a generator of VOCs, and the building of on-site passive storage, were the most sustainable solutions.

Las instalaciones de almacenamiento suelen representar la carga que más energía consume dentro de los archivos. Una solución ecológica para su manutención es la creación de un edificación pasiva con alta inercia térmica y hermeticidad, para crear condiciones ambientales estables sin intervención mecánica y proporcionar rangos adecuados de temperatura y humedad relativa y buena calidad del aire para la preservación. Sin embargo, en lo que respecta a la estanqueidad, existe la posibilidad de que se acumulen contaminantes dentro de depósitos densamente ocupados, como bibliotecas y archivos. Este riesgo no se aborda en los requisitos actuales para una operación más ecológica porque surgen conflictos operativos al equilibrar estos tres parámetros ambientales. Este artículo analiza la calidad del aire y sus efectos en los materiales de archivo. Contribuye a una mejor comprensión del funcionamiento ecológico de los archivos. A su vez presenta un estudio preliminar llevado a cabo en Norfolk Record Office en el Reino Unido sobre opciones para aumentar la capacidad de almacenamiento de archivos y al mismo tiempo mejorar tanto el acceso público como la preservación. La conclusión fue que las soluciones más sostenibles representan un programa inicial para sustituir los envases de baja calidad, que generan COV, y la construcción de almacenamiento pasivo in situ.

ARTICLE HISTORY
Received October 2023
Accepted May 2024

KEYWORDS
Passive storage; British Standards for archives storage; libraries and archives storage; low-quality archives packaging

Almacenamiento pasivo; Normas británicas para el almacenamiento de archivos; almacenamiento de bibliotecas y archivos; embalaje de archivos de baja calidad

Introduction

Minimising energy consumption within the cultural heritage sector is an urgent issue worldwide. It is widely recognised that collection storage facilities comprise the most energy-intensive burden within archives. One of the recognised greener solutions is passive storage: creating stable environmental conditions without mechanical intervention. The intention is to design stable building structures with properties such as thermal inertia and airtightness. It is increasingly recognised that intelligent building design will become a necessity in the operation of sustainable storage facilities (Clarke and Grant 2016; Ræder Knudsen and Rosenvingle Lundbye 2017; Xavier-Rowe, Lankester, and Thickett 2021). Correct temperature (T), relative humidity (RH) and good air quality have been recognised as key preservation parameters. However, airtightness may lead to accumulation of internally generated airborne pollutants within collection stores (Dabanlis et al. 2023; Dahlin, Grontoft, and Wittstadt 2013; Ryhl-Svendsen, Jensen, and Larsen 2014; Smedemark and Ryhl-Svendsen 2022). Commonly occurring pollutants are carboxylic acids (e.g. acetic acid and formic acids), aldehydes and amines

CONTACT Yuki Russell yuki.russell@norfolk.gov.uk Collection Care, Norfolk Record Office, The Archive Centre, Martineau Lane, Norwich, NR1 2DQ, UK

© The International Institute for Conservation of Historic and Artistic Works 2024

resulting from a variety of internal sources: collections themselves, and storage materials such as boxes, enclosures and shelves. Many internal pollutants are indicators of degradation, emitted from cellulose nitrate and acetate films, as well as organic materials such as acidic papers, wood and leather which are the main components of archive and library collections (Calvini, Gorassini, and Merlani 2007; Dupont and Tétreault 2000; Potthast et al. 2022; Shahani et al. 2001; Tétreault 2021; Tétreault et al. 2013).

It is worth highlighting that archive and library collection stores are often so densely occupied that the problem of internal pollutants is exacerbated. Moreover, there is the issue of growing collections, creating a shortage of suitable storage space (Boyle 2017; Chems Consulting 2005; Klemperer 2013; Stubbs and Banks 2020). As a consequence of this, unoccupied space intended for airflow to maximise ventilation forced by heating, ventilation and air conditioning (HVAC) systems becomes reduced, and the original building design no longer functions as intended. This leads to collection items being surrounded by air pollutants. The level of risk is deemed to be higher than that in museum stores; mixed collections are, by their nature, not commonly stored so densely. By contrast, library and archival collections are generally packed flat and packed as densely as possibly (in the interest of space-efficiency), to the detriment of longevity.

There is inevitably a very fine balance between demands on institutions to be financially, culturally and environmentally conscious, simultaneously. Provided that the building has thermal inertia, airtightness itself functions to stabilise the T and RH inside repositories (Padfield et al. 2018). It also reduces the ingress of externally generated pollutants such as nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and ozone (Dahlin, Grontoft, and Wittstadt 2013; Ryhl-Svendsen and Smedemark 2023; Ryhl-Svendsen, Jensen, and Larsen 2014; Smedemark and Ryhl-Svendsen 2022). On the other hand, an airtight space combined with an absence of HVAC results in stagnant air with accumulating, internally-generated pollutants.

The reasons for gradual deprioritising of air quality in recent years are complicated. Political, green, environmental, financial and technical obstacles exist which all play a significant part. However, these are not entirely related to extending the useful life of items, which is the key mission of the conservation profession. It is important to recognise what factors determine 'recommended' environmental conditions at a particular point in time. Such decisions reflect society, but lead to a mutable sense of mission and values in the sector.

This paper aims to untangle the complex issue of air quality as part of environmental control, and to contribute to better understanding of the subject in the context of greener operation of collection stores. Given that poor air quality has many unknown consequences for collections, it also summarises a preliminary study on increasing archives storage sustainably at Norfolk Record Office in the UK.

The political climate in the UK

In autumn 2023, the UK government confirmed changes to some green commitments. Goalposts were shifted to allow delay by five years on the transition to net zero by some industries, while maintaining the international obligation of delivering net zero by 2050 (UK Government 2023). The Prime Minister Rishi Sunak described the change in direction as a 'proportional, realistic and pragmatic approach to meeting our ambitions to net zero' (BBC 2023). The new decision was understood to be largely driven by the state economy which had no capacity to pay for the anticipated costs to meet the earlier target. Whilst slowing efforts to address an urgent global issue was received as confusing and showing a lack of consistency in direction by many affected businesses and industries (Horton 2023; Partridge and Partington 2023), the U-turn was further supported by the Prime Minster as a necessity to provide 'honesty' and 'transparency' about what is involved in achieving net zero (BBC 2023).

There is mounting pressure from every direction, whether organisational, financial, reputational, or environmental. There seems to be much in common between the behaviour of the state in its approach to green strategies, and environmental management in the conservation of cultural heritage sector. Some similarities can be identified in the recent transitions in environmental guidance in the relevant British Standards. It is common and often necessary to move goalposts due to various external factors. However, compromise needs to be acknowledged as a consequence of changing objectives, whether in government or the conservation profession.

Environmental guidance on temperature in the British Standards

Current British Standards such as BS 4971:2017 (BSI 2017) have been updated with recommended ranges of some key environmental parameters. As well as changes of focus regarding air quality, as outlined later, one of the elements changed was the T parameters for traditional mixed archives. The upper limit for T was increased from 20°C to 23°C. Reviewing the transition of the T recommendations, the acceptable highest T has been increased by 5–7°C over 17 years, given that BS5454:2000 (BSI 2000) recommended 18°C for frequently-handled materials and 16°C for infrequently-handled materials as the respective upper limits.

Widening the parameters results in reduced energy consumption, costs and reputational pressure. Due to

actual inefficiencies in air handling equipment and thermal inertia of vaults that many collective institutions experience, the relaxation was generally seen as a more realistically achievable target. It was difficult to determine the extent of overshoots from the recommended range under the previous narrower parameters. Particularly in publications, reporting such overshoots would be perceived as unnecessary honesty – an unfortunate smear on reputation and evidence of incompetency in compliance with standards. A contributing factor to this defensive phenomenon is the desire to prove credible heritage services for assessment regimes such as Archive Service Accreditation (https://www.nationalarchives.gov.uk/archives-sector/archive-service-accreditation/).

Evolutions in managing air quality in accordance with British Standards

BS5454:2000 Recommendations for the storage and exhibition of archival documents (BSI 2000) made statements on both internal and external pollutants. The subsequent guidance *PD5454:2012 Guide for the storage and exhibition of archival materials* (BSI 2012b) stated:

> New repositories should be provided with a controllable mechanism for ventilation with clean fresh air where it is desired as a means of managing temperature and RH and controlling internally generated pollutants. It should be used at times of the year or the day that allow the fresh air to bring the internal air into the recommended conditions.

It also continued:

> Where internally generated acetic acid vapours are reaching more than 100 µg/m^3, the air inside a repository should be ventilated with fresh air to reduce the levels.

However, this threshold was not supported by published research (Tétreault 2018). The practice was further covered by the publicly available specification *PAS 198:2012* (BSI 2012a) recommending:

> Where internally generated pollution is unavoidable, the air exchange rate of an enclosure should ideally be high enough to reduce the internal concentration of pollutants to a safe level, but not so high as to prevent effective control of the internal RH or to allow the entry of externally generated pollutants or dust.

While the idea of managing air quality has been shaped over a number of years, attention ceased with the emergence of BS4971:2017 (BSI 2017) in which there is no threshold for pollutant concentrations. Some guidance remained in sparser form in another influential document, *BS EN 16893:2018 Conservation of cultural heritage: specifications for location, construction and modification of buildings or rooms intended for the storage or use of heritage collections*. In the category of collections generating internal pollutants, this recommends (BSI 2018):

> Some collection materials emit volatile compounds of a nature and volume that place themselves and other collections at risk. An assessment shall be made to establish the level of risk of any emissive collections and where are deemed sufficiently high, ventilation shall be incorporated into storage and display. In mechanically ventilated systems carbon filtration shall be placed on recirculated air to absorb these pollutants. Dedicated storage spaces shall be constructed or used for highly emissive collections to ensure that people and other collections are not harmed.
>
> … The selection of which ventilation system, whether natural or mechanical, shall be determined by factors including safety and energy consumption.

The absence of a threshold and lack of detail in such guidance gives the impression that air quality is no longer a concern. Moreover, it creates assumptions that fresh air intake and ventilation are no longer necessary for maintaining good air quality (Woods 2018). Amidst a requirement for contributing to net zero within financial constraints, the new attitude has become more widely accepted. However, it is worth noting that increased T in stores would itself promote greater generation of internal pollutants, as has been reported in recent years (Kraševec et al. 2021; Ryhl-Svendsen and Smedemark 2023; Ryhl-Svendsen, Jensen, and Larsen 2014; Smedemark and Ryhl-Svendsen 2022; Smedemark, Ryhl-Svendsen, and Schieweck 2020), although worryingly the risk seems to be overlooked. Given the correlation between T, RH and the degradation rate of cellulose materials (Shahani and Harrison 2002), it can be assumed that volatile organic compounds (VOCs) are released into the environment as a result of ageing of cellulose and materials present in the storage environment (Kosek and Jacobs 2005).

Little monitoring of air quality in stores

While studies of air quality continue to be published (Dabanlis et al. 2023; Kraševec et al. 2021; Kraševec, Cigić, and Strlič 2022; Ryhl-Svendsen and Smedemark 2023), monitoring of air quality in large spaces such as stores has remained uncommon (Dahlin, Grontoft, and Wittstadt 2013). Lack of accurate knowledge hinders actions more commonly taken to control T and RH. Even when the opportunity arises where air quality can be actively monitored and quantified, it is profoundly difficult to interpret the measurements in relation to preservation. In fact, rather incomprehensible and random interpretations of measurements in the recent studies demonstrate the complexity of understanding the impact of air pollutants on long-term preservation (Dabanlis et al. 2023; Ligterink and

Di Pietro 2018; Menart, Bruin, and Strlič 2014; Smedemark and Ryhl-Svendsen 2022; Smedemark, Ryhl-Svendsen, and Schieweck 2020; Tétreault 2018; Tétreault et al. 2013). There is no clear understanding of the concentrations of pollutants that would be detrimental.

Combining all factors – the lack of guidance from standards, unavailability of interpretation of pollutant concentrations, and financial constraints, the current situation has made it tremendously hard to justify expenditure of specialist equipment and staff time on managing air quality.

Discussion

There has been a systematic decline in attention to the nature of collection materials, or to evidence-based approaches to the best conditions for long-term preservation. It is unclear what determines the current concept of a standard (Icon 2023; Marshall 2023), how they are created, and how they become widely applied by the conservation profession. This approach would be justified by clear evidence that collection materials are more resilient than we previously thought. The contrasting view is that we have simply arrived at a point where we can no longer afford to maintain the high standards for preservation that were achieved in the past (Di Pietro et al. 2016). If the former is the case, it is devastating that we in collections care have consumed unnecessary amounts of energy for over 40 years. One of the inherent problems in the profession is that financially favoured ideas permeate the concept of accepted standards (Ashley-Smith 2018). There is a tendency to confuse this with good practice and to outsource operational decision-making such as environmental control to those able to provide authoritative guidance.

It is difficult to quantify the useful life of many collection items. Studies reported a negligible difference in longevity between those stored with active control for internal air pollutants etc., compared to more relaxed targets (Di Pietro et al. 2016; Menart, Bruin, and Strlič 2014) that ignore the high risk of accumulation of internal pollutants in library and archive storage. With this trend, 'slightly longer' life expectancy or 'slightly better' conditions lose priority to reducing energy consumption.

Whatever sources of energy may be available in the future, it would be more beneficial for any given collection, to provide conditions at low cost with minimal fluctuations over the longer term rather than a tightly controlled the climate only when financial circumstances permit, with conditions fluctuating randomly thereafter. The former is a 'sensible and proportional approach' as the UK government stated recently in relation to green policy. Accepting our inability to supply the best conditions over a long period constitutes the 'transparent' and 'honest' approach we need, rather than assuming that materials will respond favourably to our changes in direction for policy and priorities. A clear acknowledgment of these principles would shape optimal sustainable practice that genuinely benefits all heritage materials *and* the environment we live in.

Building passive storage at the Norfolk Record Office

Background and purpose

The Norfolk Record Office (NRO) is the archive service serving the Norfolk local authority in the UK. Its mission is to collect archives, preserve them for future generations, and make them accessible to the public. As the richest non-national collection in the country, the collection numbers some 10 million items dating from the eleventh century to the present. NRO has been situated in a purpose-built facility in the Archive Centre since 2003, with a collection storage capacity of 10,522 m^3 onsite (Figure 1). Whilst maximising the use of its existing storage space proactively since 2014, it is estimated that NRO will run out of space to house new accessions beyond 2028.

With external demands for greener operation and internal demands for increasing storage capacity, the *NRO50* project has commenced, aiming for new capacity for the next 25 years of growth, then later expansion. At the outset, addressing long-term preservation and public access as top priorities, the 'optimal storage solution' was sought to enhance the entire operation of the archive service.

Preliminary work

The project incorporated two separate strands. Working from the preservation perspective, the first task was to obtain a robust idea of the collection itself, its current condition, and practice and space management within the existing strongrooms for traditional mixed collections. The aims were to rationalise environmental conditions for best preservation of the collection, and to review current methods for storage and access. This could have led to reorganising storage for the entire collection, or to leaving items in the existing storage but housing new items in new storage. The second phase assessed the optimal form of new storage. The project concluded by combining the key findings for both preservation and access.

Procedures

In phase 1, a survey of 400 randomly selected items was carried out, to quantify their materials, and trends of



Figure 1. The southern exterior of the Norfolk Record Office. The large block on the left is the strongroom.

storage and usage (Eden et al. 2006). Prior access to the collection spanning 20 years (2003–2023) was also reviewed in the second phase. Then a longlist of potential solutions was assessed against a defined set of benefits which the project aimed to deliver.

Outcomes

Project phase 1: collection survey with 400 items

This demonstrated that 18% of the material is parchment (Figure 2). It was also revealed that 30% is mixed materials which it is not practical to separate (Figure 3). As a consequence, the NRO aims for environmental conditions in the current strongrooms to be suitable for the preservation of parchment, with tighter parameters than for paper (Gonzalez and Wess 2013), maintaining a lower RH than the upper limit stated in BS 4971:2017 (BSI 2017). A major concern was lead seals attached to parchment, since these are sensitive to acidic pollutants in their environment (Tétreault, Sirois, and Stamatopoulou 1998). However, none was detected in the 400 items. The survey revealed that 38% of the items have internal packaging. Of the 62% items without, it appeared that 33% of the subset of 62% would benefit from internal packaging.

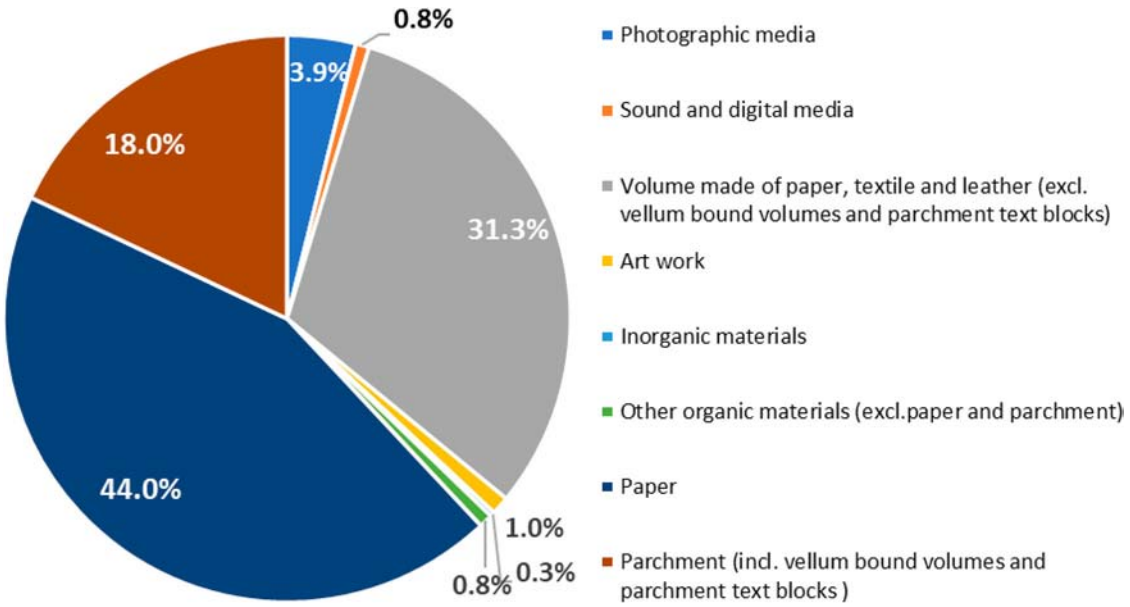


Figure 2. Material composition of the 400 items in the NRO collection stored in strongrooms A–C.

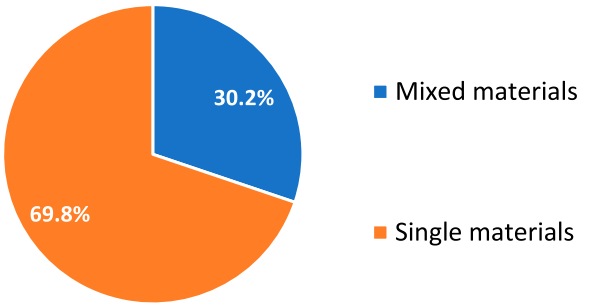


Figure 3. Proportions of mixed and single materials in the 400 items surveyed.

The majority (90%) of the sample has external packaging, 84% in some form of box. Box quality was defined by two criteria: type of material and its pH. Only 17% of boxes were of appropriate quality (such as Ryder Meridian Acid-Free, Bespoke and Non-bespoke archival box and Tyvek® wrapping) (Figure 4). In contrast, 17% were clearly inadequate and, more problematically, recognised as probable sources of internal pollutants. Included in this group were cardboard boxes (14%), extremely aged low-grade Ryder boxes (1.3%), wooden filing boxes (1.0%), non-archival slipcases (0.5%) and non-archival wrapping materials (0.3%). Unlike the low-quality paper and board integral to the items themselves, all of this could be eliminated as a source of VOCs.

The remaining 53% was also recognised to be unsatisfactory (Ryder Double Kraft low acid grade boxes for example). Many factors have contributed to this proportion of low-grade packaging materials. A vast number of items is involved and in the very nature of archives, low-value documents are often housed in low-quality boxes. Lack of resources, staff time and an insufficient number of archival quality boxes available when needed has added to the problem. A rolling programme of re-boxing and repackaging has been implemented and the situation has been steadily improving, but progress is slow due to the scale of the task and limited staff time for appraisal of contents. Having established packaging and enclosures as a significant source of internal pollutants in strongrooms, this will be addressed as a priority, regardless of plans for extending storage.

Project phase 2: Document production

Archives can only deliver their many benefits if the public has easy access. Improvements can be made through enhanced and more comprehensive metadata, and digitisation. The access review revealed that the bulk of the sample is subject to unpredictable access requests, many of which arise because of evidence provided by other documents used in the search room that day (Figure 5).

A series of options was set out to deliver the project's aims of: expansion to accommodate additional archives; long term preservation; and optimal public access to documents on the day on which they are requested. This was then subjected to an initial sift to determine which options could deliver value in terms of investment, and reduction of carbon footprint. A shortlist was the result:

- Build an extension with HVAC
- Build an extension based on passive principles
- Construct a new building with HVAC
- Construct a new building based on passive principles
- Offsite storage for digitised archives.

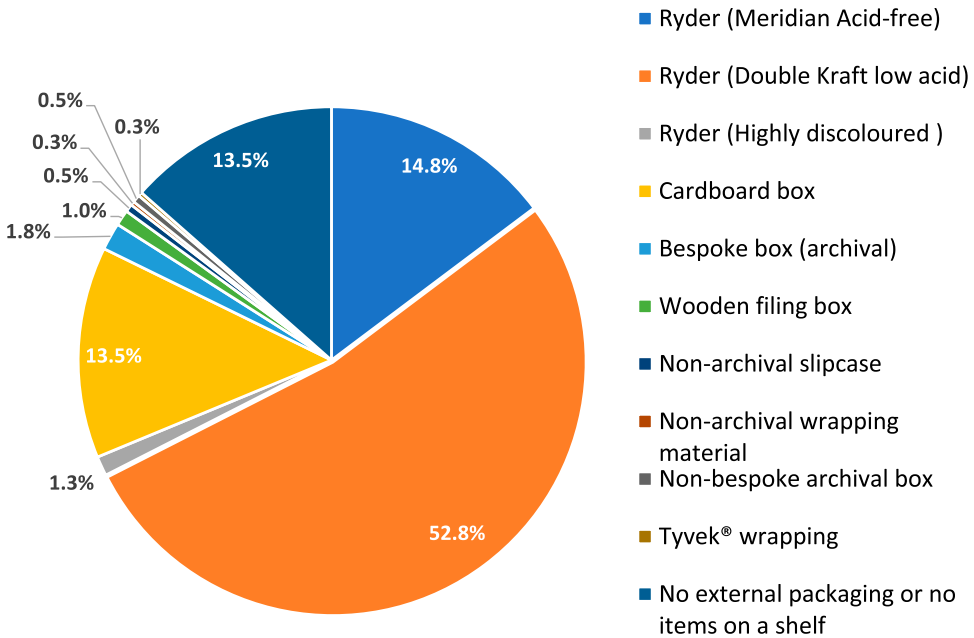


Figure 4. External packaging for the 400 items surveyed.

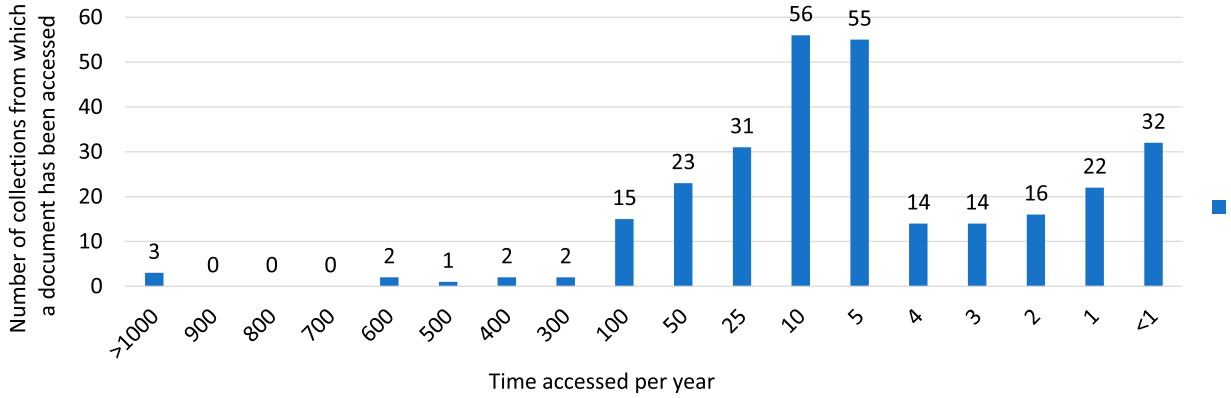


Figure 5. Average number of documents produced from individual collections (Fonds) per year (reviewed between 2003 and 2023).

With particular focus on carbon reduction, it was agreed unanimously that a low-energy solution needed to be implemented in the new extension in preference to HVAC. This option envisages an extension with high thermal inertia and high airtightness, requiring minimal intervention to its internal environment. Key to success is the collection itself whose mass acts as a buffer, meaning that dense packing gives optimal building performance. This also assumes that only paper-based archival materials would be stored here, while parchment would remain in the current store using the existing HVAC to provide the tighter environmental parameters required. It is uncertain at this point that a passive building could achieve the environmental conditions required for parchment. Having the extension on site was the most viable solution for long-term preservation, access to the collection and energy efficiency.

Conclusion

The decision has been taken that an on-site extension based on passive principles is the most suitable form of long-term storage for NRO, whilst providing public access. Now we endeavour to mitigate accumulation of internal air pollutants by replacing low-quality packing materials, and ensuring that all internal and external packaging for newly-acquired items is also made from high-quality archival materials. This is even more relevant given current trends for raising the upper temperature limits in stores.

Environmental standards such as those produced by the British Standards Institution define best practice, yet it is important to understand the current situation in collection stores in general, in real-world heritage institutions. With the requirement to save energy, we all need to review storage conditions, to achieve long-term preservation of collections. As with ours, institutions should first assess sources of internal pollutants in packaging or storage furniture. Though laborious, and not nearly so fashionable as net zero targets, focussing on eliminating these generates a significant improvement in terms of collections care.

Acknowledgements

The author is grateful to Gary Tuson and Nick Sellwood for their support during the collection survey and discussions for the future collection store at NRO.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Ashley-Smith, J. 2018. "The Ethics of Doing Nothing." *Journal of the Institute of Conservation* 41: 6–15. https://doi.org/10.1080/19455224.2017.1416650.

BBC. 2023. Interview with Rishi Sunak by Nick Robinson. *Radio 4. Today*. September 21.

Boyle, G. 2017. "Opinion. We Must all Help Solve the Storage Crisis: Tackling the Challenges Associated with Storing Collections." *Museums Journal*, March 31. https://www.museumsassociation.org/museums-journal/opinion/2017/03/01042017-we-must-all-help-solve-the-storage-crisis/.

BSI. 2000. *BS5454:2000 Recommendations for the Storage and Exhibition of Archival Documents*. British Standards Institution. https://doi.org/10.3403/02016882.

BSI. 2012a. *PAS 198:2012. Specification for Managing Environmental Conditions for Cultural Collections*. British Standards Institution. https://knowledge.bsigroup.com/products/specification-for-managing-environmental-conditions-for-cultural-collections?version=standard.

BSI. 2012b. *PD5454:2012 Guide for the Storage and Exhibition of Archival Materials*. British Standards Institution. https://doi.org/10.3403/30228041.

BSI. 2017. *BS 4971:2017 Conservation and Care of Archive and Library Collections*. British Standards Institution. https://doi.org/10.3403/30343305.

BSI. 2018. *BS EN 16893:2018 Conservation of Cultural Heritage: Specifications for Location, Construction and Modification of Buildings or Rooms Intended for the Storage or Use of Heritage Collections*. British Standards Institution. https://doi.org/10.3403/30324475.

Calvini, P., A. Gorassini, and A. L. Merlani. 2007. "Autocatalytic Degradation of Cellulose Paper in Sealed Vessels." *Restaurator* 28: 47–54.

Chems Consulting. 2005. *Optimising Storage and Access in UK Research Libraries. A Study for CURL and British Library*. https://rluk.ac.uk/wpcontent/uploads/2014/11/CURL_BLStorageReptExecSummary.pdf.

Clarke, A., and G. Grant. 2016. "The First Passivhaus Archive in the UK." In *Proceedings of the 20th International Passive House Conference 2016*, edited by W. Feist. Darmstadt: Passive House Institute [Online only].

Dabanlis, G., G. Lupo, G. Archinidis Tsalidis, E. Lostenidou, and S. Rapsomanikis. 2023. "The Interplay Between Air Quality and Energy Efficiency in Museums, a Review." *Applied Sciences* 13 (9): 5535. https://doi.org/10.3390/app13095535.

Dahlin, E., T. Grontoft, K. Wittstadt, et al. 2013. *Final Report Summary: MEMORI (Measurement, Effect Assessment and Mitigation of Pollutant Impact on Movable Cultural Assets)*. Innovative Research for Market Transfer. https://cordis.europa.eu/project/id/265132/reporting.

Di Pietro, G., F. Ligterink, H. Pork, and G. De Bruin. 2016. "Chemical air Filtration in Archives and Libraries Reconsidered." *Studies in Conservation* 61: 245–254. https://doi.org/10.1179/2047058415Y.0000000005.

Dupont, A.-L., and J. Tétreault. 2000. "Cellulose Degradation in an Acetic Acid Environment." *Studies in Conservation* 45: 201–210. https://doi.org/10.1179/sic.2000.45.3.201.

Eden, P., N. J. Bell, N. Dungworth, and G. Mattews. 2006. "Model for Assessing Preservation Needs in Libraries." BLRI report 125.

Gonzalez, L., and T. Wess. 2013. "The Effects of Hydration on the Collagen and Gelatine Phases Within Parchment Artefacts." *Heritage Science* 1: 14. https://doi.org/10.1186/2050-7445-1-14.

Horton, H. 2023. "UK Net Zero Policies: What has Sunak Scrapped and What Do Changes Mean?" *The Guardian*, September 20. https://www.theguardian.com/politics/2023/sep/20/uk-net-zero-policies-scrapped-what-do-changes-mean.

Icon. 2023. *Guidance Note on Environmental Management for Collections and Climate Sustainability*. https://www.icon.org.uk/resource/guidance-note-on-environmental-management-for-collections-and-climate-sustainability.html.

Klemperer, L. 2013. "Passively Conditioned Zero-energy Storage for Cultural Properties and Archival Material." In *Climates for Collections: Standards and Uncertainties*, edited by J. Ashley-Smith, A. Burmester, and M. Eibl, 151–162. London: Archetype Publications.

Kosek, J. M., and D. Jacobs. 2005. "What Happens to Enclosed Paper?" In *Art on Paper: Mounting and Housing*, edited by J. Rayner, J. M. Kosek, and B. Christensen, 29–37. London: Archetype Publications.

Kraševec, I., I. K. Cigić, and M. Strlič. 2022. "Findings from a Year-Round Monitoring of Museum Environment." 15th International Conference on Indoor Air Quality in Heritage Environments, Book of Abstracts, 16. Ljubljana, Slovenia.

Kraševec, I., E. Menart, M. Strlič, and I. K. Cigič. 2021. "Validation of Passive Samplers for Monitoring of Acetic and Formic Acid in Museum Environments." *Heritage Science* 9: 19. https://doi.org/10.1186/s40494-021-00495-3.

Ligterink, F., and G. Di Pietro. 2018. "The Limited Impact of Acetic Acid in Archives and Libraries." *Heritage Science* 6: 59. https://doi.org/10.1186/s40494-018-0225-y.

Marshall, A. 2023. "As Energy Costs Bite, Museum Rethink a Conservation Credo." *The New York Times*, February 1. https://www.nytimes.com/2023/02/01/arts/design/museums-energy-climate-control.html?smid=url-share.

Menart, E., G. Bruin, and M. Strlič. 2014. "Effects of NO_2 and Acetic Acid on the Stability of Historic Paper." *Cellulose* 21: 3701–3713. https://doi.org/10.1007/S10570-014-0374-4.

Padfield, T., M. Ryhl-Svendsen, P. Larsen, and L. Jensen. 2018. "A Review of the Physics and the Building Science Which Underpins Methods of Low Energy Storage of Museum and Archive Collections." *Studies in Conservation* 63 (sup.1): 209–215. https://doi.org/10.1080/00393630.2018.1504456.

Partridge, J., and R. Partington. 2023. "E.ON Boss Hits Out at Sunak's Plan to Row Back on Net Zero Policies." *The Guardian*, September 20. https://www.theguardian.com/business/2023/sep/20/car-firms-condemn-sunak-plan-delay-petrol-diesel-vehicle-ban.

Potthast, A., K. Ahn, M. Becker, T. Eichinger, M. Kostic, S. Bohmdorfer, M. J. Jeong, and T. Rosenau. 2022. "Acetylation of Cellulose – Another Pathway of Natural Cellulose Aging During Library Storage of Books and Papers." *Carbohydrate Polymers* 287: 119323. https://doi.org/10.1016/j.carbpol.2022.119323.

Ræder Knudsen, L., and S. Rosenvingle Lundbye. 2017. "Performance of Danish low-Energy Museum Storage Buildings." In *ICOM-CC 18th Triennial Conference Copenhagen Preprints*, edited by J. Bridgland. Paris: ICOM. https://www.icom-cc-publications-online.org/1601/Performance-of-Danish-low-energy-museum-storage-buildings [Online only].

Ryhl-Svendsen, M., L. A. Jensen, and P. Klenz Larsen. 2014. "Air Quality in Low-Ventilated Museum Storage Buildings." In *ICOM-CC 17th Triennial Conference Melbourne Preprints*, edited by J. Bridgland. Paris: ICOM. https://www.icom-cc-publications-online.org/1468/The-air-quality-in-low-ventilated-museum-storage-buildings [Online only].

Ryhl-Svendsen, M., and S. H. Smedemark. 2023. "Mass-Transfer Air Pollution Modeling in Heritage Buildings." *Heritage* 6: 4768–4786. https://doi.org/10.3390/heritage6060253.

Shahani, C. J., and G. Harrison. 2002. "Spontaneous Formation of Acids in the Natural Aging of Paper." *Studies in Conservation* 47 (sup. 3): 189–192. https://doi.org/10.1179/sic.2002.47.s3.039.

Shahani, C. J., S. B. Lee, F. H. Hengemihle, G. Harrison, P. Song, M. L. Sierra, C. C. Ryan, and N. Weberg. 2001. "Chemical Analysis of Degradation Products." In *Accelerated Aging of Paper*, edited by C. J. Shahani, 11–32. Washington: Library of Congress.

Smedemark, S. H., and M. Ryhl-Svendsen. 2022. "Determining the Level of Organic Acid air Pollution in Museum Storage Rooms by Mass-Balance Modelling." *Journal of Cultural Heritage* 55: 309–317. https://doi.org/10.1016/j.culher.2022.04.006.

Smedemark, S. H., M. Ryhl-Svendsen, and A. Schieweck. 2020. "Quantification of Formic Acid and Acetic Acid Emissions from Heritage Collections Under Indoor Room Conditions. Part I: Laboratory and Field Measurements." *Heritage Science* 8: 58. https://doi.org/10.1186/s40494-020-00404-0.

Stubbs, T., and C. Banks. 2020. "UKRR: A Collaborative Collection Management Success Story." *Insights the UKSG Journal* 33 (10): 1–9. https://doi.org/10.1629/uksg.503.

Tétreault, J. 2018. "The Evolution of Specifications for Limiting Pollutants in Museums and Archives." *Journal of the Canadian Association for Conservation* 43: 21–37.

Tétreault, J. 2021. "Control of Pollutants in Museums and Archives." *CCI Technical Bulletin* 37: 182.

Tétreault, J., A. L. Dupont, P. Bégin, and P. Paris. 2013. "The Impact of Volatile Compounds Released by Paper on Cellulose Degradation in Ambient Hygrothermal Conditions." *Polymer Degradation and Stability* 98: 1827–1837. https://doi.org/10.1016/j.polymdegradstab.2013.05.017.

Tétreault, J., J. Sirois, and E. Stamatopoulou. 1998. "Studies of Lead Corrosion in Acetic Acid Environments." *Studies in Conservation* 43: 17–32. https://doi.org/10.1179/sic.1988.43.1.17.

UK Government. 2023. *PM Speech on NET Zero: 20 September 2023: Prime Minister Rishi Sunak Sets Out His New Approach to Net Zero*. https://www.gov.uk/government/speeches/pm-speech-on-net-zero-20-september-2023.

Woods, C. 2018. "'Passive Aggressive': Changing the Climate in Archive and Museum Storage." Conference Series 2018, London: National Conservation Service. https://www.ncs.org.uk/presentations.php.

Xavier-Rowe, A., P. Lankester, and D. Thickett. 2021. "Principles for Developing Low-Cost, Sustainable Stores." In *Transcending Boundaries: Integrated Approaches to Conservation*. ICOM-CC 19th Triennial Conference Preprints, Beijing, edited by J. Bridgland. Paris: ICOM. https://www.icom-cc-publications-online.org/4423/Principles-for-developing-low-cost-sustainable-stores [Online only].

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S323–S332
https://doi.org/10.1080/00393630.2024.2336814

ORIGINAL RESEARCH OR TREATMENT PAPER

Calculating the Carbon Footprint of Interventive and Preventive Conservation at English Heritage, UK

Calculando la Huella de Carbono de la Conservación Interventiva y Preventiva en English Heritage, Reino Unido

Alice Tate-Harte and David Thickett

English Heritage, London, UK

ABSTRACT

English Heritage (EH) is a large cultural heritage organisation, which cares for 1million artefacts over 136 sites. Preventive conservators and conservation scientists manage a mixture of controlled and uncontrolled historic site environments housing diverse object types. Two fine art conservators manage treatment programmes for easel and wall paintings, gilded frames and gilded furniture. Other objects are managed by preventive conservators and outsourced to private conservation studios for treatment. Sustainability is becoming an increasingly important part of the conservation team's agenda. Measuring and understanding the carbon impact of both the preventive and interventive conservators' work was an important starting point for creating more sustainable solutions. To create a baseline for future monitoring and carbon reduction, carbon footprint studies were undertaken to evaluate the carbon impact of interventive painting conservation treatments; preventive conservation framing (adapting frames and making microclimates for displaying paintings in non-ideal environments); and running conservation (humidistatic) heating *vs* air conditioning systems in display rooms.

English Heritage (EH) es una gran organización de patrimonio cultural que se ocupa de medio millón de objetos en 400 sitios históricos de Inglaterra. Los conservadores preventivos y los conservadores-restauradores científicos gestionan una combinación de entornos de sitios históricos controlados y no controlados que albergan diversos tipos de objetos. Dos conservadores-restauradores de bellas artes gestionan programas de tratamiento de pinturas murales y de caballete, marcos dorados y muebles dorados. Otros objetos son gestionados por conservadores preventivos y subcontratados a estudios de conservación-restauración privados para su tratamiento. La sostenibilidad se está convirtiendo en una parte cada vez más importante de la agenda del equipo de conservación-restauración. Medir y comprender el impacto de carbono del trabajo de los conservadores preventivos e interventivos fue un punto de partida importante para crear soluciones más sostenibles. Para crear una base para el monitoreo y la reducción de carbono en el futuro, se llevaron a cabo estudios de huella de carbono para evaluar el impacto de carbono de: tratamientos interventivos de conservación de pintura; encuadre de conservación preventiva (adaptación de marcos y creación de microclimas para exhibición de pinturas en ambientes no ideales); y funcionamiento de sistemas de conservación-restauración de calefacción (humidistáticos) frente a sistemas de aire acondicionado en salas de exhibición.

ARTICLE HISTORY
Received October 2023
Accepted March 2024

KEYWORDS
Sustainable approaches; carbon footprint; energy monitoring; interventive treatment; preventive conservation; conservation heating

Enfoques sostenibles; huella de carbono; monitoreo energético; tratamiento interventivo; conservación preventiva; calefacción de conservación

Introduction

Interventive painting conservation treatment

Painting conservation treatments are carried out in the English Heritage (EH) conservation studio by the in-house fine art conservators. Objects are transported to the studio in London from historic sites around England. Three treatments were assessed to understand variation and which categories had the highest carbon footprint.

Preventive conservation framing and performance

Historic frames can be adapted to reduce the impact on paintings of moisture in their environment. Existing historic frames may be modified in different ways to achieve different levels of relative humidity (RH), buffering and protection from other risks, e.g. mould and mechanical damage. Three case studies were used to measure the performance of three different types of frame modification and the carbon footprint of carrying out the interventions.

Environmental study: conservation heating and air conditioning systems

EH operates conservation (humidistatic) heating to manage and control historic house environments, alongside displaying more vulnerable objects in showcases and microclimates (English Heritage 2009). EH

CONTACT Alice Tate-Harte alice.tate-harte@english-heritage.org.uk The Engine House, Fire Fly Avenue, Swindon SN2 2E
© The International Institute for Conservation of Historic and Artistic Works 2024

has championed the implementation of wider environmental parameters, as heating/ventilation/air-conditioning (HVAC) systems can be challenging and often less effective in historic buildings. Both carbon and financial costs are significantly reduced if HVAC can be avoided for collections that do not need very tight environmental conditions. Initial measurements were taken in different situations.

Materials and methods

Measuring the carbon footprint of interventive treatments

A simple methodology was established and implemented in 2021 to measure the carbon footprint of an easel painting conservation treatment, including calculating energy required for heating, cooling and running the studio, staff time, staff travel, object transport, storage time, materials and waste management (Tate-Harte and Thickett 2023), but is not elucidated here. This method was devised by a conservator, conservation scientist and building engineer, using widely available carbon calculators and tools. This methodology was replicated for this paper, using accessible tools to calculate materials rather than a highly accurate life cycle assessment (LCA).

The studio is sometimes unoccupied. For the first case study, emissions from energy use were derived by calculating the daily average power consumption in kWh for an occupied day in the month the treatment was carried out. The subsequent case studies were longer treatments carried out over several months.

To simplify calculating emissions from energy use for the subsequent case studies, a daily average for the year was used. In the first case study the carbon emissions from waste were calculated. This was found to be insignificant, so was not accounted for in the two subsequent case studies. The carbon calculator devised by Sustainability Tools in Cultural Heritage (STiTCH 2021) was used to calculate materials' emissions during their production. Some materials are not yet available on the STiTCH database, but these were used in small amounts and were not thought to impact on the results of the study.

Figures from the National Institute of Standards and Technology were used to calculate the carbon emissions from wrapping materials which were not available in the STiTCH database (NIST 2020) The two studio conservators travel to work by bicycle or car. For consistency, the carbon impact of commuting in a petrol-fuelled car was calculated for staff transport.[1]

Painting1. The treatment of Adriaen van Ostade, *Interior of an Inn with Card Players* 1648, oil on panel, 450 × 377 mm, Rangers House, London, took two days to complete. This involved a straightforward varnish removal, revarnishing and a small amount of retouching. No art transport was required but a hypothetical journey from a London site to a London studio was assumed for comparison.

Painting 2. Cornelius Johnson, *Portrait of Diana Cecil* 1648, oil on canvas, 2060 × 1270 mm, Kenwood House, London. This was a complicated treatment of a full-length portrait which took 37 days to complete. It involved full cleaning, including extensive overpaint removal. It travelled by van from its London site to the studio for treatment.

Painting 3. Jan van Oolen, *Cockfight* c.1710, oil on canvas, 1147 × 1353 mm, Audley End, Cambridgeshire. This was a medium-sized painting which also involved a straightforward varnish removal, varnishing and retouching, taking 9.3 days. This painting travelled by van from a site in Cambridgeshire.

Major structural work was not necessary on any of the paintings. Technical analysis, documentation, frame conservation and photography were not included, solely the treatment of the painting.[2]

Measuring the carbon footprint for preventive measures

The same methodology was used to calculate the carbon footprint of adapting historic framing systems for paintings whilst on open display in historic house environments. STiTCH (2021) was used for most of the conversion units. Glass, hardboard and felt tape were not available on the STiTCH calculator so other online sources were used (Henry, Russell, and Gollnow 2015; Puettmann, Bergman, and O'Neil 2016; SISECAM 2022). Some of the frames were adapted over a decade ago, therefore calculations are based on estimates of the size and weight of materials determined by the size of the frame. Estimates were made for staff time and a hypothetical journey was used for object transport. The storage period was not accounted for, because it was unknown, so this departs from the methodology for calculating the interventive painting conservation treatments. Because of the difficulty of getting LCA or the weight of gas emissions as $kgCO_2e$ values from suppliers for some composite materials, e.g. Marvelseal®, the most significant material (aluminium) was used for the calculation. However, the result was found to be negligible because the metal layer was so thin (0.08μm). Three types of frame adaptations were investigated.

A Backing: A rigid backing board made of Foamcore® or AluPV (a stiffened metal-coated fabric), is applied using screws or staples and then sealed with gum strip or aluminium 3M 425 tape. The backboard may be lined with Marvelseal® (an aluminium film) to reduce off-gassing from the hardboard or to improve the moisture permeability of Foamcore®. *Painting 4*: Wouvermans, *Hunting* seventeenth century, oil on canvas, 430 mm × 545 mm, Rangers House, London, was used as a case study.

B Backing and glazing: Glazing is added (sealed with gummed paper tape) and the frame is backed with similar board or fabric to protect the painting from accidental damage, dust, pests, and RH fluctuations.

Painting 5: Velazquez, *The Waterseller of Seville* c.1620, oil on canvas, 1077 × 813 mm, Apsley House, London, was used as a case study.

C Microclimate (MC) frame: This system is used if a painting is particularly vulnerable to its environment. This category includes panel paintings, unlined canvas paintings or paintings which demonstrate inherent weakness (from EH's condition audit history) or stable paintings which are housed in an 'extreme' environment (outside the parameters 35–65% RH). This is similar to type B, but the glass and backing are sealed with 3M 425 aluminium tape to reduce air leakage and Artsorb® is added to buffer RH changes within the frame. Established methods and materials were used as described by the National Gallery, London (Harrison, Saunders, and Higgitt 2018). *Painting 6:* Rubens, *Portrait of an Old Man* 1620, oil on panel, 495 × 358 mm, Apsley House, London, was used as a case study.

Measuring the performance of framing systems

Four different types of framing were investigated. The performance of the different types of frames and their backing structures was measured using a mixture of ACR smartreader 002 and Rotronic Hygroclip loggers installed within the frames, then compared with RH data for the room collected via loggers and radio telemetry.

A Backing: The simplest preventive measure, applying a backboard without glazing, was measured using Painting 4. The frame was built up with timber to make the back of the frame flush with the protruding painting. A backing of hardboard was screwed into the timber build-up and sealed with gum strip. Rotronic Hygroclip T/RH probes on Eltek leads (were sealed behind the canvases in the frames. Initial data is shown in Figure 2.

B Backing and glazing a lined canvas painting: Glazed frames, produced without the additional glass sealing used for MC frames and with gum paper taped backboards, were measured for Painting 5. The system is designed chiefly to provide physical protection from visitors and some protection from a fluctuating environment. The same logging system was used as in example A. Initial data is shown in Figure 3.

C Historic frame converted to an MC frame: Painting 6 from Apsley House, London. This was measured with an ACR smart reader 002 logger inside the frame. The frame contained 0.52 kg/m^2 Artsorb® sheet and was tested whilst it was being built to identify any gaps in sealing that could then be addressed. The air exchange rate was measured at 0.12/day.

D *High-performance MC frame:* Painting 7, after Titian, *Julius Caesar* seventeenth century, oil on canvas, 1320 × 1040 mm, Bolsover Castle, was used. Some historic rooms there have very damp environments and a design with a large amount of buffer was developed, using a 10 mm Prosorb® customised panel with a loading of 20 kg/m^2. This high-performance MC frame was made by an external conservation studio and this carbon footprint was not calculated because the painting could not be easily accessed. The painting was installed in the Riding School at Bolsover Castle in 2014, where the RH is frequently over 75%. The internal environment was monitored with an ACR smartreader 002 logger and the room environment was monitored with a Rotronic hygroclip probe on a Meaco radio telemetry system. The Prosorb® was preconditioned to 45%, deliberately set to a low value to maximise lifetime.

Measuring carbon footprint of conservation heating/air conditioning

It is extremely difficult to directly compare the carbon footprint of conservation heating with air conditioning because it depends on the outdoor climate and the building environment. Initial work on this has been published and the measurement issues discussed (Thickett 2020). Using pre-existing energy data and standard methodology the indicative carbon footprint of running both conservation heating and air conditioning was calculated to compare the carbon cost of operating these systems in display rooms (BIS 2011; ISO 2006).

Results

Carbon footprint of interventive conservation treatments

See Figure 1.

Carbon footprint of preventive conservation framing

See Table 1. For each adaptation case study, the task of converting historic frames was estimated to take one day. It was observed that making an MC frame would not greatly increase the time, other than in sourcing materials and thinking about the design on the first occasion, as the same process was followed, but with different sealing tapes and systems. The bulk of the $kgCO_2e$ was due to transport. Staff could travel to historic sites by public transport to undertake the work, which would represent an emission saving compared to transporting the art works to the studio. Materials had a low impact overall, but solid and composite materials such as glass and hardboard represented the highest material emission costs, so the size of the painting (and amount of materials) had the greatest impact after art transport (which happened to be the same in each case study).

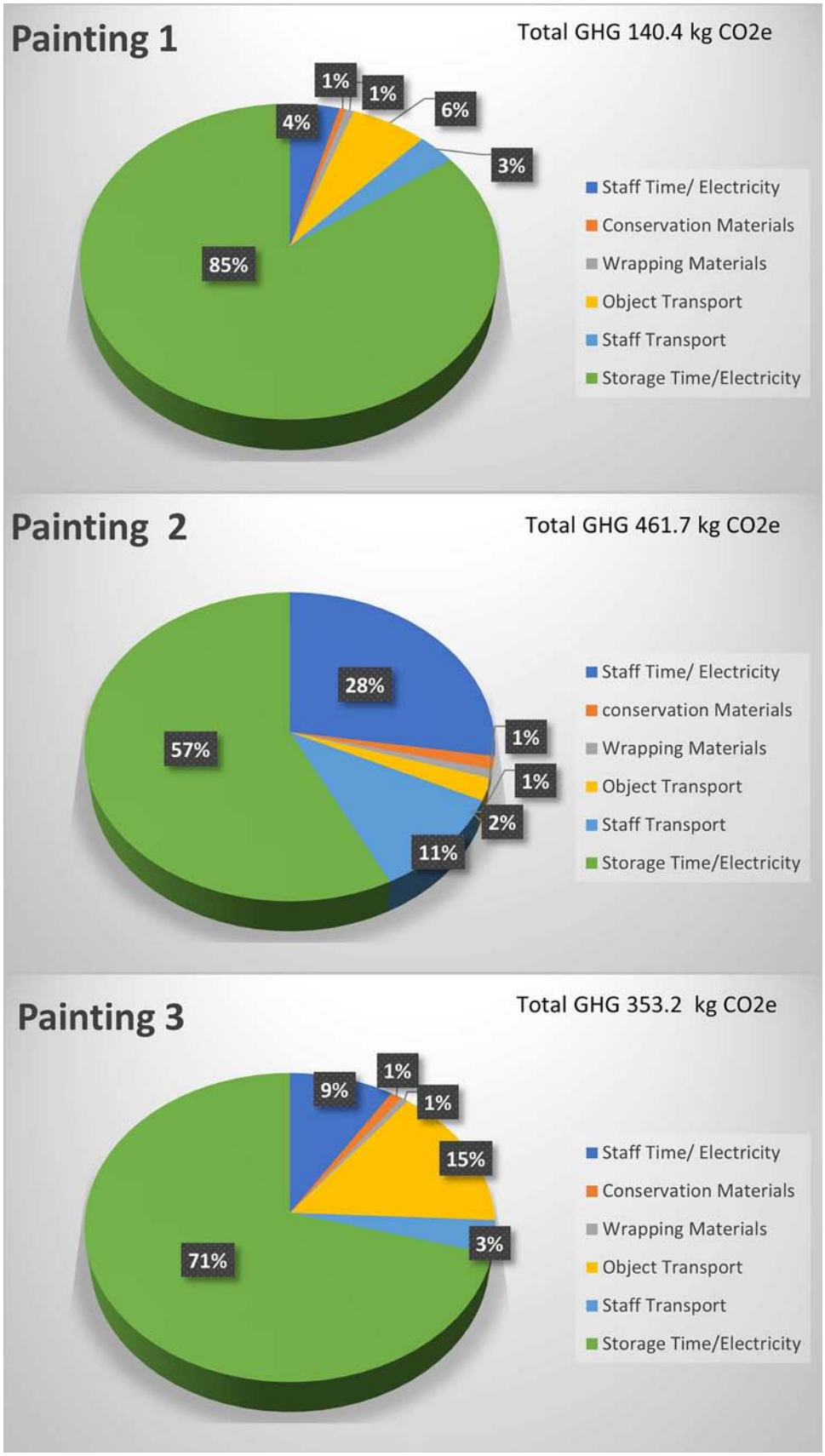


Figure 1. Carbon dioxide emissions ($kgCO_2$ e) for Paintings 1–3.

Performance of different framing systems

The back-boarded frame (Figure 2) showed a higher RH fluctuation than the MC frame. The glazed frame (Figure 3) appeared to perform quite well, although the room conditions were quite benign over the monitored period. However, sharp, rapid drops and jumps in RH can be seen which were possibly due to air movement over the glazed surface, which was simply

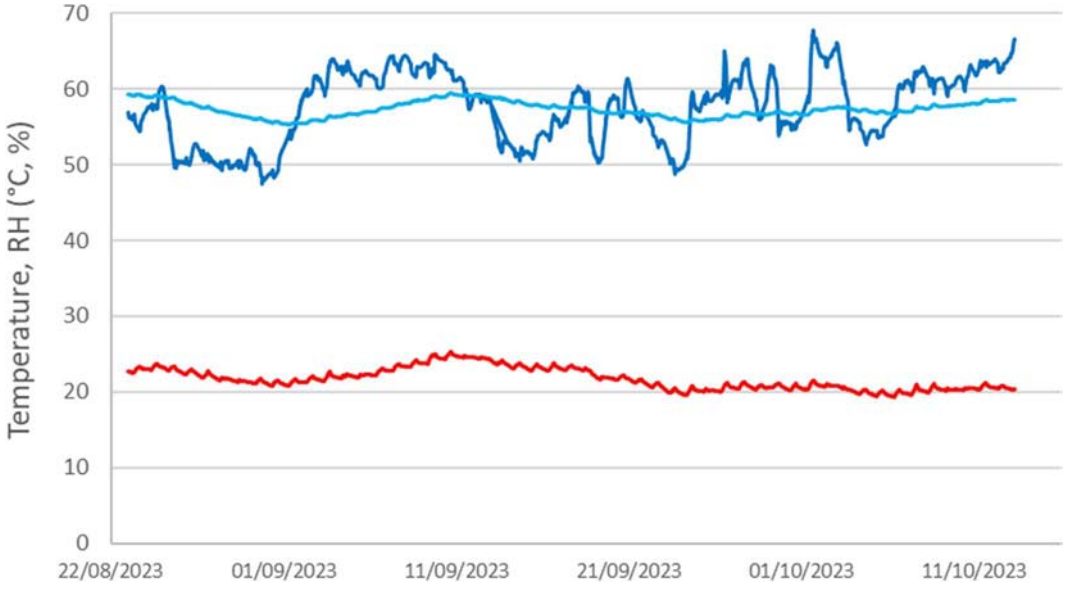


Figure 2. Performance of backed Painting 4 in Rangers House.

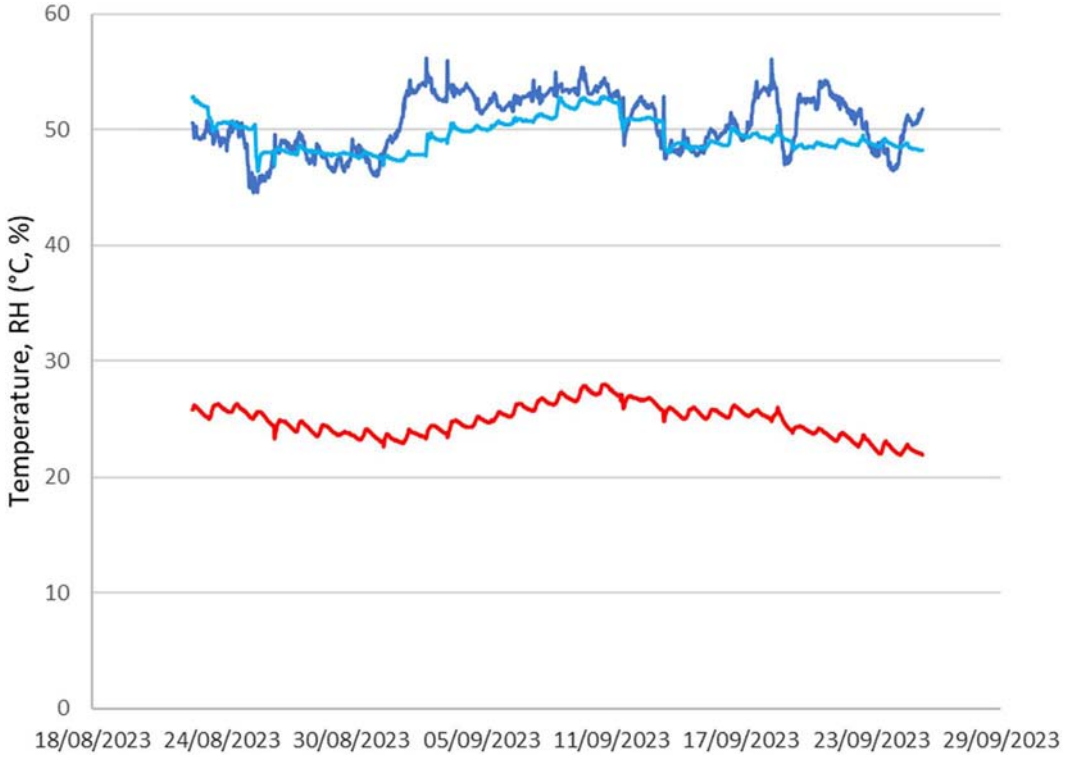


Figure 3. Performance of glazed Painting 5 in Apsley House.

sealed with gum strip rather than aluminium tape or adhesive. Examination of pollution data (nitrogen dioxide) from the room showed large rapid changes in concentrations at the same times as the rapid changes in RH inside the frame, possibly indicating air movement into the room. The two approaches appear to have good performance. Longer monitoring and a much larger number of frames would be needed to draw firm conclusions.

A year of data is shown in Figure 4a. Painting 6 in the converted MC frame is located in Apsley House, which is representative of a historic house environment with excessive winter heating and solar gain (and hence low RH). The frame provided excellent buffering, almost totally removing RH fluctuations and keeping the RH near 50%. Figure 4b shows the internal and room environments for Bolsover Castle in 2022–2023. The high-performance MC frame has performed reasonably well with the internal RH steady, and only rising from 45% to 50% over nine years. There are relatively large RH fluctuations compared to the MC frame from Apsley, and the room environment is clearly

Table 1. GGE for preventive conservation framing (case studies A,B,C).

Case Study A Wouvermans Rangers House. Unglazed, backed with hardboard, sealed with brown tape

Material			Weight, kg	Area, m^3	$kgCO_2e$ UNIT	Unit source	GHG ($kgCO_2e$)
Timber				0.00125	45.736 kg per m^3	STITCH (pine)	0.057
Felt Tape			0.015 kg		8.19 kg per kg	LCA Textiles	0.123
Hardboard			0.95 Kg	0.000915	658 per m^3	CPA	0.602
Brass Mirror plates small			0.0096		5.465 per kg	STiTCH	0.053
Brass Mirror plates medium			0.0306		5.465 per kg	STiTCH	0.167
Marvelseal® (aluminium content only)			0.0017		6.92 per kg	STiTCH (Aluminium)	negligible
Steel screws large			0.0416		4.132 per kg	STiTCH	0.172
Stainless Steel screws small			0.0276		4.132 per kg	STiTCH	0.114
Brass Screws			0.01		5.465 per kg	STiTCH	0.055
Gum Strip			0.0177		0.035 per kg	STiTCH (butchers' paper)	negligible
Total Materials							1.34
Staff Time/Electricity usage	Days equiv. ÷2	Daily av. kWhs	Actual kWhs		**$kgCO_2e$ UNIT**		**($kgCO_2e$)**
Hours worked: 7	0.5	32.7	16.8		0.21	BEIS UK	3.53
Staff Transport	Days equiv.	return trip (km)			**$kgCO_2e$UNIT**		**($kgCO_2e$)**
Hours worked: 7	1	12			0.18785	BEIS UK	2.25
Transport to and from Studio	km travelled return trip		Artworks on truck: ÷ 2		**$kgCO_2e$ UNIT**		**($kgCO_2e$)**
Diesel Type III Van		68	34		0.26529	BEIS UK	9.02
TOTAL							**16.14**

Case Study B Velazquez Apsley House. Glazed with 4.4 mm glass sealed with gum strip, Harboard Backboard sealed with 3 M 425 tape

Material	Weight, kg	Area, m^3	$kgCO_2e$ UNIT	UNIT SOURCE	GHG ($kgCO_2e$)
Timber Buildup (pine)	1.0500	0.0022	45.736 per m^3	STITCH (pine)	0.099
Timber Slip (pine)	0.7500	0.0002	45.736 per m^3	STITCH (pine)	0.011
Felt tape	0.0119		8.19 per kg	LCA of Textiles	0.101
Hardboard		0.0033	658 per m^3	CPA	2.189
'Art Glass' (low reflect/laminate)	11.0000		15.28 per m^2	SISECAM	13.840
Brass Straps large	0.0556		5.465 per kg	STiTCH	0.300
Marvelseal® (aluminium content only)			6.92 per kg	STiTCH	Negligible
Steel screw short	0.0255		4.132 per kg	STiTCH	0.120
3M 425 tape wide (50 mm) (Aluminium content only)	0.1032		6.92 per kg	STiTCH	0.714
Gum Strip	0.0139		0.035 per kg	STiTCH (butchers' paper)	0.040
Total Materials					17.41
Staff Time/Electricity usage					3.53
Staff Transport					2.25
Transport to Studio					9.02
TOTAL					**32.21**

Case Study C. Rubens Apsley House Glazed Microclimate, backed with hardboard, sealed with dow-corning adhesive and 3M 425 tape

Material	Weight, kg	Area, m^3	($kgCO_2e$) UNIT	UNIT SOURCE	($kgCO_2e$)
Timber (estimate based on frame dims)		0.0043	45.736 per m^3	STITCH (pine)	0.197
Slip (estimate based on frame dims)		0.0001	45.736 per m^3	STITCH (pine)	0.006
Felt Tape (estimate based on frame dimensions)	0.0105		8.19 per kg	LCA of Textiles	0.086
Hardboard		0.0006	658 per m^3	CPA	0.375
Glass 4.4 mm (low reflect/ laminate)		0.1900	15.28 per m^2	SISECAM	0.550
Brass Straps Medium	0.0102		5.465 per kg	STiTCH	0.056
Marvelseal® (aluminium content only)	not measured		6.92 per kg	STiTCH (Aluminium)	negligible
Steel screws large	0.0146		4.132 per kg	STiTCH	0.172
Brass Screws	0.0020		5.465 per kg	STiTCH	0.011
3M 425 tape narrow (25 mm)	0.0240		6.92 per kg	STiTCH	0.025
Gum Strip	0.0139		0.035 per kg	STiTCH (butchers' paper)	negligible
Art-Sorb	0.2000			not available	not calculated
Dow Corning Adhesive	not measured			not available	not calculated
Total Materials					1.48
Staff Time/Electricity usage					3.53
Staff Transport					2.25
Transport to Studio					9.02
TOTAL					**16.28**

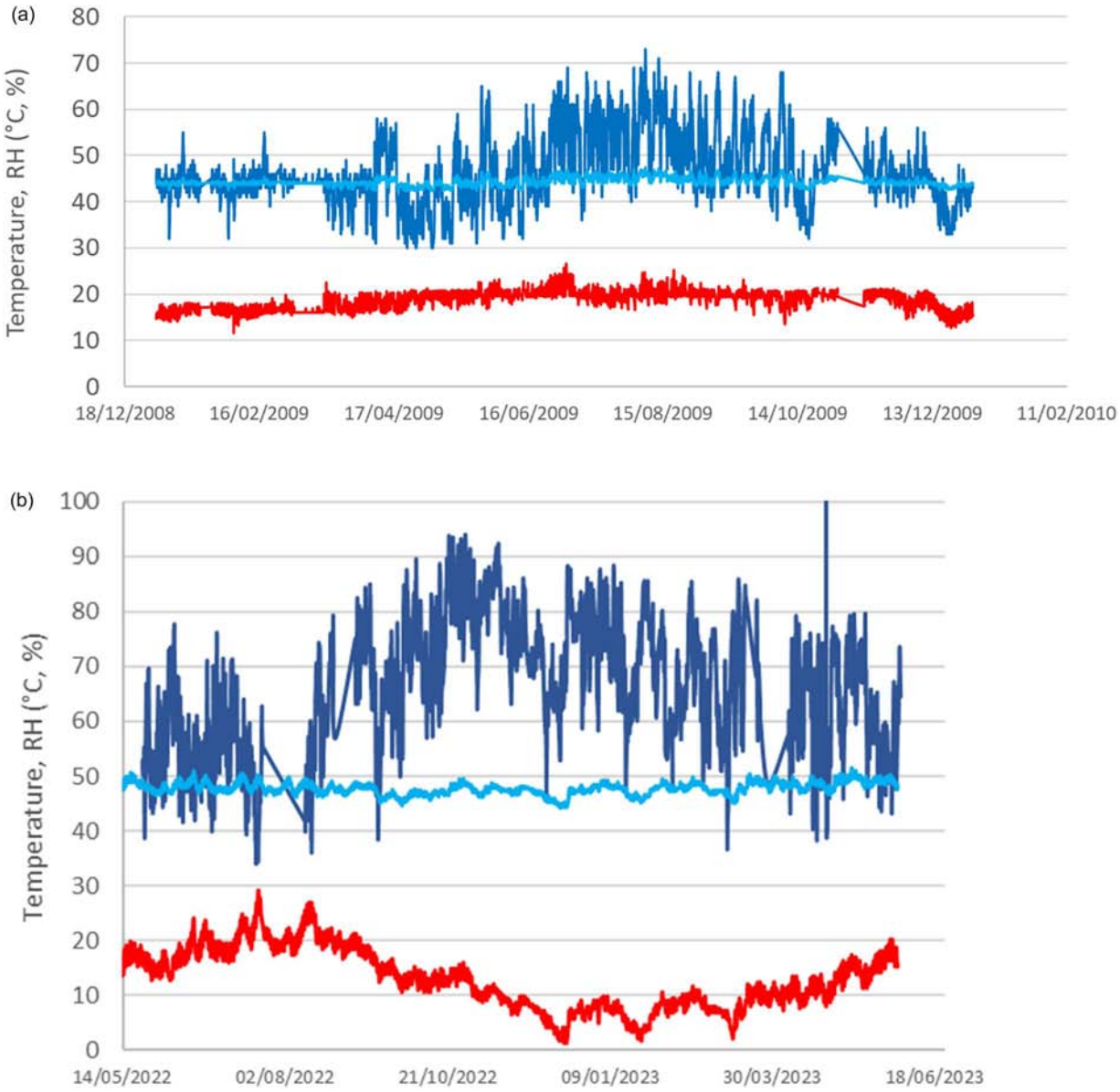


Figure 4. Performance of an MC frame in a typical historic house environment (Painting 6, Apsley House) compared to a challenging environment in a castle (Painting 7, Bolsover Castle).

having more of an impact. This is likely due to poor sealing of the frame; the air exchange rate was not measured, nor leakage testing used to identify any gaps in sealing. Ambient air therefore ingresses the frame altering the RH, but the large amount of Prosorb® buffer then stabilises the RH. This process takes some days, leading to the fluctuations observed.

Carbon footprint of room conditioning systems

It is extremely carbon-intensive to condition large volumes of ambient air in publicly accessed buildings to achieve the close parameters panel paintings require. The tighter the temperature and RH band, the higher the energy use and carbon footprint (Artigas 2007). EH therefore uses MC frames (with intentionally sealed glazing and back boarding, and sometimes Artsorb® included) to display panel paintings in historic rooms with fluctuating environments. EH participated in a research project to assess MC frame performance and to optimise their design (Dahlin 2010).

At EH, monitoring through condition audits every 5 years over a 30-year period has shown that over 1200 historic canvas paintings can, on the whole, tolerate an environment with broader parameters. Having been displayed in rooms controlled with conservation heating for decades, it is rare that substantial damage is observed, such as flaking. For the last part of the study, the carbon footprint of such a system was investigated at Rangers House, London. Calculating carbon footprints can be complicated in a mixed-use building. Rangers House has a heating system fed from a central boiler with valves controlling four zones. Three zones house collection material, while the fourth houses staff workspaces. At present only total gas usage is recorded although the building

Table 2. GGE emissions for conservation heating and air-conditioned spaces.

Site and heating type	Period	Gas usage (kWh)	Conversion figure (net calorific value)	GGE ($kgCO_{2eq}$)	GGE per volume, $kgCO_{2eq}/m^3$
Rangers House, comfort heating (radiators in room)	March 2021 – March 2022	142,497	0.20297	28,922	Not determined
Rangers House, conservation heating	March 2022 – March 2023	110,463	0.20297	22,420	1.64
Eltham Palace, conservation heating	March 2021 – March 2022	Not determined	Not determined	23, 586	Not determined
Eltham Palace, conservation heating	March 2022 – March 2023	Not determined	Not determined	25,237	Not determined
Apsley House, Waterloo gallery air conditioned via BMS	2013	Not determined	Not determined	Not determined	8.45

management system (BMS) has recently been modified to record the zone valve positions, which will enable control of and assessment for either collections or staff comfort in future.

The house ran on comfort heating until March 2022 and was converted to conservation heating from then on.[3] Using the UK Department for Business, Energy and Industrial Strategy conversion figure for 2022, the gas usage was converted to greenhouse gas emission values (GGE, measured in $kgCO_2e$) (BEIS 2022). The move to conservation heating reduced the carbon footprint by 29%, likely due to the modified operation. The value is in the lower quartile of previous measurements (Thickett 2020), although the gas usage is clearly weather dependant. Eltham Palace is situated c.5 km away and was already on a conservation heating setting, and was compared as a control. The Eltham Palace values were 7% higher in the second year, indicating the drop in the Rangers House data was not due to the weather. Indicative data for an air conditioning system was also examined. Data was available from 2013 for the Waterloo Gallery at Apsley House which was controlled via an HVAC. The GGE electricity conversion figure from that year was used (Table 2). The energy usage was 35kWh/m^3, equivalent to 12.42 $kgCO_{2eq}/m^3$. The gallery had an independent electricity metering system. For comparison, the value using 2022 GGE data would be 8.54 $kgCO_{2eq}/m^3$. This is in the upper quartile of previous measurements for such systems (Thickett 2020). It is 5.2 times the GGE/volume of the Rangers House conservation heating system.

Discussion

Interventive painting conservation treatment and preventive conservation framing

The work of preventive conservators and conservation scientists in controlling environments to acceptable levels for objects was predicted to be more significant in reducing carbon than the mitigations interventive conservators can put in place. However, without a body of existing carbon footprint studies on interventive object conservation treatment, conservators could not improve their understanding of impacts of both interventive and preventive conservation, or identify where improvements could be made. This study begins to address this (Tables 3 and 4).

The first part of the study represents an initial attempt at calculating a carbon footprint for interventive treatments. One challenge involved in this sort of study was apportioning time correctly. Heating/electricity incurred by supporting staff in the organisation such as the work done by human resources, finance and estates departments has not been accounted for. These would represent the carbon 'on-costs' of a conservation staff member's time. The methodology has been further appraised in the earlier paper (Tate-Harte and Thickett 2023). Obtaining accurate LCA or manufacturing data on materials from suppliers was challenging and there are gaps in the data where these were not available. LCAs from local suppliers of materials and equipment would improve the accuracy of the calculations used to compare GHG data for materials.

The conservation studio where the treatments were undertaken is located in a listed building. It has been retrofitted and insulated to an extent, and an air source heating system installed. Ground source heating would be difficult to install on account of sensitive archaeology on this site, but other renewable electricity could be considered in the future. Object transport is already consolidated across EH to reduce carbon emissions and cost where possible. The studio conservators work at multiple sites across England as well as in the studio and therefore storage accounts for a large proportion of the treatment time. As a result of the study, as well as green practice initiatives,[4] the conservators have made their practice more sustainable, preferring to travel to work by bicycle and public transport where possible and minimising car trips to sites by storing bulk materials required for site work at hubs around the country.

Conservators naturally focus on material choices as they have direct responsibility and control over these, but interestingly this was not found to be the first category to address in terms of carbon reduction because the impact of materials compared to other categories

Table 3. Materials, their composition, and suppliers.

Material	Purpose	Material composition	Supplier
Timber	Building up the back of the frame to the depth of the painting to accept a flush backboard	Unsorted (e.g. good quality) European redwood *Pinus Silvestris*, sourced from Finland/ Sweden, and Forest Council Stewardship compliant.	Fulham Timber (UK) (https://fulhamtimber.co.uk/?mh_matchtype = &mh_keyword = &mh_adgroupid = &mh_network = x&gad_source = 1&gclid = EAIaIQobChMI5Mim9_X6gwMVgZpQBh3nrQOoEAAYASAAEgJroPD_BwE)
Foamcore®	Backboard	Paper sheets with foam inner	PEL (Preservation Equipment Limited) UK (https://www.preservationequipment.com/)
Hardboard	Backboard	Engineered high density fibreboard	Various hardware shops
AluPV	Backboard	Polyester non-woven film with LDPE coating with aluminium film and adhesive	Protpak (UK) (https://www.protpack.com/)
Archival corrugated cardboard, B flute	Backboard	Acid-free, buffered, Perma/Dur®	PEL https://www.preservationequipment.com/
Art glass (4.4 mm laminate)	Glazing	2 layers of 2 mm glass with glue interlayer, UV-resistant low-reflective coatings	Wessex Pictures (https://www.wessexpictures.com/)
Artsorb®	Buffering internal environment	A non-woven sheet of archival polyethylene/ polypropylene fibres impregnated with fine particles of silica gel	PEL https://www.preservationequipment.com/
Prosorb® customised board	Buffering internal environment	Hexalite® panel filled with Prosorb® (silica gel) desiccant beads	Long Life for Art, Germany (https://llfa.eu/prosorb-customized-panel.html)
Dow Corning Adhesive 744	Sealing Glass	Sealant	Sealants Online (https://www.sealantsonline.co.uk/)
Marvelseal®	Lining backboards to improve environmental seal and prevent off-gassing	Aluminised polyethylene and nylon barrier film	PEL https://www.preservationequipment.com/
3M 425 aluminium tape	Sealing glass and timber	Aluminium foil with acrylic adhesive	3M (https://www.3m.co.uk/3M/en_GB/p/c/adhesives/)
Gum strip	Sealing glass, lining rebate and backboard	Paper and natural adhesive	Various
Felt tape	Cushioning frame rebate	Wool with acrylic adhesive pressure-sensitive tape	British Felt Company (https://www.britishfelt.com/)
Brass straps	Holding painting in frame	Brass	Scraggs (https://www.britishfelt.com/)
Brass mirror plates	Holding paper in frame	Brass	Scraggs (https://www.frankscragg.co.uk/)
Balsa wood	Creating shaped spacers	Fast-growing tropical tree	Various
Cork	Creating shaped spacers	Sustainable European wood	Various

was low. Solid materials, or those with a high level of processing (such as glass and hardboard), have the highest carbon impact, with plastic materials and solvents having less of an impact per kg. However, virgin plastic materials and petroleum-based solvents may eventually become unavailable or unaffordable, so it is important to pursue and research alternatives. Conservators should continue to care about the LCAs of their materials, not just the carbon footprint, to protect other sustainable goals, such as clean water, air and soil systems, protecting biodiversity and human health.

Table 4. Equipment for monitoring.

Rotronic Hygroclip T/RH probes	RS Online (https://www.frankscragg.co.uk/)
Eltek radiotelemetry sensors	Eltek (https://eltekdataloggers.co.uk/transmitters_menu.php)
ACR smartreader 002	ACR Dataloggers (https://www.acrdatasolutions.com/products/smartreader-plus-4-lpd)
Meaco radio telemetry system	Meaco (https://meaco.co.uk/)

Since this study, EH conservators have changed the way they use materials, for example, we have swopped hardboard and Foamcore® backboards for corrugated cardboard, and we reuse or recycle glass as well as packing materials for transporting paintings. Solvents are now re-used for cleaning brushes and solvent guns where possible.

Environmental study: conservation heating and air conditioning systems

This study has elucidated the carbon footprint of conservation heating. EH has developed a series of MC frames to protect objects from environments without acclimatising the display rooms. Exactly how much energy this saves is difficult to calculate without an example of monitoring before and after the intervention. However, the proven performance of the MC frames has meant that in some instances air conditioning systems could be decommissioned (e.g, at Apsley House), and the spaces controlled through conservation heating only (to wider RH parameters),

representing a carbon saving. Further monitoring is required to assess the performance of glazed non-MC frames and frames which are simply back-boarded.

Assessing and comparing the carbon footprint of the different heating and control systems across EH sites has generated a 40% reduction in energy use for climate control (Thickett 2022). Whilst control systems will be different in the global south, involving ventilation rather than heating, this research demonstrates the actual carbon savings when heritage organisations use more passive control systems combined with local enclosures for sensitive objects.

EH is a project partner of the recently begun GoGreen project, a four-year European Union-funded Horizon 2020 project which will further investigate the sustainability of conservation treatments and the development of new greener ones (GoGreen 2022). This will include carbon footprints for interventive painting treatments and climate control.

Notes

1. This method deviates from PAS 2050:2011 which excludes the transport of employees to and from their normal workplace. Transport was included as it represented an activity individual where conservators could demonstrate some impact (BIS 2011).
2. These tasks were not included although they did comprise part of these particular conservation treatments, and could be included in future studies. Recording work carried out by other departments would be necessary to achieve this.
3. Comfort heating was delivered via radiators to keep staff warm in winter (21°C during working hours) whereas conservation heating is designed to prevent objects freezing whilst avoiding high temperatures that lead to low RH. It is allowed to fall below minimum temperatures for sedentary workers in the UK. This was delivered though low levels of background heating by turning down the radiators).
4. The conservation studio and conservation science laboratory took part in University College London's Laboratory efficiency Assessment Framework (LEAF), a system for improving sustainability in conservation workshops and laboratory practice, and were awarded gold level. (https://www.ucl.ac.uk/sustainable/what-ucl-does/leaflaboratory-efficiency-assessment-framework).

Acknowledgements

The authors would like to thank Liam Galvin, Ruth Knight and Caroline Baker for their help with this project.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Artigas, D. J. 2007. "A Comparison of the Efficacy and Costs of Different Approaches to Climate Management in Historic Buildings and Museums," 77–95. Masters dissertation, University of Pennsylvania. https://repository.upenn.edu/handle/20.500.14332/37182.

BEIS. 2022. *Greenhouse Gas Reporting: Conversion Factors* 2021 (2.0). Department for Business, Energy and Industrial Strategy and Department for Energy Security and Net Zero. https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors2021.

BIS. 2011. *The Guide to PAS 2050: 2011. How to carbon footprint your products, identify hotspots and reduce emissions in your supply chain*. Department for Business Innovation and Skills. https://www.bsigroup.com/globalassets/localfiles/en-th/carbon-footprint/pas-2050-2011guide.pdf.

Dahlin, E. 2010. *Improved Protection of Paintings during Exhibition, Storage and Transit Final Activity Report*. 42. https://www.researchgate.net/publication/282247431_PROPAINT_Improved_Protection_of_Paintings_during_ExhibitionStorage_and_Transit_Final_Activity_Report.

English Heritage. 2009. *Environmental Management Performance Standards: Guidelines for Historic Buildings*. https://historicengland.org.uk/imagesbooks/publications/environmental-management-performance-standards/environmentalmanagement-performance-standards/.

GoGreen. 2022. *Gogreen: Green Strategies to Conserve the Past and Preserve the Future of Cultural Heritage*. https://cordis.europa.eu/project/id/101060768.

Harrison, L., D. Saunders, and C. Higgitt. 2018. "Variations on a Theme: Re-evaluating the Performance of Modified Microclimates for the Protection of Old Master Paintings." *The Picture Restorer* 52 (Spring): 23–31.

Henry, B. K., S. J. Russell, and S. Gollnow. 2015. "10 LCA of Wool Textiles and Clothing." In *Handbook of Life Cycle Assessment (LCA) of Textiles and Clothing*, edited by S. S. Muthu, 217–254. Cambridge: Woodhead publishing. https://doi.org/10.1016/B978-008-100169-1.00010-1.

ISO. 2006. *14044:2006 Environmental Management –Life Cycle Assessment – Requirements and Guidelines*. https://www.iso.org/standard/38498.html.

NIST. 2020. *Plastic LCA Evaluation Across Available LCA Modelling Tools and Databases*, National Institute of Standards and Technology. https://www.nist.gov/el/applied-economics-office/lca-polymers-plastics-improve-circularity.

Puettmann, M., R. Bergman, and E. O'Neil. 2016. *Cradle-To-Gate Life Cycle Assessment of North American Hardboard and Engineered Wood Siding and Trim Production*. https://www.fs.usda.gov/research/treesearch/52618.

SISECAM. 2022. *EPD for Laminated Glass*. https://www.environdec.com/library/epd4818.

STiTCH. 2021. *Sustainable Tools in Cultural Heritage*. https://stich.culturalheritage.org/here.

Tate-Harte, A., and D. Thickett. 2023. "How to Calculate the Carbon Footprint of a Painting Conservation Treatment at English Heritage." 5–10. https://www.english-heritage.org.uk/siteassets/home/learn/conservation/collections-advice-guidance/how-to-calcluate-the-carbon-footprint-of-a-painting-conservation-treatment_alicetate-harte_david_thickett.pdf.

Thickett, D. 2020. "Comparison of Environmental Control Strategies for Historic Buildings." *Studies in Conservation* 65: 314–320. https://doi.org/10.1080/00393630.2020.1778296.

Thickett, D. 2022. "Carbon Footprinting of Conservation Processes at English Heritage." Presented at National Trust Conservators CPD Sustainability Training, 29 Nov 2022, English Heritage.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S333–S340
https://doi.org/10.1080/00393630.2024.2336772

ORIGINAL RESEARCH OR TREATMENT PAPER

The Positive Role of Trees in Protecting Outdoor Painted and Engraved Rock Sites

El Papel Positivo de los Árboles en la Protección de Sitios Rocosos Pintados y Grabados al Aire Libre

Andrew Thorn

ARTCARE, Fitzroy, Australia

ABSTRACT

The general view of trees is that they threaten heritage structures, their roots disrupt archaeological features, or that they create microclimates conducive to biodeterioration. The conservator's experience in assessing the impact of trees on various cultural assets highlights the positive role they can play in modifying the outdoor environment to reduce stress mechanisms. Trees intercept sunlight and rain, absorb ground water and stabilise soils. This is particularly beneficial at rock art sites where infrastructure must be kept to a minimum to maintain the spiritual and aesthetic ambience. While focussing on studies demonstrating the protective role of trees, it is critical to make balanced assessments that recognise both positive and negative implications; a tree can both shade an object and increase the risk of mechanical damage from roots and falling branches. Objective assessments consider all implications rather than through intellectual and operational bias. Laboratory studies demonstrate hydrothermal stress to be greater than heating or wetting alone, and freeze–thaw that has been traditionally considered one of the most destructive mechanisms disrupting outdoor stone. Interventive approaches for reducing hydrothermal stresses in stone rely upon chemical treatments to repel water, and consolidation to better resist such stresses. A well-designed tree canopy can substantially reduce thermal expansion and almost completely remove rain from the object through interception, funnelling to the trunk and uptake of groundwater.

La opinión general sobre los árboles es que amenazan las estructuras patrimoniales, sus raíces alteran las características arqueológicas o crean microclimas propicios al biodeterioro. La experiencia del restaurador en la evaluación del impacto de los árboles en diversos bienes culturales pone de relieve el papel positivo que pueden desempeñar en la modificación del entorno exterior para reducir los mecanismos de estrés. Los árboles interceptan la luz del sol y la lluvia, absorben el agua subterránea y estabilizan los suelos. Esto es particularmente beneficioso en sitios de arte rupestre donde la infraestructura debe mantenerse al mínimo para mantener el ambiente espiritual y estético. Si bien nos centramos en estudios que demuestran el papel protector de los árboles, es fundamental realizar evaluaciones equilibradas que reconozcan las implicaciones tanto positivas como negativas; un árbol puede dar sombra a un objeto y aumentar el riesgo de daños mecánicos por raíces y ramas que caen. Las evaluaciones objetivas consideran todas las implicaciones y no a través de sesgos intelectuales y operativos. Los estudios de laboratorio demuestran que el estrés hidrotermal es mayor que el calentamiento o la humectación por sí solos, y que el hielo y el deshielo se han considerado tradicionalmente uno de los mecanismos más destructivos que alteran la piedra al aire libre. Los enfoques interventivos para reducir las tensiones hidrotermales en la piedra se basan en tratamientos químicos para repeler el agua y la consolidación para resistir mejor dichas tensiones. Una copa de árbol bien diseñada puede reducir sustancialmente la expansión térmica y eliminar casi por completo la lluvia del objeto mediante la interceptación, canalización hacia el tronco y absorción de agua subterránea.

ARTICLE HISTORY
Received October 2023
Accepted March 2024

KEYWORDS
Hydrothermal stress; tree screening; environmental modification; chemical intervention reduction; sustainable preventive conservation

estrés hidrotermal; protección de árboles; modificación ambiental; reducción de intervenciones químicas; conservación preventiva sostenible

Introduction

The relationship between trees and heritage assets tends to be negative due to damage from falling limbs, penetrating roots (Biddle 1998) and, for buildings where they remove excessive water from foundation soils and can cause subsidence and the cracking of walls. On the other hand, trees provide shade, intercept rainwater, and their roots can stabilise soils. This paper will present three case studies, with reference to additional sites where the benefits reduce damage mechanisms at rock art sites. This follows earlier publications on the beneficial role of trees at non-indigenous outdoor sites (Thorn 1994; 2018; Thorn and Piper 1996).

CONTACT Andrew Thorn andrew.thorn@artcare.cc ARTCARE, Fitzroy, VIC, Australia
© The International Institute for Conservation of Historic and Artistic Works 2024

Planting trees is not the focus of this paper but rather, the application of scientific methods that provide a precise understanding of the relationship between a rock surface and the sun, analysis of salt species, and hydrological studies to devise a modified environment that can be applied to any situation including museum collections (Thorn 2005a). The ability of trees to intercept, funnel and absorb rainwater provides a further protection to painted shelters formed within natural rock formations. Scientific study is central to this discussion, whereas trees are an available resource.

The function of trees

Not all trees are beneficial and not all aspects of a tree's environmental influence are positive. While a tree lowers rock surface temperatures and reduces water flow through rainfall interception, it may also increase humidity and provide nutrients for the establishment of microflora. Caneva et al. (2015) considered the potential for vegetation to promote damaging biota at Ankor Wat, for example. Demas et al. (1996) identified the destructive intrusion of acacia roots into the hominid footprints at Laetoli, Tanzania. Tree roots are generally not found to be an issue in natural rock formations as the preferred locations for paintings tend to avoid excessive water flow, with exceptions. Some tree species (*Ficus benghalensis, Ficus virens*) attach themselves into rock crevices for support, from where they have the potential to expand and destabilise the surrounding rock structure. Tree fruits and exudates may also deposit onto surfaces, providing nutrients for biota to flourish. Examples of such damage can be dramatically seen at Angkor Wat and in the painted rock shelters of northern Australia.

A Tasmanian sandstone studied in three different conservation contexts: a painted shelter (Thorn 1996) 90 headstones in a cemetery (Thorn 1994; 2018; Thorn and Piper 1996) and a 170-year-old building (Thorn 2008b), has enabled the author to model the hydrothermal behaviour of a specific stone when exposed to variable climatic regimes. The most significant finding from climate chamber simulations was that hydrothermal variation, specifically heating after a rain event, was the greatest stress induced into that particular sandstone. The induced stress was far greater than wetting without heat or heating the dry stone. The implication of this finding is that reducing insolation lowers surface temperatures and hence, the stress on a wet stone. A reduction in wetting will also reduce stresses on rock surfaces, and the cracking and detachment of clay-based paintings applied to those rocks (Thorn 2005b).

Water reducing capacity of trees

Trees alter the passage of rainwater to the ground in three significant ways. Firstly, they intercept and hold up to 65% of rainfall in their canopy (Li et al. 2016). This is very species and rainfall intensity dependent but indicates the level of interception. Of the 35% that passes through the canopy a large proportion, up to 30% of total rain, flows down the stem (Metzger et al. 2021) leaving a very low level of rain reaching directly to the soil. This can be significant in situations where trees grow over a rock surface supporting cultural material. The final mitigation of rainwater is through the uptake of water from the soil, which can be up to 3 mm per day (Demir et al. 2024). The significance of water uptake from the soil may seem somewhat peripheral to stabilising a rock surface, however the case study at Te ana a maru illustrates the significance of this (Thorn 2011).

Surface shading of trees

There is no need to expound on the ability of tree shade to lower temperatures on rock surfaces. Studies have considered both temperature suppression and relative humidity (RH) increase to fully understand the impact of a tree plantation on underlying surfaces (Haydock and MacLeod 1987; Thorn 1994; 2008a; Thorn and Piper 1996). These studies have confirmed that while there is a heightened RH as a direct result of lower air temperature, there is no significant moisture increase from transpiration of the plants themselves. Rock surface temperatures can be lowered to air temperature in the shade whereas a fully exposed rock can be 170% higher. This is especially significant in hotter climates where, for example, a 30^{o}C air temperature can see rock surface temperatures exceed 50^{o}.

To assess the screening potential of trees it is important to model the sun's movement in relation to the surface to determine which trees provide effective shade and where future screen trees should be planted. A solar calculator has been developed to determine, throughout the year, the insolation at any point on a rock surface. The model is complex and can be studied in more detail in a recent publication (Thorn 2021). Examples of its use are given in the case studies below. The model is developed with CAD software to take advantage of several computational features; however, an approximate model can be sketched on graph paper. The critical geometry is that of the surface exposure to the sky, the path of the sun at the winter and summer solstices, and the rising and setting azimuth for each.

Figure 1 shows the model in its skeletal form with the arc of the sun's passage scribed for the winter

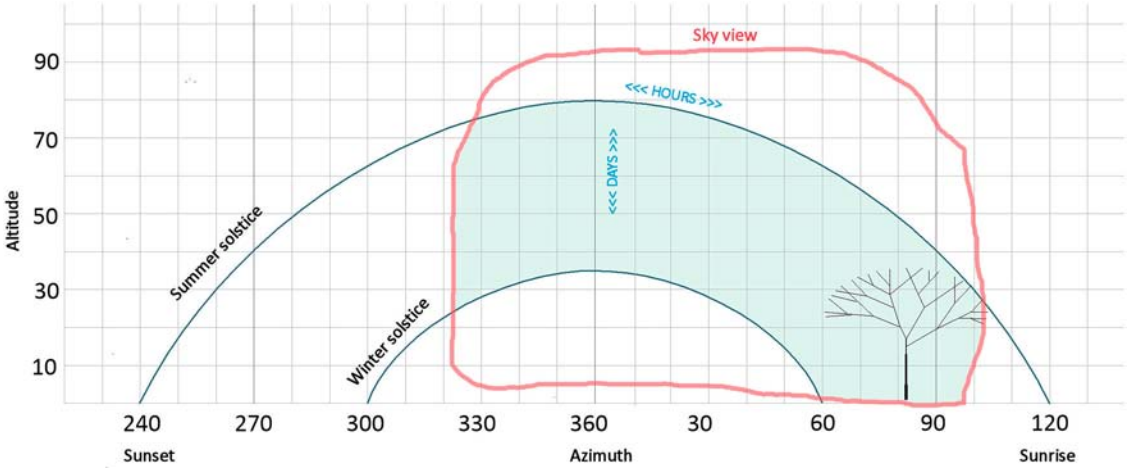


Figure 1. An explanatory insolation model showing the various attributes required for calculating insolation. This model is for a southern hemisphere site with the midday sun appearing at azimuth 360°. It shows sunrise ranging seasonally from 60–120° and sunset from 240–300°. The vertical axis represents solar altitude. The red outline represents a 'sky view' of a shelter, that is a polar co-ordinate representation of the opening of the shelter to the sky. The intersection of sky view and solar traverse has been shaded. Using the time scaling illustrated it is possible to calculate the time of day when the sun insolates and to calculate the total annual insolation. Trees lying outside these co-ordinates provide no shade benefit. The altitude co-ordinates determine the requisite height, dependent on distance from the surface to be shaded.

and summer solstices. These arcs define the boundary of the sun's position in the sky, with the sun appearing at any point within these arcs at least once in the year, but never outside them. The altitude of both arcs is calculated from the site latitude. A site located 10° from its nearest tropical latitude will have a maximum summer altitude of 80° and a winter altitude 45° lower. The azimuth of sunrise and sunset can be derived from numerous solar almanacs. The sky view from any point on the surface is plotted in polar co-ordinates, represented by the red outline in Figure 1. Time dimensions are also inherent in the model, with the linear distance between the solstice arcs being six months in total and the length of each arc being the daylight hours, typically between nine and fourteen hours in winter and summer respectively.

For this discussion tree screening is the only concern. Figure 1 indicates that trees in the azimuth arc 322–103° contribute shade to this southern hemisphere site. A tree has been placed at 82° to show how this part of the site will be shaded. Further trees to the left, within the shaded intersection of sky view and solar traverse would provide a complete screen.

Generally, endemic species are appropriate to revegetate a site for screening purposes and the model can determine whether this is achievable in both height and distance from the surface, based on the altitude co-ordinates represented. Figure 1 shows that trees would need to achieve the full 80° geometry to effectively shade the surface at midday in summer. It was found at the Walghana site in central Western Australia, where revegetation had been recommended (Haydock and MacLeod 1987) and implemented, that the geometry of the site was such that the endemic species could not provide an effective screen. Generally however trees can attain the required height, subject to distance from surface criteria being met.

Yuwengayay: controlling salt damage

Yuwengayay is a significant painted site located in the traditional country of the Myali-speaking people and within Kakadu National Park in the Northern Territory of Australia. The site consists of an accumulation of paintings over at least a 5000-year period, including recent paintings by known painters in the 1960s. The paints are made from natural earth pigments and charcoal, applied progressively one over another to achieve multi-layer paint sequences of 1–2 mm in thickness. The paintings extend for 80 m and to a height of six metres on a flat vertical rock face with almost no overhang to protect the paintings from rain. The site is in a hot tropical climate zone where wet season conditions can include air temperatures above 40^{0}C followed in the afternoon by rain exceeding 50 mm per day.

As mentioned earlier, a 40°C air temperature will translate to 65° on a sun-exposed rock surface. One of the deterioration mechanisms observed at Yuwengayay is the washing-out of parts of paintings in discreet circular patterns (Figure 2), which had previously been ascribed to water percolation through the rock surface (CORLAB 1988). This was a reasonable assumption given that the circular loss areas were wet at certain times of the day. Clearly the study had observed the deterioration when wet, without the benefit of observation throughout the day or over several days. The recommendation based on this cursory observation was to modify the



Figure 2. A painted kangaroo at Yuwengayay with salt-generated paint loss to its body and forearms indicated with arrows. The circular loss area on the body has a small white crystalline patch at its centre as it was imaged in the morning prior to the salt melting.

landscape above the site to divert water, an almost insurmountable task.

Observing the wet patches over several days revealed that they were dry with a white crystalline centre in the mornings, identified by CORLAB as polyhalite. This intermittent behaviour prompted a study of the surface using conductivity probes connected to a data logger (see Thorn 1994 for method detail). The logged data showed fluctuations in conductivity corresponding very closely to the visual transition from a crystalline nucleus in the mornings to saturation in the afternoons. Figure 3 presents a 3–4-day snapshot of the data in June, the mildest month with very little rain, moderate humidity and mild air temperatures in the low 30°Cs. On the left of Figure 3, surface conductivity (red) is compared to RH (green) and surface temperature (blue). Conductivity, indicating surface moisture, responds to rising RH with a minor peak synchronised to the maximum humidity each day. RH is moderately low during the observation

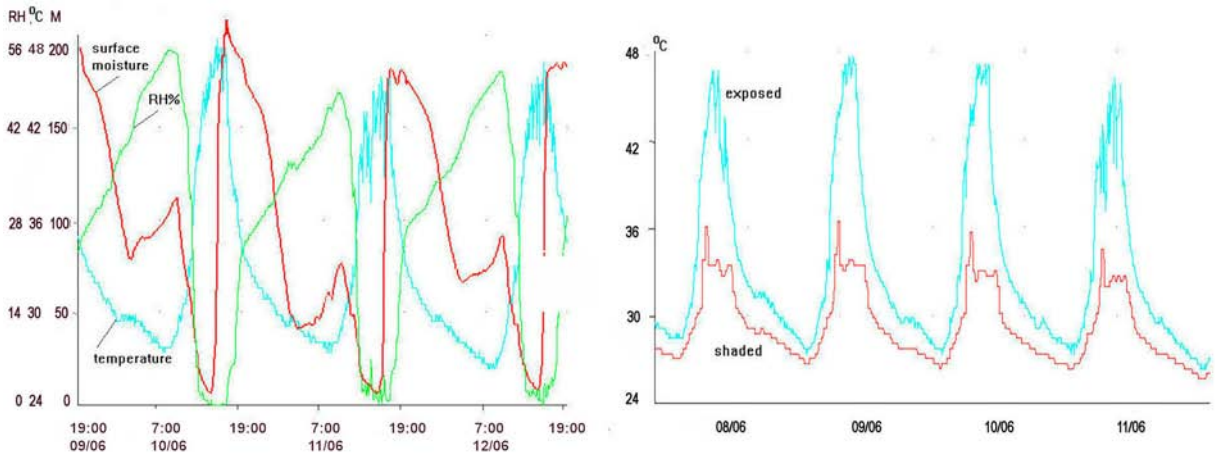


Figure 3. Three days of comparative data at Yuwengayay revealing the minor relationship between surface moisture, M (red) and humidity, RH (green), overshadowed by the significant increase in moisture when the rock temperature (blue) rises above c.44°C. The data shows that the salt melts to become a liquid dispersing unbound pigment. The right-hand side of the graph shows the impact of shades on reducing the surface temperature to ensure that salt melting does not take place. This is supported by observations at the site that no salt loss areas were present under permanent tree shade.

period, contrasting with the excessively high RH throughout the wet season.

The more significant peak has no correlation to RH but is directly related to temperature rise. Detailed study of the moisture response to heat shows that as the surface is warmed in the morning there is an initial drop in surface moisture, followed by a dramatic increase when the surface reaches c.44°C. This is higher than air temperatures throughout the year and hence higher than rock surfaces shaded by trees, as illustrated on the right side of Figure 3. This type of paint loss did not occur in the wall section fully shaded by trees (seen in Figure 4) indicating that tree shade would be a sufficient means of controlling the mechanism.

Figure 4 shows the insolation model on the left, taken from a point on the surface fully exposed to the sun with an image on the right looking back at the same point. The model is inverted to the image due to the opposing viewpoints. While the elevated view back at the site makes the opening in the tree screen very apparent, this was not available until the model had been constructed. The model does provide valuable information about the location of trees required to screen the exposed part of the site. More important than these details is the fact that tree shade can provide permanent control of the damage.

Rogers 2: stabilising hydrology

This painted site is a shallow cavern on what was private farmland, on Tasman's Peninsula, southern Tasmania, Australia. The cavern is set into an exposed sandstone cliff just above a stream and below a wooded hill that gives way to cleared farmland above the site. The hillslope above retains much of the endemic vegetation except for a tract of cleared ground on the crest used for farming. The site is subjected to granular disaggregation through high levels of magnesium sulphate salts, existing in several humidity-dependent hydration states. From the published equilibrium RH values the following sequence is established for stable and metastable states: anhydrous magnesium sulphate ($MgSO_4$) – 5% RH, kieserite ($MgSO_4{\cdot}H_2O$) – 23% RH, hexahydrite ($MgSO_4{\cdot}6H_2O$) – 54% RH, epsomite ($MgSO_4{\cdot}7H_2O$) – 87% RH, dodecahydrite ($MgSO_4{\cdot}12H_2O$). It is rare to find other than the intermediate states epsomite and hexahydrite although the RH recorded at the site over 16 months may support the formation of higher stable hydration states such as meridianiite ($MgSO_4{\cdot}11H_2O$), although this has not been confirmed at the site. A fuller description of the site conditions and the impacts of salt and infiltrating moisture has been published previously (Thorn 1996). Another salt, tinsleyite, was identified from a sample in the upper reaches of the alcove where high moisture driven disaggregation had scalloped out the ceiling and upper walls. Tinsleyite ($KAl_2(PO_4)_2(OH){\cdot}2H_2O$) is a phosphate, generally associated with bird guano and rarely encountered in rock shelters without this source. It is quite plausible that tinsleyite has formed through the interaction of phosphate fertilisers, as confirmed by the farmer, percolating through from the cleared grazing land above and interacting with the breakdown of biotite (dark mica) present in the sandstone.

Recommendations to protect the site included two key actions. Firstly, the site should be closed to the public as the few surviving paintings were very vulnerable to accidental damage, and secondly, that the application of phosphate fertiliser to the hillslope above should cease and the bare ground be revegetated. The farmer mentioned that he would be happy to sell this portion of land, and this was passed on through the report. The subsequent sale achieved the first recommendation that farming activities cease. The recommendation to close the site to all

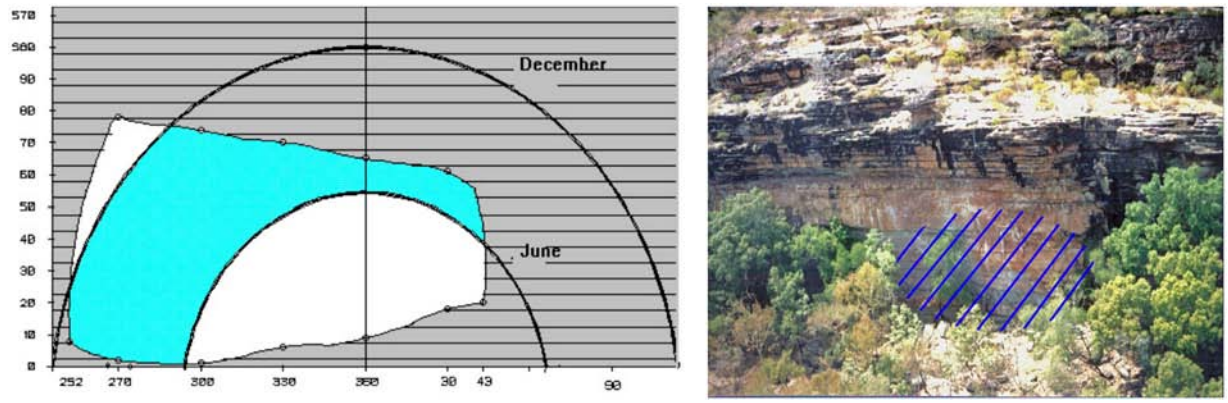


Figure 4. The insolation diagram for Yuwengayay shows sun entering the site from mid-morning in June, a mild dry month when the surface temperatures do not rise above the critical salt melt threshold. In December the sun enters after noon but often at times when late afternoon tropical thunderstorms reduce the insolation impact. The key to this diagram has been the ability to determine where trees need to be planted to provide permanent shade to the rock surface, as illustrated by the aerial photograph on the right side.

but Indigenous Tasmanians has meant the conservator has been unable to determine whether revegetation has been undertaken. This latter recommendation would substantially reduce water flow through the hillslope, ensuring that less water reached the cavern.

Te ana a maru: stabilising hydrology

Te ana a maru is a unique site in world rock art terms for containing a series of relief carvings, in contrast to the more prevalent breaking through a patinated surface to form an engraving. The site is located south of Rotorua, New Zealand, in the Kaingaroa forest, the second largest conifer plantation in the southern hemisphere. The site is a low shallow cavern formed by the more rapid erosion of the lower of two ignimbrite (tuff) benches of either two lava flow events or a lava flow and ash settlement sequence.

The cavern ceiling is approximately two metres above current ground level and reaches a depth of four metres. The six-metre-thick ceiling bench is intersected with cooling cracks and covered above by endemic vegetation, constrained to a small pocket of undisturbed natural bush in what is otherwise a massive expanse of Douglas fir plantations that come to within 30 m of the ground above the site.

Details of the site's condition, hydrology and conservation needs have been published (Thorn 2011; 2014) while this paper focusses on the relationship between the hydrology of the site and the trees above. The hydrological regime is dominated by two factors, a 1600 mm annual rainfall and the fact that when it rains water drips from the ceiling within 30 min, not from the fissures but directly through the blocks themselves with no apparent fissuration. The consequences of this are manifest vegetal growth on the carved rear wall and spalling of the very fragile ignimbrite.

The original condition assessment studied the surrounding forest to recommend a suitable buffer zone for a Treaty of Waitangi land transfer (Treaty of Waitangi 1840). The impact of the surrounding land, especially the forest, included protection from opportunistic visits, re-establishment of a pre-forest outlook from the site, and management of forestry harvesting not to dramatically change the hydrological regime.

A 20-hectare area (Figure 5) was legislated to be set aside as sufficient protection through the various criteria the report presented. The focus of the determination was the need to ensure that the entire rain catchment and drainage area was fully manageable from within the protected zone and for a phased transition from commercial to endemic forest. Figure 6 presents one example of the contour mapping undertaken to develop the drainage area requirement, using the altitude readings from Google Earth to plot an approximate extent of the ground levels. These were ground-truthed in critical areas around and above the site.

The rainfall at Te ana a maru is 1600 mm annually, which is almost exactly the rainfall intercepted and taken up by Douglas fir. To remove the mature forest with conventional clear felling would make a huge change in water seeping into the carved site. The proposal to replace the introduced species with endemic species requires at least a 30-year revegetation before the new forest could match the water uptake of the conifers, if at all. In 2009 the whole forest area, excluding the commercial standing trees, was handed back to various Māori stakeholders. Ownership

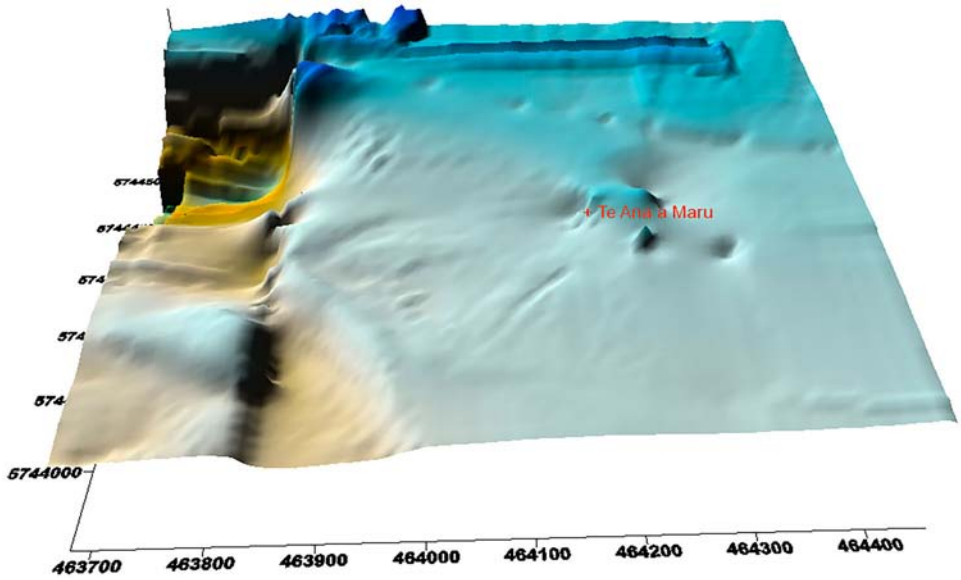


Figure 5. A contour map of the area around the Te ana a maru site, developed from Google Earth's altitude readings helped establish the drainage area affecting the site.

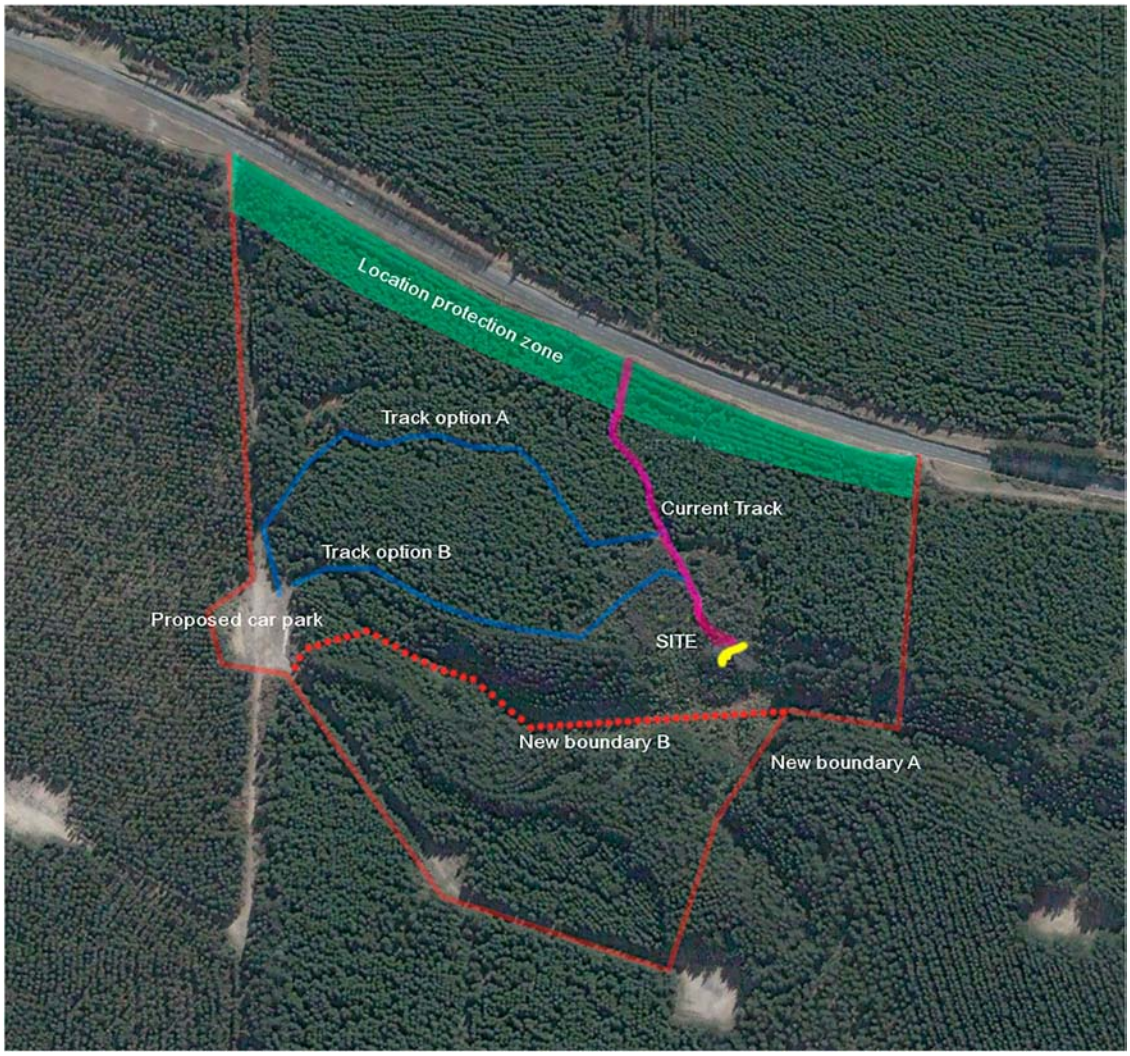


Figure 6. The various land protection criteria for Te ana a maru developed a map of a critical 18-hectare zone based on drainage, seclusion and undisturbed views from the shelter.

of the entire 2900-hectare forest makes management of this very special cultural place far more achievable.

Conclusion

Trees around cultural sites are often viewed as a threatening intrusion. The case studies presented here, together with other cited examples, illustrate that in some circumstances trees provide benefits difficult to achieve through more interventive means. An awareness of negative impacts must be considered to avoid invasive roots, limb fall or an increase in fire-related rock stress. A judicious screening of trees can favourably modify a site environment in a passive long-term system that requires minimal maintenance. Reducing insolation and intercepting rainfall can improve site stability in a manner unachievable by industrial means.

For the various recommendations, implementation has not been fully taken up in every instance. In the case of Rogers 2 the land has been acquired and farming activities ceased. The removal of grazing animals will ensure that the natural bush will re-establish without aid, albeit somewhat more slowly than if replanting were implemented. It is not known if the Yuwengayay site has had its vital tree screening proposal implemented. What is more important there is the fact that the need for trees in the designated area is understood and that regrowth will be encouraged. The Te ana a maru forest removal process, if adopted, needs to be scheduled, contractually, around commercial harvesting value, albeit with an understanding that clear-felling of the whole surrounding area may have devastating consequences for the carved site.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Biddle, P. G. 1998. *Tree Root Damage to Buildings*. Wantage: Willowmead Publishing.

Caneva, G., F. Bartoli, S. Ceschin, O. Salvadori, Y. Futagami, and L. Salvati. 2015. "Exploring Ecological Relationships in the Biodeterioration Patterns of Angkor Temples (Cambodia) Along a Forest Canopy Gradient." *Journal of Cultural Heritage* 16 (5): 728–735. Accessed May 13, 2023. https://www.academia.edu/12048620/Exploring_ecological_relationships_in_the_biodeterioration_patterns_of_Angkor_temples_Cambodia_along_a_forest_canopy_gradient.

CORLAB. 1988. *Conservation of Post-Estuarine Period Rock Art in Kakadu National Park: Final Report on Phase 3 Study*. Wilson: Australian Nature Conservation Agency.

Demas, M., N. Agnew, S. Waane, J. Podany, A. Bass, and D. Kamamba. 1996. "Preservation of the Laetoli Hominid Trackway in Tanzania." In *Archaeological Conservation and its Consequences*, edited by A. Roy, and P. Smith, 38–42. London: IIC. https://doi.org/10.1179/sic.1996.41.Supplement-1.38.

Demir, G., A. J. Guswa, J. Filipzik, J. C. Metzger, C. Römermann, and A. Hildebrandt. 2024. "Root Water Uptake Patterns are Controlled by Tree Species Interactions and Soil Water Variability." *Hydrology and Earth System Sciences* 28: 1441–1461. https://doi.org/10.5194/hess-28-1441-2024.

Haydock, P., and I. D. MacLeod. 1987. "The Use of Micrometeorological Studies as an Aid to the Conservation of Aboriginal Rock Art." In *ICOM-CC 8th Triennial Meeting, Sydney, 6–11 September 1987*, edited by G. Kirsten and H. JoAnn, 3, 1149–1154. Paris: ICOM. https://www.icom-cc-publications-online.org/3284/the-use-of-micrometeorological-studies-as-an-aid-to-the-conservation-of-aboriginal-rock-art.

Li, X., J. Niu, L. Zhang, Qingfu Xiao, Gregory E. McPherson, Natalie van Doorn, Xinxiao Yu, et al. 2016. "A Study on Crown Interception with Four Dominant Tree Species: A Direct Measurement." *Hydrology Research* 47 (4): 857–868. Accessed September 27, 2023. https://iwaponline.com/hr/article/47/4/857/1005/A-study-on-crown-interception-with-four-dominant.

Metzger, J. C., J. Filipzik, B. Michalzik, and A. Hildebrandt. 2021. "Stemflow Infiltration Hotspots Create Soil Microsites Near Tree Stems in an Unmanaged Mixed Beech Forest." *Frontiers in Forests and Global Change* 4: 1–14. Accessed September 27, 2023. https://www.frontiersin.org/articles/10.3389ffgc.2021.701293.

Thorn, A. 1994. "Direct Measurements to Determine Sandstone Deterioration." In *Preventive Conservation: Practice, Theory and Research*, edited by A. Roy, and P. Smith, 85–89. London: IIC. https://doi.org/10.1179/sic.1994.39.Supplement-2.85.

Thorn, A. 1996. "(Rogers 2).7H_2O." In *ICOM-CC 11th Triennial Meeting, Edinburgh*, edited by J. Bridgland, 471–479. Paris: ICOM. https://www.icom-cc-publications-online.org/2987/Rogers-27H2O.

Thorn, A. 2005a. "Predicting the Solar Impact of the Restored Glazing Regime of the Domed Reading Room, State Library of Victoria." In *ICOM-CC 14th Triennial Meeting, The Hague*, edited by J. Bridgland, 716–725. Paris: ICOM. https://www.icom-cc-publications-online.org/2101/Predicting-the-solar-impact-of-the-restored-glazing-regime-of-the-Domed-Reading-Room-State-Library-of-Victoria.

Thorn, A. 2005b. "Moisture Instability in Loosely Bound Pigmented Surfaces." In *ICOM-CC 14th Triennial Meeting, The Hague*, edited by J. Bridgland, 409–415. Paris: ICOM. https://www.icom-cc-publications-online.org/2069/Moisture-instability-in-loosely-bound-pigmented-surfaces.

Thorn, A. 2008a. "The Yuwengayay Preservation Project." In *Preserving Aboriginal Heritage: Technical and Traditional Approaches*, edited by C. Dignard, K. Helwig, J. Mason, K. Nanowin, and T. Stone, Proceedings of a Conference Symposium 2007, Ottawa, Canada, 333–339. CCI Ottawa. https://publications.gc.ca/site/eng/9.670573/publication.html.

Thorn, A. 2008b. "Mechanical Response of a Tasmanian Sandstone to Heat and Moisture." In *ICOM-CC 15th Triennial Meeting, New Delhi*, edited by J. Bridgland, 949–956. Paris: ICOM. https://www.icom-cc-publications-online.org/1969/Mechanical-response-of-a-Tasmanian-sandstone-to-heat-and-moisture.

Thorn, A. 2011. "Cultural Stability in an Unstable Environment: The Waka of Te ana a maru." In *ICOM-CC 16th Triennial Meeting, Lisbon*, edited by J. Bridgland, 1–9. Paris: ICOM. https://www.icom-cc-publications-online.org/1208/Cultural-stability-in-an-unstable-environment–The-waka-of-Te-Ana-a-Maru-.

Thorn, A. 2014. "Lithium Silicate for the Consolidation and Grouting of Murals, Stone and Rock Art." In *ICOM-CC 17th Triennial Meeting, Melbourne, Australia*, edited by J. Bridgland, 1–7. Paris: ICOM. https://www.icom-cc-publications-online.org/1464/Lithium-silicate-for-the-consolidation-and-grouting-of-Murals-Stone-and-Rock-Art—.

Thorn, A. 2018. "Re-evaluation of Environmental Modifications to an Island Cemetery After 28 Years." *Studies in Conservation* 63 (Supp. 1): 268–273. https://doi.org/10.1080/00393630.2018.1504513.

Thorn, A. 2021. "A Model to Assess Insolation Impact on Painted Rock Surfaces." In *Transcending Boundaries: Integrated Approaches to Conservation*, edited by J. Bridgland, 1–9. ICOM-CC 19th Triennial Meeting, Beijing. Paris: ICOM. https://www.icom-cc-publications-online.org/4468/A-model-to-assess-insolation-impact-on-painted-rock-surfaces.

Thorn, A., and A. Piper. 1996. "The Isle of the Dead: An Integrated Approach to the Management and Natural Protection of an Archaeological Site." In *Archaeological Conservation and its Consequences*, edited by A. Roy, and P. Smith, 188–192. London: IIC. https://doi.org/10.1179/sic.1996.41.Supplement-1.188.

Treaty of Waitangi. 1840. Accessed December 26, 2023. https://nzhistory.govt.nz/politics/treaty/read-the-treaty/english-text.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S341–S344
https://doi.org/10.1080/00393630.2024.2376471

ORIGINAL RESEARCH OR TREATMENT PAPER

Fotográfica en Red: A Working Group for Latin American Photographic Heritage

Fotográfica en Red: Un Grupo de Trabajo sobre el Patrimonio Fotográfico Latinoamericano

Natalia Ulloa[1] and Isabella Gama[2]

[1]Fotográfica en Red, Lima, Perú; [2]Studio Lumaca, Madrid, Spain

ABSTRACT

Fotográfica en Red is a collective network of professionals dedicated to preserving the photographic heritage in Latin America. This group was only possible thanks to online tools that allowed the meeting and parallel work and research between people of different countries. The purpose of this paper is to share our experience as a working group to encourage and reinforce the importance of collective work as a tool for the widespread dissemination of knowledge, validation of methodologies adapted to our reality, and claiming our own narrative as agents of custody of Latin American photographic heritage.

Fotográfica en Red es una red colectiva de profesionales dedicados a preservar el patrimonio fotográfico en América Latina. La creación del grupo sólo ha sido posible gracias a herramientas en línea que permiten el encuentro, el trabajo paralelo y la investigación entre personas de diferentes países. Este artículo comparte nuestra experiencia como grupo de trabajo para fomentar y reforzar la importancia del trabajo colectivo como herramienta para la difusión generalizada de conocimientos, la validación de metodologías adaptadas a nuestra realidad y la reivindicación de nuestra propia narrativa como custodios del patrimonio fotográfico latinoamericano.

ARTICLE HISTORY
Received October 2023
Accepted June 2024

KEYWORDS
Collective; network; photographic heritage; Latin America; online tools

Colectivo; red; patrimonio fotográfico; América Latina; herramientas en línea

Introduction

The 2020 pandemic enabled new digital spaces for those who had not yet tried online learning and work tools. It made us realize that remote education, collective work and research are possible and effective between people from different Latin American countries.

Fotográfica en Red (www.fotograficaenred.wordpress.com) is a collective of professionals from diverse specialties who share a commitment to preserving the photographic heritage in Latin America. This collaborative group makes up a dynamic learning space, fostering the exchange of experiences and knowledge that address the practical realities of daily work within both public and private institutions, as well as private practice, across nine countries in the region. In 2024, we will mark the fourth anniversary of our activities, made possible by the valuable contributions from each of the 20 members from Argentina, Uruguay, Bolivia, Chile, Peru, Colombia, Brazil, Guatemala and Mexico (Figure 1) within their respective areas of interest and expertise: conservators, archivists, documentation specialists, museologists, photographers and researchers for photographic heritage (Figure 2).

We have identified and prioritized needs within the Latin American context of managing and preserving photographic heritage. We aim to find a balance between collectively intriguing areas to investigate and develop and the practical realities of the region. Thematic axes were identified, and eventually, five working groups were established. Each group comprises three to six professionals, pooling specialized expertise to address shared challenges:

- *Glossary:* development of an updated compilation of terms related to photography, photographic conservation, and documentary processing, including synonyms and translations. This resource is crafted by and for Spanish and Portuguese and is accessed at https://fotograficaenred.wordpress.com/glosario/.
- *Latin American archive census:* compiling data on photographic archives within the region to assess methodologies used in previous censuses. Currently, the group is collaborating closely with local stakeholders, to gain insights into the current status of archives and professionals.
- *Photographic materiality:* focuses on studying and promoting photography as both an image and as a complex and, for the most part, stratified object. This involves technical and expressive aspects, as

CONTACT Natalia Ulloa natulloar@gmail.com Peru, Lima, 15074; Isabella Gama studiolumaca.cr@gmail.com Spain, Madrid, 28008
© The International Institute for Conservation of Historic and Artistic Works 2024

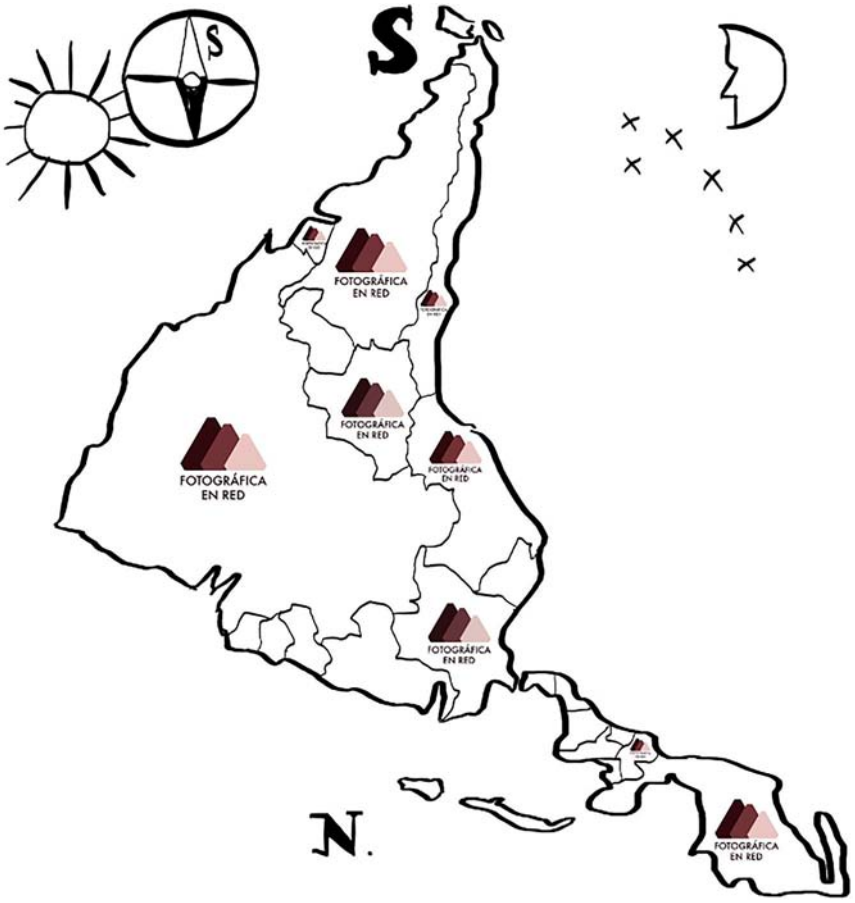


Figure 1. Graphic inspired by Joaquín Torres García, *América Invertida* 1936, in which the artist inverted the map so that "the tip of [South] America insistently points us to our North" with the group logo placed in each member country. The original was published in *Círculo y cuadrado,* Montevideo.

well as permanence properties and degradation pathways for different photographic processes.

- *Communication and dissemination:* responsible for maintaining continuous and close communication with the community, understanding the collective challenges, and providing guidance on best practices and regulatory guidelines. Additionally, this group ensures the effective flow of internal communication within *Fotografica en Red*.



Figure 2. Online meeting of *Fotográfica en Red* in 2021.

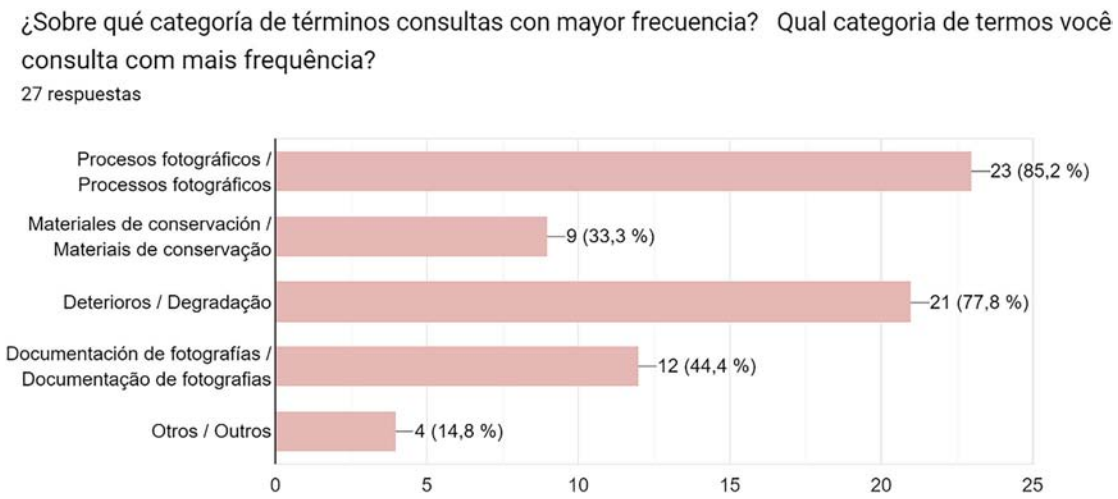


Figure 3. Preliminary results at May 2023 of the Glossary working group survey on the categories of frequently used terms for: photographic processes, conservation materials, deterioration, photographic documentation (May 2023).

- *Events and training:* organizing events to connect with members of our network, raise awareness in the region, and participate in dissemination activities. Additionally, arranging training sessions tailored to the interests and needs of our community.

The strength of a working group composed of different professional backgrounds, including conservators, archivists and researchers, lies in its ability to harness a wealth of expertise and resources. This unfolds due to the wide spectrum of knowledge, skills, and perspectives, enabling the group to benefit from a broad network of connections within the photographic heritage field.

In our journey of continual growth, guided by metrics at a human scale, we also wish to highlight certain achievements that fortify our commitment to the preservation of photographic heritage.



Figure 4. International Archives Day (2022) and World Photography Day (2023) organised by *Fotografia en Red*.

Glossary working group

As part of the methodology and so that the information is not limited to the knowledge of the group members, a survey was developed and sent by email to professionals and institutions related to photography in Latin America. At the same time, it was shared through our social networks, such as Instagram and Linkedin. The results of this survey, which now has over 60 responses by professionals from the countries of Chile, Argentina, Peru, Mexico, Brazil, Uruguay, Guatemala, Cuba and Honduras, were an important contribution to defining the priority of the categories to consider (https://fotograficaenred.wordpress.com/glosario/) (Figure 3).

In addition, the data indicates specific needs that professionals related to photography face, when consulting glossaries and thesauri. This will allow us to continue developing this tool in the long term.

The project to develop a glossary of terms linked to photography and its management in Latin America was presented at the *FOTOForo 2023* at *Fotobservatorio*[1], and received the 'Encouragement of Good Practices' award.

The generous participation of external agents directly involved in projects designed and developed in Latin America is essential for *Fotografica en Red* and its working groups. The Latin American census working group identified the need for discussion about the experiences of colleagues in carrying out research, surveys and directories of photographic repositories in Latin America. Different meetings were held with professionals such as Ilonka Csillag (Procultura Foundation – Chile), Gabriela González (Fotobservatorio – Mexico) and Samuel Salgado (Cenfoto – Chile). It was possible to learn about the main issues, needs at the national or regional level, and social impact. These confirmed the important work of quantifying the repositories, the people in charge, the materials in collections, and their preservation needs.

Photographic materiality working group

This working group is compiling a list of suppliers of photographic conservation materials and a specialized bibliography curated by the members of the group, that will soon be available to the community.

Communication and dissemination working group

This working group maintains a presence on social networks ((LinkedIn: https://www.linkedin.com/company/fotografica-en-red/, Instagram: https://www.instagram.com/fotografica.en.red)) and instigates an open dialogue with the community interested in the preservation of Latin American photographic heritage. We have recently opened a website (www.fotograficaenred.wordpress.com) and a Youtube channel (https://www.youtube.com/@fotograficaenred) to share all of our events, videos, research and new information.

Events and training working group

In the 4 years since *Fotográfica en Red* was established, we have carried out six important events and seminars (Figure 4) (https://fotograficaenred.wordpress.com/eventos/) with specialists from Latin America such as Abel Alexander (Photohistorian), Ilonka Csillag (Procultura), Gabriela González (Fotobservatorio), Samuel Salgado (CENFOTO), Oscar Chambi (Asociación Martín Chambi), Myriam Ramírez and Brenda Chávez (Fundación Ajaraca A.C.), Alexis Placencia (Oficina del Historiador de la Ciudad de La Habana), Carlos Montoya (Biblioteca Pública Piloto de Medellín para América Latina), Cecilia Salgado (private practice photo conservator), Gabriela Escobar and Santusa Marca (historians), Emilio Suárez (private practice archivist), Andrea Durán (Archivo Central Andrés Bello, University of Chile), Anaís García (CIRMA). Nowadays, it is possible to register for our online talks through our website and to access some of them through our Youtube channel (Figure 4).

In 2024, we shall continue to develop these projects. *Fotográfica en Red* has established itself as an educational platform for its members and as custodians of Latin American photographic memory.

Acknowledgements

We would like to thank our fellow colleagues and members of Fotográfica en Red: Laura Caroni, Ana Laura Cirio, Gustavo Lozano, Carla Fusaro, Emilio Suárez, Anaís García, Mirasol Estrada, Vianka Hortuvia, Carolina Nastri, Cristina Machicado, Sandra Suárez, Juliana Bittencourt, Mayumi Higa, Matías Acosta and Andrea Durán, and former members Soledad Abarca, Ximena Bruna and Laura Gómez, for their active engagement and all the effort put into the collective work.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Isabella Gama http://orcid.org/0000-0001-9160-7964

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S345–S351
https://doi.org/10.1080/00393630.2024.2339712

ORIGINAL RESEARCH OR TREATMENT PAPER

Introducing a Risk-, Value- and Collection Lifetime-Based Lighting Policy at the Victoria and Albert Museum in London

Presentación de una Política de Iluminación Basada en el Riesgo, el Valor y la Colección en Función de la Vida Util en el Victoria and Albert Museum de Londres

Sarah VanSnick and Pedro Gaspar

Victoria and Albert Museum, London, UK

ABSTRACT

In 2001, the conservation department at the Victoria and Albert Museum, London, implemented a risk-based lighting policy for highly light-sensitive collection objects that has been influential across the museum sector and informed the rotation of these objects across its permanent galleries and touring exhibitions. As the V&A grows into a family of museums – opening three new sites between 2023 and 2025 – and with ambitious exhibition and display programmes, the challenge facing the museum is to continue to balance the care of collections, increase access to them, and keep resource requirements sustainable. To address this challenge, the conservation department developed a new risk- and value-based policy to manage highly light-sensitive collections on display in its permanent galleries. This policy builds on the earlier risk-based approach to lighting policies and introduces value assessment, microfadometry and collection lifetimes as tools for optimal collections management to the wider organisation.

En 2001, el departamento de conservación del Victoria and Albert Museum de Londres implementó una política de iluminación basada en el riesgo para objetos de colección altamente sensibles a la luz que ha tenido influencia en todo el sector de los museos y ha informado la rotación de estos objetos en sus galerías permanentes y exposiciones temporales. A medida que el V&A se convierte en una familia de museos (con la apertura de tres nuevos sitios entre 2023 y 2025) y con ambiciosos programas de exposición y exhibición, el desafío que enfrenta el museo es continuar equilibrando el cuidado de las colecciones, aumentar el acceso a ellas y mantener los recursos requeridos sostenibles. Para abordar este desafío, el departamento de conservación desarrolló una nueva política basada en riesgos y valores para gestionar colecciones altamente sensibles a la luz que se exhiben en sus galerías permanentes. Esta política se basa en el enfoque anterior basado en el riesgo para las políticas de iluminación e introduce la evaluación del valor, la microfadometría y la vida útil de las colecciones como herramientas para una gestión óptima de las colecciones en toda la organización .

ARTICLE HISTORY
Received November 2023
Accepted March 2024

KEYWORDS
Lighting policy; value assessment; risk assessment; collection lifetime

Política de iluminación; evaluación de valor; Evaluación de riesgos; vida útil de la colección

Introduction

The Victoria and Albert Museum (V&A) in London, UK, is the world's leading museum of art, design and performance. From its 2.8 million collection items there were in April 2023 over 85,000 objects on display across over 100 permanent galleries at the museum's South Kensington site. With such varied collections including textiles, artworks, manuscripts, and modern materials, many of the objects include materials or colourants that can be considered highly sensitive to light (BSI 2018).

In the late 1990s and early 2000s the V&A pioneered a risk-based lighting policy that set out the idea of an institution agreeing an acceptable rate of change for its objects on display over a certain period (Derbyshire and Ashley-Smith, 1999). Based on the materials present in each object a light budget in lux-hours could then be established, enabling a more flexible approach to lighting and display times. One just noticeable change (JNC) (Michalski 2018) in 50 years was then agreed as a pragmatic approach to balancing access and care of collections, driving the rotation cycle of light-sensitive objects on display.

However, over the last 20 years the application of the policy to objects on display in the V&A permanent galleries has been inconsistent. While everyone accepted the soundness of the risk-based approach in theory, it was often not carried into practice. Reasons for its failure can be grouped into two main themes, according to feedback from colleagues:

- *Process.* There were limited systems in place to facilitate the rotation of objects. Galleries at the V&A are

CONTACT Sarah VanSnick s.vansnick@vam.ac.uk Conservation Department, Cromwell Road, Victoria and Albert Museum, London SW7 2RL, UK
© The International Institute for Conservation of Historic and Artistic Works 2024



Figure 1. (Left) Ardabil carpet on display in the Islamic Gallery within a specially designed case that includes lighting that comes on only for 10 min an hour. (Right) Table carpet on display for 20 years in the *Bromley-by-Bow* room of the British Galleries, where light levels are low, with no attempt made to mitigate light exposure.

managed by different curatorial teams and there was no central list of objects on display to guide a museum-wide rotation schedule. Most curatorial teams relied on individual conservators to alert them to the need to rotate an object. The collection management system which is used for museum objects did not include archive and library materials on display, further fragmenting the management of rotations, and databases did not record light levels or display periods.

- *Resources*. Swapping objects in a gallery requires not only conservation resources, but also input from other teams (such as curatorial, design, and museum technicians), costs for new mounts or backboards in cases, and object availability.

This has resulted in some objects being regularly rotated, approximately every two years, as well as significant investment in mitigation solutions for some key items, such as the Ardabil carpet (V&A 2019). In less successful scenarios some highly light-sensitive objects have been left in galleries for 20 years because they are, or are perceived to be, too difficult or complex to replace (Figure 1).

As the V&A enters a period of rapid expansion – opening three new museum sites in London (named Young V&A, V&A East Storehouse and V&A East Museum) between 2023 and 2025, new ways of working are being developed to meet the challenges of delivering museum functions across a multi-site model. This has included the creation of a new preventive conservation team within the conservation department with responsibility for managing rotations of light-sensitive objects on display (across all galleries and sites) and who also led on the development and implementation of a new policy discussed here.

Materials and methods

Initial attempts to understand the scale of rotations needed across the V&A South Kensington site led to the first attempt to create a list of highly light-sensitive objects on display using a search of the museum collections management system (CMS) with keywords such as 'watercolour', 'textile' and 'poster'. This initial list suggested there were 3000–5000 objects that could be considered highly light-sensitive. This proved that resourcing the existing policy would simply not be sustainable; it would require changing or swapping 2000–2500 objects a year (as some galleries are brighter than 50 lux), when what was being achieved was closer to 50–100. With additional permanent galleries at the new sites, the backlog would only grow. The V&A has a large conservation department with over 50 permanent conservators; however, they are primarily dedicated to delivering the ambitious public programme of exhibitions, displays, loans and tours, which number in the hundreds annually. Substantial investment in staff and other resources would be required to deliver the existing policy and would only increase with time.

A new approach was needed, building on the risk-based approach pioneered by the V&A decades earlier. In 2019 the V&A had launched its own organisational risk management policy, with the intention of it becoming a universal language across all departments and teams. Conservators, curators and exhibition project managers were already making some use of risk assessment frameworks to communicate projects' risks. To build on this the conservation department invited Anna Bülow and Agnes Brokerhof, both conservation professionals who have carried out extensive work in risk management, to host a cross-departmental workshop to develop a collective understanding of collections risk assessment at the V&A. This session helped the group look at risk but also collection value assessment, taking the V&A's *1900–Now* gallery at South Kensington as a case study, using a number of tools (Brokerhof and Bülow 2016; Michalski and Pedersoli 2016) and providing a catalyst for a new lighting policy.

The conservation management team could see the potential offered in attempting to develop a policy

that had both risk and value components. Taking the lead from Bülow's prioritisation experiment at the British Museum (Bülow et al. 2016), conservators developed a draft policy where conservators would take on the risk assessment elements of the policy and the curatorial team the value assessment portion.

The risk assessment element of the policy required the conservators to create a list of all highly light-sensitive objects across all permanent galleries at the South Kensington site and to determine their light exposure for their current period of display. This required three pieces of information to be brought together – the list of objects to be covered by the policy, the light levels in the galleries, and how long each object had been on display.

Conservators opted to use the 'high sensitivity' category from Annex E. *Light Sensitivity – Sensitivity of coloured materials to light* in British Standard EN 16893:2018 (BSI 2018) and/or in *Table 3. Sensitivity Levels and Fading* as published on the Canadian Conservation Institute webpage *Agents of Deterioration: Light, Ultraviolet, and Infrared* (Michalski 2018) as the definition of 'light-sensitive' for the policy. In the majority of cases, there is no information on the specific dyes or pigments used for the object, so it required identifying all objects that could potentially contain these materials – such as watercolours, miniatures, textiles, photographs, books, costumes, etc. This results in large general categories of objects being identified, but it is hoped that over time this list can become more specific, through further research and literature review.

The V&A has a range of light levels across its permanent galleries, so a list of average lux levels was created for each gallery based on spot readings. These averages ranged from 50 to 400 lux. Light levels were assigned to each object based on the gallery it was located in. Then the length of the display was calculated based on records in the museum's collection management system. By multiplying the lux levels by the display period in hours (assuming 9 h per day, across all galleries and sites), the overall exposure was calculated for each light-sensitive object. For the initial pilot year, conservators prioritised the value assessment of those objects at the greatest risk – those objects with a known exposure of more than 1,000,000 lux-hours. This resulted in a list of approximately 1500 objects to be value assessed and rotated.

The value assessment has been designed to identify and prioritise objects of high value(s) to the museum. To obtain curatorial buy-in and resources to carry out these assessments the process would have to be both simple and quick to carry out. This meant that current value assessment methods published in the literature (Michalski and Pedersoli 2016; Reed 2018; Versloot 2014) were discounted or needed substantial modifications to meet our needs to engage stakeholders successfully.

To keep the assessment simple, we first opted for three possible value outcomes – High, Medium, or Low. To determine the outcome three 'yes' or 'no' questions would be asked about each object. For each 'yes', one point is received. So, three yeses would score 3, two yeses would score 2 and one yes, 1.

In trying to identify which questions to ask curatorial colleagues and which values to highlight, conservators, in consultation with curatorial colleagues, opted to modify the value assessment set out in *Assessing Museum Collections: Collection Valuation in Six Steps* (Versloot 2014). This was also the approach at the British Museum in Bülow's attempt to develop a shared set of priorities (Bülow et al. 2016) between curators and conservators, which in essence, is what this policy was ultimately trying to achieve.

After some discussion with conservators and curators, the decision was made to use one attribute and two values for the value assessment taken from the framework in *Assessing Museum Collections*. Each assessment question was to be presented as a group of statements expressing the attribute or value where the assessors would overall agree a 'yes' or 'no'. The question groups are as follows:

- *Uniqueness*. Is the object of national/international significance? Is it unique? Is it a rare example of a more common object? Would it satisfy one or more of the 'Waverley Criteria' (ACE 2024)?
- *Historical and Societal*. Is there a link with a particular historical person, event, period, or process etc.? Does the object fulfil a certain function for a group or community? Does it have a social, religious, or political meaning for a group or community? Does the item play a decisive role in the identity of a group or community?
- *Use*. Is the object popular – does it attract visitors? Does it generate revenue for the museum? Is it used frequently for educational or research purposes? Is it often requested for loan, exhibition, or tours?

These attributes and values were chosen deliberately to work together. The broad value of 'social/historical' covers what many would consider to be the main reason objects enter museum collections. It is essentially a value we would anticipate that most collection items have. It is anticipated therefore that most objects would have a 'yes' for this value, giving them a minimum score of 1. However, it was felt there would be occasions where an object might only get a score of 1 for 'use'. These objects are often acquired as part of setting up an exhibition to more fully explore a theme or tell a story. An example of such objects are the 'Hello Kitty' branded kettle, toaster and rice maker which were purchased from a high street shop to accompany other museum

objects telling the story of *Lolita fashion* in the V&A South Kensington *Japan* gallery.

The other elements of the assessment rate the object's rarity and popularity, getting one additional point for each. If an object is both unique *and* in high demand (by visitors, exhibitions, researchers, for loans, etc.), it is given the highest rating of 3. If the object is unique *or* popular (but not both) it gets a rating of 2 and if the object is only awarded one 'yes' out of three questions, it gets a rating of 1.

In value assessments, the rating categories are often identified as High, Medium, and Low, but curatorial colleagues are often not comfortable or keen to apply a 'low' value assessment to their collection objects. Rating scales and scoring of objects are far more common in the conservation profession (National Portrait Gallery 2021) than in curatorial circles. Bülow and Brokerhof commented during their risk assessment workshop that they in the past had had to use High, Medium Medium, and Medium, because 'low' was just not deemed an acceptable descriptor. In response to this challenge, the V&A chose to use descriptive category names for the different value ratings in place of High, Medium and Low. High became Exemplar, Medium became Standard and low became Engagement (Table 1).

Given the large number of light-sensitive objects in the museum galleries, to manage and resource a programme of rotation, each descriptive value rating category was assigned a different assumed collection lifetime. These collection lifetimes are based on the same just noticeable fade or JNC principle found in the original V&A lighting policy (Derbyshire, Ashley-Smith, and Pretzel 2002), where an acceptable period to a JNC is 50 years (or two generations) and a range of 10–30 JNCs will lead to full colour loss in an object (Derbyshire, Ashley-Smith, and Pretzel 2002; Michalski 2018). For Exemplar objects, the 50-year period to reach a JNC was retained, for Standard objects it was halved to 25 years and for Engagement objects it was set at 10 years. Based on the assumption that JNCs continue to happen at the same rate over the

Table 1. Example of a value assessment spreadsheet.

Museum number	Maximum exposure (lux hours)	Description	Type	Value – Uniqueness	Value – Societal/ Historical/ Aesthetic	Value – Use	Score	Value rating
CIRC.45-1970	5,268,000	Furnishing fabric 'Lunar Rocket' of screen-printed cotton, designed by Eddie Squires, made by Warner and Sons, Great Britain, 1969	Furnishing fabric	No	Yes	Yes	2	Standard
CIRC.303-1970	5,268,000	model 582; French 1965 des. P.Paulin man. Artifort	Chair	Yes	Yes	No	2	Standard
CIRC.101-1977	5,268,000	English, 1970–1975, plastic, Conran Associates	Wastepaper bin	No	Yes	No	1	Engagement
CIRC.113-1977	5,268,000	Wastepaper bin from Input range, designed by Conran Associates	Wastepaper bin	No	Yes	No	1	Engagement
W.661-2001	5,268,000	Videosphere television set, made by JVC, Japan, 1970. Includes white ABS plastic television, two base units (one with alarm clock) and spare ring aerial	Television; clock; base unit; aerial	No	Yes	Yes	2	Standard
M.24-1993	5,241,600	Olivetti Valentine Typewriter, designed by Ettor Sottsass and Perry King for Olivetti, Milan, made in Spain, ca.1969.	Typewriter	No	Yes	Yes	2	Standard
W.1-2016	5,241,600	RR126 radiogram; white plastic laminate, wood, aluminium; Achille and Pier Giacomo Castiglioni for Brionvega; Italy, 1966	Radiogram	Yes	Yes	Yes	3	Exemplar
M.35-1992	5,241,600	Standard lamp, steel and glass, Italy, Brescia, made by Flos s.p.a., 1962–1970, designed by Achille and Pier Giacomo Castiglioni, 1962	Standard lamp	No	Yes	No	1	Engagement
CD.31-2021	1,060,800	Hand-knitted wool pouch made for joeys (baby kangaroos), affected by the Australian bushfires in 2019 and 2020	Joey pouch	No	Yes	No	1	Engagement
CD.33-2021	1,060,800	Hand-knitted wool pouch made for joeys, affected by the Australian bushfires in 2019 and 2020	Joey pouch	No	Yes	No	1	Engagement
CD.32-2021	1,060,800	Hand-knitted wool pouch made for joeys, affected by the Australian bushfires in 2019 and 2020	Joey pouch	No	Yes	No	1	Engagement
W.5-2020	1,060,800	Cosmolux Sun Lamp (model HUV 1XX), Dieter Rams, Reinhold Weiss, Dietrich Lubs, 1964, Manufactured by Braun AG, Frankfurt, Germany. Anodised aluminium, enamelled steel and plastic	Cosmolux Sun Lamp (model HUV 1XX)	No	Yes	No	1	Engagement

Table 2. Light budgets and collection lifetimes for each value category.

Collection value category	Light budget (lux hours) for 10 years (BW2)	Preservation target	Object lifetime	Who will see change
Exemplar	200,000	1 JNC in 50 years	c.500–1500 years	Grandchildren
Standard	400,000	1 JNC in 25 years	c.250–750 years	Children
Engagement	1,000,000	1 JNC in 10 years	c.100–300 years	You

lifetime of the object, which is a very conservative approach, these agreed timelines for a JNC would suggest an object lifetime of 500–1500 years for Exemplar objects, 250–750 years for Standard objects and 100–300 years for Engagement objects. Finally, each value rating category was given a light budget based on the number of lux-hours required to bring about a JNC with an object with light sensitivity equivalent to Blue Wool 2.

These time periods are abstract, and it is challenging to convey the impact of decisions made today on the future of an object. In response to this, along with JNCs and the total lifetime years for objects, our communication with stakeholders was also expressed in relative terms for change to be visible. Exemplar objects were described as 'Your grandchildren will see a visible change', Standard ones as 'Your children will see visible change' and Engagement ones as 'You will see change within your professional career' (Table 2).

Due to the way, galleries are often designed, some light-sensitive objects are installed as star items or written into the narrative of the gallery in a way that makes it very difficult, or essentially impossible, to remove and replace them without a complete redesign. The policy needed to take this into account and instead of advocating for the removal of these key objects from display, the objective is to ensure that appropriate mitigation measures are in place to reduce light exposure as much as possible. To inform these decisions, specifically with objects valued as Exemplar by the curatorial teams and that need to remain on display, the preventive conservation team will prioritise resources on microfadometry (Beltran et al. 2021) to better assess the risks to objects, instead of relying on the more generic light budgets based on Blue Wool 2.

The rotation policy also clarified the decision-making process around the display of duplicates in the collection. It makes a clear statement that the V&A intends to use at least one duplicate as the 'display copy', and to keep at least one as the 'research copy', not rotating duplicates with each other, thus taking the 'sacrifice' approach to managing change over the 'spread' approach (Brokerhof, Kuiper, and Scholten 2018).

Results

As the new policy marked a new approach to care of collections at the V&A it was developed in consultation with curatorial colleagues and in open workshops to discuss and feedback concerns from all stakeholders. The final draft was then approved by the Keepers of all V&A curatorial departments, the Director of Collections and the museum's Director. Final approval was obtained by the Board of Trustees. This ensured that this new approach had approval from across the organisational hierarchy.

With approvals in place, the preventive conservation team led sessions in different galleries to assist curatorial colleagues with the value assessment process of the first half of the list of light-sensitive objects. These were considered the highest-risk objects as all had over 1,000,000 lux-hours of exposure. Over 1962 objects were assessed with the breakdown between the value categories set out in Figure 2.

In order to prioritise the highest-value objects, conservation management decided that for the first pilot year the focus for the rotations would be on those objects that received Exemplar rating. The next stage was back to the curatorial team to determine if there was a possible swap item for each Exemplar object, and if so, whether it was accessible, as the V&A is currently in the middle of a large collection move project, and access to much of the collection in storage is restricted. For those objects where there was no possible swap as the object was too integral to the narrative of the gallery, the team would carry out microfadometry to determine the actual risk level of the object remaining on long-term display. From there, if required, a programme of mitigations could be developed, specific to each object and gallery.

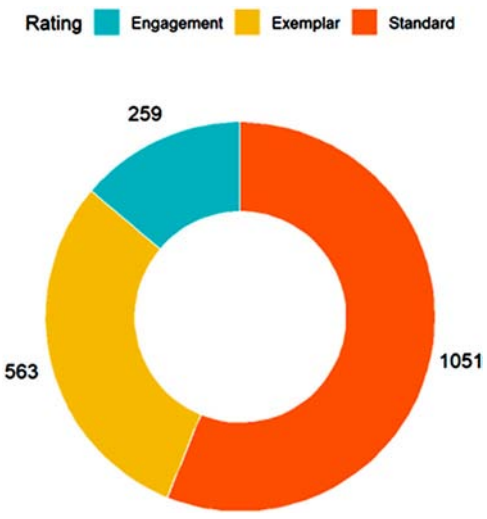


Figure 2. Split between the different collection value categories for the first half of collection objects assessed.

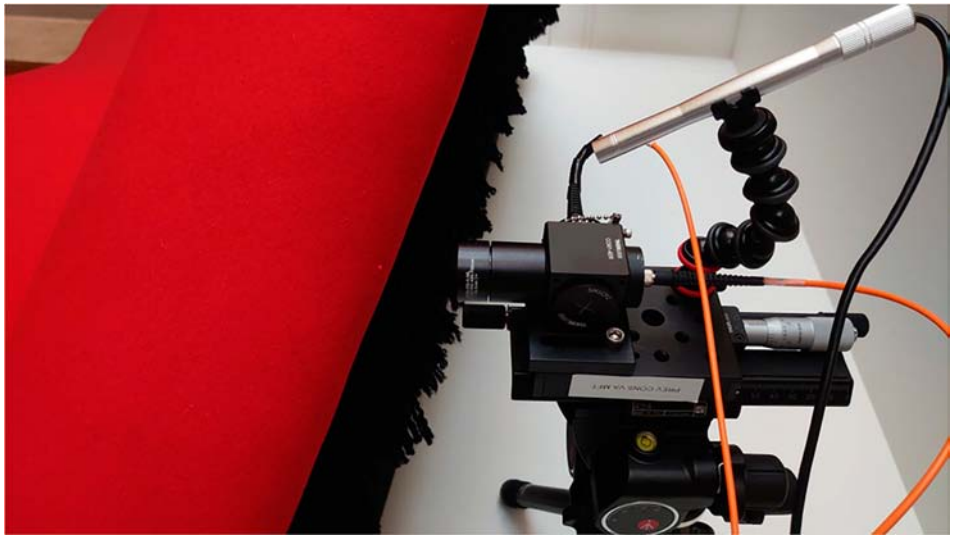


Figure 3. Microfadometer set-up to test the *Mae West Lips Sofa*.

Of the 563 Exemplar objects, we ended up with a list of 120 objects that could be rotated. Those with swaps currently in storage were put on a holding list and those without swaps or existing mitigation strategies in place were placed on a list for microfadometry.

One of the first objects we investigated with microfadometry was the *Mae West Lips Sofa* designed by Salvador Dali and Edward James, located in the *1900-Now* gallery. While the sofa had only been on display for 3 years, the high light levels in the reading-room-turned-gallery meant that this was one of the most valuable objects with the highest levels of light exposure across the museum. However, the microfadometry (Figure 3) revealed that the sofa was not as sensitive to light as anticipated, being closer to Blue Wool 4 than Blue Wool 2, but that the current light levels in the gallery could result in a JNC in only 6.5 years. Given this information, the decision has been made to rotate the object and to pursue a mitigation strategy that will reduce the light levels across the gallery.

Discussion

The policy seeks to achieve a balance between access and care of collections in a multi-site museum with multiple priorities. The consultative approach to its development, building on existing approaches, with workshops to introduce new concepts and gather feedback, finally seeking endorsement across the institutional hierarchy, has been successful. The various curatorial teams have for the most part engaged with the value assessment. There have been some issues with consistent application of the value assessment across teams. In some cases, this is simply due to lack of clarity or understanding but there have been a very limited number of colleagues who have tried to assess all of their collections on display as Exemplar. In order to address this going forward, we have asked the Keepers (leaders of the curatorial departments) to provide some oversight of the rating system and question any outliers to hopefully provide a more consistent assessment in the future. We have also addressed curatorial concerns over the permanency of a value assessment, offering them the opportunity once a year to review and make changes to value assessments to reflect the relative nature of value assessment.

While there is a significant backlog of object rotations needed, with the V&A opening three new sites between 2023 and 2025, additional resource have been hard to obtain. However, the new policy and processes established have ensured that the resource available is being directed to the highest-value and most at-risk objects for which we have available alternatives. It has also started conversations between teams about objects that were felt to be too difficult to remove, and offers a mechanism to enable those conversations to become action.

The first round of assessments identified a large number of Exemplar objects for which there was no alternative object available for rotation. These are now being put on a microfadometry plan so we can better assess the risks with exposure for each object and have a more fruitful discussion with curators and the V&A estates department on mitigations and priorities for gallery redevelopments.

Currently this value and lifetime-based approach is only in place for the purpose of rotating light-sensitive objects in the permanent galleries. The desire and intention is to expand it to temporary exhibitions and loans of V&A collection objects in the short to medium term, once the new processes are well established and working smoothly. We also aim to make use of this approach as part of new permanent gallery design going forward – to ensure that where Exemplar objects are being selected for display that there are

sufficient objects to swap in the future within the collection for the lifetime of the gallery or that mitigations to reduce light exposure of the object are integrated into the project to design of the gallery.

Acknowledgements

The authors wish to first thank Anna Bülow and Agnes Brokerhof for sharing their knowledge and experience and for providing valuable feedback on initial drafts of the policy. Thanks are due to Susana Fajardo and Bhavesh Shah for developing the process to go along with the policy and for evaluating the data. This work would also not have been possible without the large number of V&A curatorial colleagues who provided feedback and have participated in the value assessments – our thanks for approaching this new way of working with generosity.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

ACE. 2024. *Export Licensing: Guidance Documents*. Arts Council England. Accessed January 5, 2024. https://www.artscouncil.org.uk/supporting-arts-museums-and-libraries/export-licensing#t-in-page-nav-3.

Beltran, V. L., C. Pesme, S. K. Freeman, and M. Benson. 2021. *Microfading Tester: Light Sensitivity Assessment and Role in Lighting Policy*. Los Angeles: Getty Conservation Institute. http://hdl.handle.net/10020/gci_pubs_microfading_tester.

Brokerhof, A. W., and A. E. Bülow. 2016. "The QuickScan – a Quick Risk Scan to Identify Value and Hazards in a Collection." *Journal of the Institute of Conservation* 39 (1): 18–28. https://doi.org/10.1080/19455224.2016.1152280.

Brokerhof, A., P. Kuiper, and S. Scholten. 2018. "Spread or Sacrifice: Dilemma for Lighting Policies." *Studies in Conservation* 63 (sup1): 28–34. https://doi.org/10.1080/00393630.2018.1504439.

BSI. 2018. *BS EN 16893:2018. Conservation of Cultural Heritage. Specifications for Location, Construction and Modification of Buildings or Rooms Intended for the Storage or Use of Heritage Collections*. London: British Standards Institution.

Bülow, A. E., A. W. Brokerhof, C. Barry, and H. Chapman. 2016. "Pride and Prejudice." *Journal of Paper Conservation* 17 (3–4): 100–111. https://doi.org/10.1080/18680860.2016.1287479.

Derbyshire, A., and J. Ashley-Smith. 1999. "A Proposed Practical Lighting Policy for Works of Art on Paper at the V&A." In *ICOM-CC 12th Triennial Meeting*, Lyon 29 August – 3 September 1999, Vol. 1, 8–41. Paris: ICOM. https://www.icom-cc-publications-online.org/2358/A-proposed-practical-lighting-policy-for-works-of-art-on-paper-at-the-VA-.

Derbyshire, A., J. Ashley-Smith, and B. Pretzel. 2002. "The Continuing Development of a Practical Lighting Policy for Works of Art on Paper and Other Object Types at the Victoria and Albert Museum." In *ICOM-CC 13th Triennial Meeting*, Rio de Janeiro, 20–27 September 2002, 3–8. Paris: ICOM. https://www.icom-cc-publications-online.org/2181/The-continuing-development-of-a-practical-lighting-policy-for-works-of-art-on-paper-and-other-object-types-at-the-Victoria-and-Albert-Museum.

Michalski, S. 2018. *Agents of Deterioration: Light, Ultraviolet and Infrared*. Ottawa: Canadian Conservation Institute. Accessed January 5, 2024. https://www.canada.ca/en/conservation-institute/services/agents-deterioration/light.html#dil1.

Michalski, S., and J. L. Pedersoli. 2016. *The ABC Method: A Risk Management Approach to the Preservation of Cultural Heritage*. Ottawa: Canadian Conservation Institute. https://www.canada.ca/en/conservation-institute/services/risk-management-heritage-collections/abc-method-risk-management-approach.html.

National Portrait Gallery. 2021. *Archive Collection Care and Conservation Policy – Section 6.0 Conservation*. Accessed October 30, 2023. https://www.npg.org.uk/about/corporate/gallery-policies/archive-collections-care-and-conservation-policy.

Reed, C. 2018. *Reviewing Significance 3.0: A Framework for Assessing Museum, Archive and Library Collections' Significance, Management and Use*. Accessed October 24, 2023. https://collectionstrust.org.uk/resource/reviewing-significance-3-0/.

Versloot, A. 2014. *Assessing Museum Collections: Collection Valuation in Six Steps*. Amersfoort: Cultural Heritage Agency of the Netherlands.

Victoria and Albert Museum. 2019. *The Ardabil Carpet*. Accessed October 24, 2023. https://www.vam.ac.uk/articles/the-ardabil-carpet.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S352–S359
https://doi.org/10.1080/00393630.2024.2380610

OPEN ACCESS Check for updates

Implementing an Adaptive Climate Control Strategy: Collection Monitoring and Sustainability Outcomes

Implementación de una Estrategia de Control Climático Adaptativo: Monitoreo de Colección y Resultados de Sostenibilidad

Michael Varcoe-Cocks[1], MaryJo Lelyveld[1], Caitlin Breare[1], Alexandra Bridarolli[2], Vincent Laudato Beltran[2], Youkyoung Kim[2,3], Cecilia Winter[2] and Michał Łukomski[2]

[1]Conservation Department, National Gallery of Victoria, Melbourne, Australia; [2]Getty Conservation Institute, Los Angeles, CA, USA; [3]M+ Museum, West Kowloon Cultural District, Hong Kong

ABSTRACT

In 2022, the authors presented the first stage of implementing a revised climate control strategy at the National Gallery of Victoria, monitoring collection object response in collaboration with the Getty Conservation Institute using acoustic emissions (AE) monitoring. The research and education, motivating factors, and interdepartmental alignment required for adopting the Bizot Green Protocol (BGP) were discussed, as well as the experimental design and set-up of the AE system on a large Flemish altarpiece in an active gallery. This second and concluding paper presents the results of the AE monitoring study along with energy used by the HVAC system for the gallery housing the AE monitoring study, during the transition from traditional environmental parameters through to broadened parameters as defined in the BGP. The project highlights the importance of understanding individual gallery and building behaviour as well as the HVAC system in place. In the case of the gallery housing the AE study, the implementation of BGP parameters resulted in smaller environmental fluctuations than expected. That HVAC energy efficiency could be improved with a relatively low impact on the gallery environment was an unexpected but welcome outcome. This case study describes some common challenges faced when considering such a change operationally, including resourcing and communication needs. Identifying points of resistance, framing problems clearly, and identifying common goals were essential to making progress. In this case, sustainability has compelled many stakeholders into alignment and enabled a shift in institutional culture.

En 2022, los autores presentaron la primera etapa de implementación de una estrategia revisada de control climático en la Galería Nacional de Victoria, monitoreando la respuesta de los objetos de colección en colaboración con el Getty Conservation Institute mediante el monitoreo de emisiones acústicas (AE). Se discutieron la investigación y la educación, los factores motivadores y la alineación interdepartamental necesaria para adoptar el Protocolo Verde de Bizot (BGP), así como el diseño experimental y la configuración del sistema AE en un gran retablo flamenco en una galería activa. Este segundo y último artículo presenta los resultados del estudio de monitoreo de AE junto con la energía utilizada por el sistema HVAC para la galería que alberga el estudio de monitoreo de AE, durante la transición de los parámetros ambientales tradicionales a los parámetros ampliados como se define en el BGP. El proyecto destaca la importancia de comprender el comportamiento individual de las galerías y edificios, así como el sistema HVAC implementado. En el caso de la galería que alberga el estudio AE, la implementación de los parámetros BGP resultó en una fluctuación ambiental menor de lo esperado. Que la eficiencia energética de HVAC pudiera mejorarse con un impacto relativamente bajo en el entorno de la galería fue un resultado inesperado pero bienvenido. Este estudio de caso describe algunos desafíos comunes que se enfrentan al considerar un cambio de este tipo desde el punto de vista operativo, incluidas las necesidades de recursos y comunicación. Identificar los puntos de resistencia, enmarcar los problemas con claridad e identificar objetivos comunes fue esencial para lograr avances. En este caso, la sostenibilidad ha obligado a muchas partes interesadas a alinearse y ha permitido un cambio en la cultura institucional.

ARTICLE HISTORY
Received October 2023
Accepted June 2024

KEYWORDS
Sustainability; environmental guidelines; environmental monitoring; Bizot Green Protocol; acoustic emission monitoring

Sostenibilidad; directrices ambientales; monitoreo ambiental; Protocolo Verde Bizot; monitoreo de emisiones acústicas

CONTACT Michael Varcoe-Cocks michael.varcoe-cocks@ngv.vic.gov.au Conservation Department, National Gallery of Victoria, Melbourne, Australia

© 2024 J. Paul Getty Trust and National Gallery of Victoria. Published by Informa UK Limited, trading as Taylor & Francis Group
This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (http://creativecommons.org/licenses/by-nc-nd/4.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

Introduction

Broadening parameters for collection environments from traditional narrow settings for relative humidity (RH) and temperature (*T*) is a strategy collecting institutions may consider to reduce energy consumed by heating, ventilation, and air conditioning (HVAC) systems, but it is one that can be challenging to realise. It is a topic that has been debated, often fiercely, for decades with little agreement (Bickersteth 2014; Kirby Atkinson 2014; Staniforth 2014). Even when a set of parameters is settled upon, points of resistance to change from many sources can slow or prevent the transition. Almost a decade after first agreeing to the Bizot Green Protocol (BGP), the majority of Bizot Group members are yet to adopt the recommended environmental parameters (NMDC 2015). The BGP guidelines propose 40–60% relative humidity and 16–25°C temperature range with a maximum 10% RH/4°C daily variation, which are broadly supported for temperate climate zones by conservation professional organisations including IIC, ICOM-CC, AICCM and AIC (Bickersteth 2016; Pagliarino 2022). Inhibiting factors include uncertainty as to how gallery conditions and collection materials may respond, what the actualised energy reduction, and risk to benefit, might be, as well as a lack of access to the tools or anticipated time and financial resources required to make such a change. Guidance has been published to address these (Ankersmit and Stappers 2017; IPI 2012; Taylor and Beltran 2023), which the present case study aims to support.

The National Gallery of Victoria (NGV) in Melbourne, Victoria, Australia, now operates its NGV International (NGV-I) building environment based on the BGP guidelines in all collection areas, except for temporary exhibition spaces when lender requirements call for tighter parameters. A cautious and evidence-based approach was used to progressively implement these changes. The steps taken to prepare for the transition, which included research, testing, interdepartmental alignment and co-ordination, and the installation of an acoustic emissions monitoring study in collaboration with the Getty Conservation Institute (GCI), have been previously published (Varcoe-Cocks et al. 2022). The outcomes of the newly implemented strategy are described below, including data on changes to energy consumption, actual gallery environment conditions, and object response. In addition to these empirical results from an *in situ* climate control transition, reflections on the complexities of implementing change are also presented.

Outcomes from the BGP transition

The results presented below are from a single gallery in the NGV-I building served by a dedicated air-handling unit (AHU), hereafter in referred to as Gallery E14 and AHU406, respectively. This gallery houses the subject of the AE monitoring study, a sixteenth-century Flemish retable. This object was monitored for over 12 months under the traditional tightly held

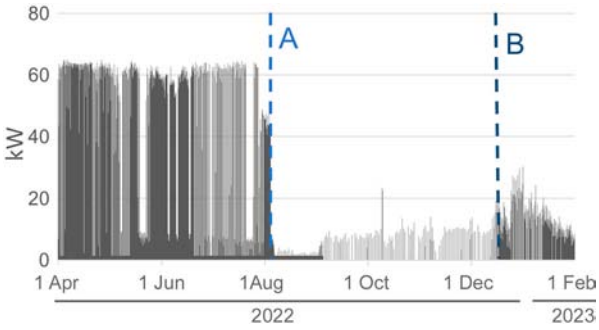


Figure 1. Hourly average total mechanical power load for AHU406. A: BGP implemented in gallery E14 (AHU406), 31 July 2022. B: BGP implemented across permanent collection galleries throughout building, 12 December 2022.

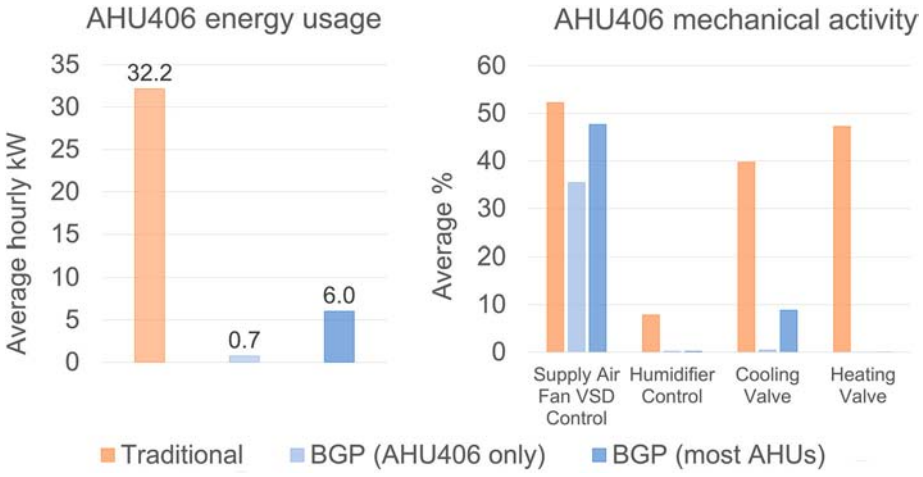


Figure 2. Hourly energy usage (left) and mechanical activity (right) from AHU406 at different climate control settings; traditional settings used by the NGV were 21.5 ± 2°C, 50% RH ± 5%; the first activation of BGP for AHU406 only; and for BGP settings activated across most of the building.

environmental settings before activating the BGP. While this study progressed, all other permanent collection galleries transitioned from a traditional setting to an intermediary 'soft Bizot' (46–56% RH range, ≤±4% change over 24 h, and 20–23°C range, ≤±1.5°C change over 24 h) set of parameters. These galleries were also set to full BGP settings after over 4 months of observing minimal change to the gallery environment and no increase in AE monitoring signals. Temporary exhibition spaces remained in traditional settings due to stipulations in loan contracts.

Energy efficiency

Energy meters were installed on AHU406 to understand the impact of the BGP settings on energy consumption. Mechanical activity for this space was also monitored, as this correlates to mechanical wear and the resultant frequency that various HVAC components will require replacing. Minimising activity and extending the lifespan of the chillers, heating elements, valves, humidifiers, and fan components is desirable, as each carries a sustainability burden, both environmentally and economically, to produce, maintain, and dispose of.

Power usage for AHU406 before and after BGP implementation is presented in Figures 1 and 2(a). (The total mechanical load is calculated from the sum of energy meter readings for return air fan instantaneous power; supply air fan VSD power; and humidifier instantaneous power; as well as chilled and hot water load calculations based on the supply and return temperature differentials.) Activation of BGP resulted in a large drop in both energy consumption and mechanical activity (Figure 2(b)) for AHU406. Both these factors increased slightly once BGP was activated across most of the other collection spaces in the building, presumably because these spaces initially acted as a buffer, aiding in the maintenance of gallery conditions in E14. Comparing AHU406 power requirements at traditional settings with BGP enabled across the building represents a saving of almost 230 MkWh annually. AHU406 is one of 71 AHUs operating across the building, so the energy reductions achieved by this change building-wide are much greater.

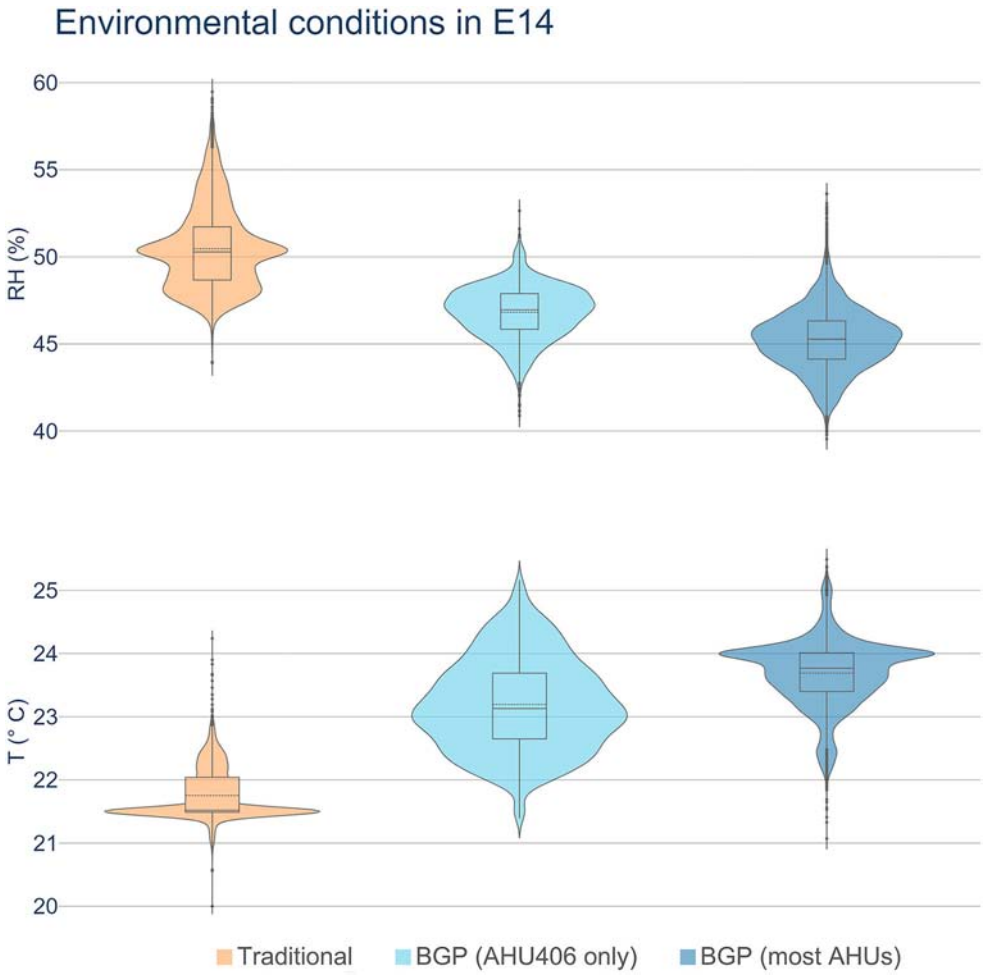


Figure 3. Box plots with overlaid kernel density estimate plots (the frequency distribution of values) for *T* (left) and RH (right) across three climate settings in gallery E14 (AHU406); traditional settings, BGP activated in E14 only, and BGP activated across most NGVI galleries. Top row shows conditions in gallery E14. Bottom shows the conditions at times excluding evening shutdown hours.

Gallery environment response to BGP

Many factors contribute to environmental conditions beyond set RH and *T* ranges, including the building envelope, HVAC system design, external conditions, occupancy levels and use. This makes predicting building behaviour in response to new settings difficult. Intuitively, the expectation of moving from traditional tightly held (50 ± 5% RH and a setpoint of 21.5°C, 20–24°C range at NGV) settings to the broadened RH and *T* ranges prescribed by the BGP was to observe increased fluctuations and total range of both RH and *T* in the gallery.

Changes to environmental conditions can be observed between the traditional and BGP settings, but also between the period when BGP was activated in gallery E14 only, and when it was activated across most of the NGVI collection spaces including the level 2 (L2) galleries that surround E14. (Note that the practice of evening HVAC shutdowns from 7pm to 7am, introduced at NGVI in 2011, was continued through all phases of the study.) All three periods are presented in Figure 3, which shows that *T* trended warmer in BGP settings (an increase in average *T* of 1.9°C), and RH trended drier (a decrease in average RH of 5.5%). *T* showed increased variability when the BGP was activated in E14 only, but once most galleries were operating at BGP this variability reduced again slightly. At the latter setting, the maximum value of 25°C was more often reached, activating HVAC cooling to control conditions. No seasonal variability was observed during daytime hours when the system was active (there was some modest seasonal variation during nightly shutdown periods). This, along with the good stability of conditions, may be due in part to a design feature of the NGVI HVAC system that performs coarse pre-conditioning of external air prior to supply to internal spaces.

While the BGP settings did result in observable changes to gallery conditions, the stability of both RH and *T* exceeded expectations. These observations may be due to building and HVAC design factors, such as the high thermal mass of the NGVI building, the minimal impact of supply air on conditions due to pre-conditioning and the low volumes needed to meet air exchange requirements, and the decreased mechanical activity at BGP settings, which allowed for more coasting and less variability caused by the system 'fighting itself'.

Object response

Installation of the AE system to monitor a sixteenth-century Flemish retable on display in gallery E14, including details of the equipment, the object, the strategic placement and mounting of sensors, and initial monitoring results has been described previously (Varcoe-Cocks et al. 2022). Here the results of monitoring the retable at traditional and BGP conditions are presented, along with monitoring and data analysis protocols. These protocols were established in the first few weeks following installation and remained unchanged throughout the monitoring campaign.

Monitoring protocols

Sensor-surface contact

A challenge in long-term AE monitoring is ensuring that sensors remain firmly attached to the object's surface. The quality of sensor-surface contact can be assessed by the pencil lead break (PLB) test as described in Łukomski et al. (2020) where a pencil lead is broken on the material surface close to the sensor location, generating a repeatable broadband

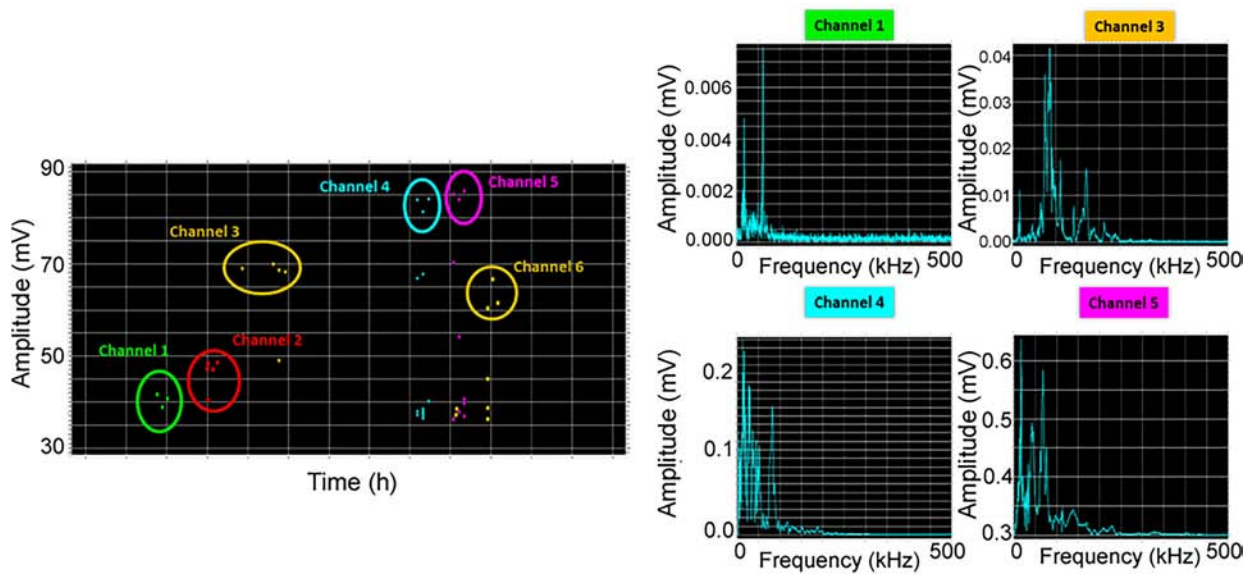


Figure 4. PLB tests for all sensors used for monitoring. (a) The amplitude measured by each sensor depends on the distance at which PLB test is performed, (b) examples of frequency distribution for PLB signals measured by selected sensors.

acoustic wave (Acoustic Technology Group 2023; ASTM International 1984). Change to sensor-surface contact can be assessed by comparing a test signal with the initial PLB reference recorded after installation. The PLB tests were performed monthly by NGV staff for each sensor at set locations marked and protected by tissue facing (Figure 4(a)).

Amplitude threshold

The sensitivity of the measuring system is determined by the amplitude threshold that a signal must exceed before being recorded; increasing the amplitude threshold reduces the system sensitivity, and vice versa. High system sensitivity was necessary to detect the minimal micro-changes expected, so a low amplitude threshold of 36.6 dB was used for all six sensors. This is more typical of laboratory rather than *in situ* recording where high levels of acoustic noise due to visitor, security, and custodial activity could be expected. As the measured data contains more noise than 'real' signals, substantial noise filtering was required.

Noise filtering

The noise filtering process comprised three interconnected steps:

- *Anti-correlation.* The six sensor locations were distributed across the object at such distances that fracture events recorded by one sensor would be out of range for the others, whereas environmental or electrical noise would impact all or multiple sensors simultaneously. When signals were recorded by two or more sensors within an anti-correlation time window of 1 microsecond, they were excluded from the recorded dataset. This filter proved to be particularly effective in removing signals caused by electrical noise.
- *External source identification.* External sources for signals, including visitor activity, gallery functions, or maintenance and cleaning procedures by NGV staff were identified by comparing the time of the recorded signals with the surveillance footage from cameras installed in the gallery. It necessitates effective communication between the data analyst and museum security staff.
- *Signal frequency.* For wood, signals with high-frequency content are associated with fracture of the material structure, while signals with low-frequency characteristics (below 50 kHz) are typical for ambient noise (Jakieła and Kozłowski 2008; Strojecki, Łukomski, et al. 2013; Strojecki, Colla, et al. 2013), which was corroborated in this case by PLB tests that all exhibited frequencies higher than 50 kHz (Figure 4(b)). To ensure none of the small number of relevant signals were discarded, a manual (rather than automated) signal examination was performed to compare frequency characteristics to the PLB tests.

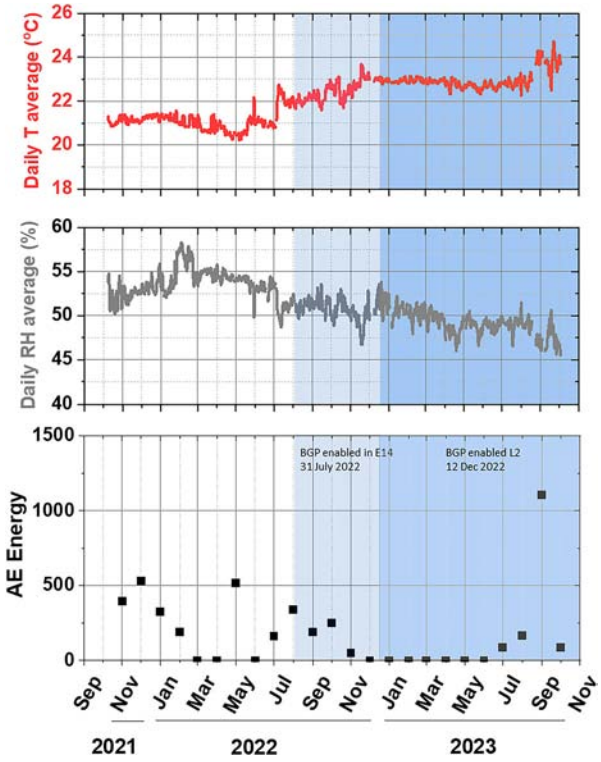


Figure 5. Acoustic emission energy recorded each month by five KRNBB-PC sensors during the monitoring period. Dates of significant changes in HVAC operation are indicated. Climatic conditions in the gallery (*T*/RH) are presented in the form of a time series plot.

Whenever there was doubt about the origin of the signal, it was classified as related to wood fracturing, potentially leading to an overestimation of the risk associated with climatic conditions.

AE results

Following noise filtering, only a few signals out of hundreds recorded each month were associated with wood fracture. It was expected that an extremely sensitive system would be able to record some micro-fracture events even at traditional environmental settings. The average AE energy from all sensors after filtering for every month of monitoring is shown in Figure 5.

For the 24 months of monitoring, changes in the operation of the HVAC system did not significantly impact the measured AE energy. There is variability of AE energy ranging from 0 to 500 arbitrary units (1100 in September 2023). The extent of micro-changes related to the measured energy can be calculated as under 0.56 mm^2 total per month for the five KRNBB-PC sensors, based on a calibration factor experimentally established by Lukomski et al. 2017 (1 mm^2 damaged surface area to an AE energy of 1.95×10^3 in arbitrary units – note that calibration data is not available for the PCA WD sensor used for channel 2).

However, with so few AE events associated with wood micro fracturing, this number is approximate and likely overestimates actual change, especially as no correlation can be established between the measured AE signals and the variation in room climate.

Complementary monitoring techniques

While AE monitoring is well-suited to detect micro-change in wooden objects with great sensitivity, it is restricted to recording from a limited number of channels, in this case, 6, and so did not present a practical method of monitoring the many objects on display. To complement the AE monitoring, NGV staff carried out periodic macrophotographic surveys on objects of varied materials, origins and age that were considered potentially vulnerable to change in response to the new environmental conditions. Other imaging techniques were trialled, including 3D scanning and reflectance transformation imaging (RTI). Macro-photography was preferable both in terms of the clarity of information recorded, and time-efficiency. Across the course of the project, there was no visual change found in the objects surveyed, negating any need to review the implementation strategy or consider ideas of risk and acceptable change over time.

Reflections on implementing change

Gaps in our knowledge and understanding of the response of different materials to environmental conditions are only part of the challenge of implementing change. Given NGV's early adoption of the BGP, in addition to deviating from what were normative settings for art museums, NGV collections staff had few precedents to guide the technical transition. Despite these barriers, sustainability (of environmental and financial resources, as well as for broader public access) has aligned stakeholders to work to a common goal. As a public institution, the NGV has sought to reduce its carbon footprint to meet state government legislation of a net-zero 2045 target (Climate Change Act 2017). Projects such as this demonstrate the conservation profession's commitment to the long-term sustainability of collections, institutions, and culture, through an evidence-based approach to climate change adaptation.

Cultural and operational change can be hard to implement in a large, long-established institution. Early scepticism and doubts of the purpose or likely success of such a complicated change made the BGP implementation initially challenging. Long-serving staff had fluency and reassurance with historical parameters, which have been achieved through considerable advocacy and then safeguarded over decades. In deviating from 'best practice' environmental settings, there was concern not only for artworks but reputational risk and personal liability. Ongoing dialogue was encouraged and strong advocacy from the conservation department for whom artwork care is a high priority, helped to guide a collection risk-managed approach.

There were genuine resourcing and technical concerns in the planning and implementing phases given that the BGP implementation staff resourcing was absorbed into the existing work programme which sometimes delayed progress. The financial outlay for new componentry and building automation system (BAS) reprogramming was supported through a state government Greener Building Program (Varcoe-Cocks et al. 2022) with *ad hoc* costs for data collection and energy monitoring as part of this project, absorbed into the Conservation budget.

Communication

Communication has been a significant enabler in this project and it addressed key stakeholders. Within the NGV, monthly internal department-specific meetings addressed technical and operational issues, including budgets and impacts on exhibition programming and loans. Regular updates were given to the executive level and presented to the Council of Trustees. This increased institutional-wide collaboration has continuing benefits to the NGV.

External communications included:

- Advocacy through the regional art museum network that regularly participated in the exchange of loans with the NGV. A roundtable discussion with collection and facilities representatives from member institutions of the Council of Australian Art Museum Directors (CAAMD) was held at the NGV in 2019. This forum was designed to share experiences and collectively identify ways to initiate change between lending partners for loan agreements, couriers, and transport. Following this forum, CAAMD endorsed the BGP and the Australian Institute for the Conservation of Cultural Materials environmental guidelines (AICCM 2019). Ongoing webinars and informal site visits with regional lenders guiding them through their adaption are continuing.
- The GCI's *Managing Collections Environments* initiative *Changing Climate Management Strategies Workshop* was held at the NGV in 2023. Bringing together 40 participants from heritage institutions across Asia and Oceania, its primary objectives were not only to facilitate dialogue on sustainable collection environments, emphasising 'why' we need more sustainable strategies but also to provide tools and insights into the 'how' to achieve this.
- NGV's public have been given the opportunity to understand the institution's sustainability initiative.

Research from this project including AE equipment has been made publicly visible as part of artwork display that directed visitors to the project microsite on the NGV website. Volunteer Guides were provided lectures so they, in turn, could speak on the programme as part of guided tours and project updates were posted on various social media channels.

Loans

The debate over environmental conditions tends to focus on either permanent collection needs or loan policy. The experience of implementing the BGP at the NGV has demonstrated that these two areas are more interdependent than expected.

Like many exhibition programmes, NGVs temporary exhibitions are formed around a singular theme that is reliant on multiple lenders. The traditional narrow parameters stipulated in many loan agreements override any lender who would opt for broader BGP parameters. If this balance were reversed, then outlying lenders specifying narrow parameters might be displayed within broader BGP conditions using microclimate systems or architecture. However, these options are not always aesthetically or financially achievable and currently there is little likelihood of achieving BGP in temporary exhibitions without broader sector change.

Loan requirements for these borrowed works have also limited testing of the NGV HVAC system to the degree desired by the authors since AHUs for both the loan and permanent collection galleries are serviced by a continuous loop of pre-conditioned external air. Initial testing indicated that adjusting the pre-conditioning system would likely result in an inability for narrow parameters to be maintained in the loan gallery spaces. In this way, loan agreements have inhibited the NGV's control of its own collection galleries and have been a barrier for research in this area.

Conclusion

For many collecting institutions, HVAC systems are responsible for a significant proportion of total building energy consumption. Given sustainability imperatives, it is critical that the profession reconsider the risk-benefit relationship of tight environmental controls. The implementation of an adaptive climate control strategy based upon the BGP was carried out as a staged transition during an active exhibition and loan programme.

The NGV's experience was that it was difficult to anticipate fully what a transition to BGP would involve until after the process had begun, but GCI support helped to make the project visible to stakeholders and the public, monitor change in a significant collection work, and review environmental data from unexpected technical challenges.

As more art museums shift to institutionally adapted environmental settings for collections and loans, each will need to address challenges specific to their context but the following observations are offered based on the case study presented:

- Implementing a revised climate control strategy for collection and loan galleries requires substantial financial and time resources. There are costs associated with HVAC modifications and possible building upgrades in addition to staff and contractor time to research, consult, test, monitor and implement operational changes.
- The scope of change is gallery-wide and network-wide. Advocacy, support, and action are required across all levels from operations through to executive and stakeholders. Communicating changes should flow through decision-making hierarchies and support change workflows at the operations level.
- Introducing more flexible environmental parameters does not necessarily correlate to damage to in sensitive collection materials. Conservators should make use of a wide range of tools and knowledge to ensure that anticipated risks are considered, managed and assessed using evidence-based approaches where possible.
- As defined in the BGP guidelines, the BGP-recommended environmental parameters are best used as a starting point for institutions to adjust according to individual circumstances for buildings, collections, and local climate.

The NGV will continue to refine and adapt its environmental strategy to meet both collections care and sustainability goals.

Acknowledgements

The authors would like to acknowledge the ongoing cooperation of NGV colleagues Tony Ellwood (Director), Tony Henshaw (Manager, Facilities), Gilles Bonnet (Building Engineer), Lucy Hastewell (Associate Director, Facilities and Operations), Catherine Earley (Senior Conservator for Exhibitions), Paula Nason (Head of Registration) and Ieva Kanepe (Senior Registrar, Loans) in implementing the Bizot Green Protocol at the NGV. We thank Tim Whalen (then GCI Director) and Tom Learner (GCI Head of Science) for their support in facilitating this partnership, and Choon Lim for assistance with data visualisation.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Acoustic Technology Group. 2023. "AE Calibration and Simulators: Signal Source." Accessed November 2023. https://atgndt.com/ae-calibration-and-simulators/calibration-signal-source/.

AICCM. 2019. "Australian Institute for the Conservation of Cultural Materials Environmental Guidelines." AICCM National Newsletter 155. Accessed May 2024. https://aiccm.org.au/network-news/environmental-guidelines-update/.

Ankersmit, B., and M. H. L. Stappers. 2017. *Managing Indoor Climate Risks in Museums*. Cham: Springer.

ASTM International. 1984. *ASTM E976: Standard Guide for Determining the Reproducibility of Acoustic Emission Sensor Response*. Last Approval E976 – 15 (Reapproved 2021). West Conshohocken: ASTM.

Bickersteth, J. 2014. "Environmental Conditions for Safeguarding Collections: What Should Our Set Points Be?" *Studies in Conservation* 59:218–224. https://doi.org/10.1179/2047058414Y.0000000143.

Bickersteth, J. 2016. "IIC and ICOM-CC 2014 Declaration on Environmental Guidelines." *Studies in Conservation* 61 (sup1): 12–17. https://doi.org/10.1080/00393630.2016.1166018.

Climate Change Act. 2017. Melbourne: Parliament of Victoria. Accessed May 2024. https://content.legislation.vic.gov.au/sites/default/files/75815dbf-519f-3f1d-8ae6-a074d6dc9d4b_17-005aa%20authorised.pdf.

IPI. 2012. *IPI's Guide to Sustainable Preservation Practices for Managing Storage Environments*. Rochester: Image Permanence Institute, Rochester Institute of Technology.

Jakieła, S., and R. Kozłowski. 2008. "Acoustic Emission for Tracing Fracture Intensity in Lime Wood Due to Climatic Variations." *Wood Science and Technology* 42 (4): 269–79.

Kirby Atkinson, J. 2014. "Environmental Conditions for the Safeguarding of Collections: A Background to the Current Debate on the Control of Relative Humidity and Temperature." *Studies in Conservation* 59:205–212. https://doi.org/10.1179/2047058414Y.0000000141.

Lukomski, M., M. Strojecki, B. Pretzel, N. Blades, V. L. Beltran, and A. Freeman. 2017. "Acoustic Emission Monitoring of Micro-Damage in Wooden art Objects to Assess Climate Management Strategies." *Insight – Non-Destructive Testing and Condition Monitoring* 59 (5): 256–264. https://doi.org/10.1784/insi.2017.59.5.256.

Łukomski, M., Ł. Bratasz, E. Hagan, M. Strojecki, and V. L. Beltran. 2020. *Acoustic Emission Monitoring for Cultural Heritage*. Los Angeles, CA: Getty Conservation Institute. http://hdl.handle.net/10020/gci_pubs/acoustic_emission.

NMDC. 2015. "Bizot Green Protocol." In *Environmental Sustainability: Reducing Museums' Carbon Footprint*. London: National Museum Directors' Council. Accessed May 2024. https://www.nationalmuseums.org.uk/what-we-do/contributing-sector/environmental-conditions/.

Pagliarino, A. 2022. *Environmental Guidelines*. Moonah: AICCM. Accessed October 2023. https://aiccm.org.au/conservation/environmental-guidelines/.

Staniforth, S. 2014. "Environmental Conditions for the Safeguarding of Collections: Future Trends." *Studies in Conservation* 59:213–217. https://doi.org/10.1179/2047058414Y.0000000142.

Strojecki, M., C. Colla, M. Łukomski, and E. Gabrielli. 2013. "Kaiser Effect in Historic Timber Elements." *European Journal of Wood and Wood Products* 71 (6): 787–793. https://doi.org/10.1007/s00107-013-0738-8.

Strojecki, M., M. Łukomski, C. Colla, and E. Gabrielli. 2013. "Acoustic Emission as a Non-Destructive Method for Tracing Damage: From Laboratory Testing to Monitoring Historic Structures." In *Nondestructive Testing of Materials and Structures*, edited by O. Güneş and Y. Akkaya, 1131–1136. RILEM Book Series, Vol. 6. Dordrecht: Springer.

Taylor, J., and V. L. Beltran, eds. 2023. *Managing Collection Environments: Technical Notes and Guidance*. Los Angeles, CA: Getty Conservation Institute.

Varcoe-Cocks, M., M. Łukomski, M. Lelyveld, V. L. Beltran, C. Breare, and C. Winter. 2022. "Developing an Adaptive Climate Control Strategy and Programme Monitoring Micro-Change in Wooden Heritage Objects." *Studies In Conservation* 67 (sup.1): 283–292. https://doi.org/10.1080/00393630.2022.2076779

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S360–S368
https://doi.org/10.1080/00393630.2024.2354589

ORIGINAL RESEARCH OR TREATMENT PAPER

Conservation as a Tool for Cultural Rights in the Democratic Republic of the Congo: The *We have gaps* Project

La conservación como herramienta para los derechos culturales en la República Democrática del Congo: el proyecto *Tenemos brechas*

Muriel Verbeeck [1,2] and Israel-Prince Wingenga[3,4]

[1]Art Archaeology and Heritage Research Unit, Université de Liège, Liège, Belgium; [2]Conservation Department, École Supérieure des Arts Saint-Luc de Liège, Liège, Belgium; [3]Collège Universitaire Henry Dunant, Université de Kinshasa, Kinshasa, Democratic Republic of the Congo; [4]Curator of university museums (UNIKIN), Kinshasa, Democratic Republic of the Congo

ABSTRACT

This paper outlines the aim, methodology, and initial results of a joint initiative between two universities (Université de Kinshasa in Kinshasa, Democratic Republic of the Congo and Université de Liège in Liège, Belgium), two conservation training courses (Academy of Fine Arts of Kinshasa and École Supérieure des Arts Saint-Luc in Liège), and the Institute of National Museums of Congo. The *Nous avons des lacunes (We have gaps)* project plays on the notion of loss – both material and of knowledge – to involve communities in the construction of endogenous knowledge on the conservation of objects: a task to be carried out by the Congolese, for the Congolese. For many Congolese, concepts such as 'museum' and 'conservation' sound foreign, and the idea of cultural rights remains highly abstract and theoretical. The challenge is to transform the manifestation of these rights through conservation into a real tool for empowerment. The exhibition concept is two-fold: conservators explain what loss or material alteration has occurred in a specific object, and how they remedy it, thus arousing interest in a little-known profession. At the same time, they show and explain their own gaps in knowledge, and ask the public for information about the technique, function, use, naming, or names of the mystery object in the four national languages and numerous Congolese idioms. The *Nous avons des lacunes* project aims to highlight the role and involvement of communities and different social entities as active guardians of their heritage, by humbly admitting the lack of knowledge among professionals.

Este artículo describe el objetivo, la metodología y los resultados iniciales de una iniciativa conjunta entre dos universidades: La Universidad de Kinshasa en la República Democrática del Congo y la Universidad de Liège, Bélgica, dos cursos de capacitación en conservación (Academia de Bellas Artes) de Kinshasa y Saint-Luc, Liège, y el Instituto de Museos Nacionales del Congo. El proyecto *Nous avons des lacunes (Tenemos lagunas)* juega con la noción de pérdidas – tanto de material como de conocimiento – para involucrar a las comunidades en la construcción de conocimiento endógeno sobre la conservación de objetos: una tarea que deben llevar a cabo los congoleños. Para muchos congoleños, conceptos como 'museo' y 'conservación' suenan extraños, y la idea de derechos culturales sigue siendo muy abstracta y teórica. El desafío del proyecto es transformar la manifestación de estos derechos, a través de la conservación, en una verdadera herramienta de empoderamiento. El concepto expositivo es doble: los conservadores explican qué pérdida o alteración material se ha producido en un objeto concreto, y cómo remediarla, despertando así el interés por una profesión poco conocida. Al mismo tiempo, muestran y explican sus propias lagunas de conocimiento y solicitan al público información sobre la técnica, la función, el uso, la denominación o los nombres del objeto misterioso en los cuatro idiomas nacionales y numerosos modismos congoleños. El proyecto *Nous avons des lacunes* pretende enfocarse el papel y la implicación de las comunidades y diferentes entidades sociales como guardianes de activos de su patrimonio, admitiendo humildemente el desconocimiento de los profesionales.

ARTICLE HISTORY
Received October 2023
Accepted April 2024

KEYWORDS
Cultural rights; knowledge; involvement; empowerment; language; Democratic Republic of the Congo

Derechos culturales; conocimiento; intervención; empoderamiento; idioma; República Democrática del Congo

Introduction

The *Patrimoine, Identité Culturelle et Conservation* (PICCo) project is a Belgian-Congolese project aimed at empowering the Congolese in the field of heritage conservation. Elsewhere, we have outlined certain aspects of this collaboration, such as the development of joint webinars, or the development of 'remote' condition reports, using 3D tools. In the context of this

CONTACT Muriel Verbeeck muriel.verbeeck@ceroart.org Art Archaeology and Heritage Research Unit, Université de Liège, Liège, Belgium; Conservation Department, École Supérieure des Arts Saint-Luc de Liège, Liège, Belgium

© The International Institute for Conservation of Historic and Artistic Works 2024

project, we will outline here the aim, methodology, and first results (to April 2024) of a joint initiative between two universities (Université de Kinshasa in Kinshasa, Democratic Republic of the Congo (UNIKIN in DRC) and Université de Liège in Liège, Belgium (ULiège)), two conservation training courses (Académie des Beaux-Arts de Kinshasa in DRC, École Supérieure des Arts Saint-Luc in Liège), and the Institut des Musées Nationaux du Congo (IMNC).

The *Nous avons des lacunes* project plays on the notion of loss – both material and of knowledge – to involve communities in the construction of their own knowledge of the conservation of objects: a task to be carried out by the Congolese, for the Congolese. For many Congolese, concepts such as 'museum' and 'conservation' sound foreign, and the idea of cultural rights remains highly abstract and theoretical. The challenge is to transform the manifestation of these rights through conservation into a real tool of empowerment.

Cultural rights

Cultural rights are an integral part of the *Universal Declaration of Human Rights* of 1948.[1] Their content was clarified by the 'Fribourg Group' at the end of the 1990s and, in 2007, became the subject of a twelve-point declaration known as the *Déclaration de Fribourg (Fribourg Declaration)* (UNESCO 2007). The introduction to this major text reminds us that many conflicts arise from violating or marginalizing cultural rights, and that development strategies that minimize their importance are often doomed to failure. The *Fribourg Declaration* was discussed again in 2010 (Meyer-Bisch and Bidault 2010). It is this enlightening document that has served as a guide to our thinking, notably during a study day organized at UNIKIN in April 2023, when, under the direction of Antoine Tshimpi, then Secretary General for Research at UNIKIN, it brought together jurists, criminologists, anthropologists, and UNIKIN museum curators, as well as a representative of the Minister of Culture, to discuss these questions in the Congolese context. This meeting aimed to reflect on the use that could be made of the university's museum collections, to raise awareness among students, and the wider public, of these cultural rights. To do this, it was necessary to identify the main points in the document likely to shed light on the methodological approach.

The *Fribourg Declaration* states *inter alia*: the right to cultural identity (Article 3); refers to cultural communities (Article 4); the right to education and training (Article 6); the right to information (Article 7); and the right to participate in cultural cooperation measures (Article 8). Article 3 entitled *Identity and Heritage* was pivotal, since it concerned heritage and museum collections, while the other articles were used as objectives. Article 3 states that:

> Everyone, alone as well as in a community with others, has the right … to have access, through the exercise of the rights to education and information, to the cultural heritage that constitutes the expressions of different cultures, and a resource for present and future generations. (Meyer-Bisch and Bidault 2010)

This article describes three rights which embody three aspects of the general definition of cultural rights: choice and respect for one's identity is the basic right, but cannot be exercised without knowledge of and respect for one's own and other cultures; and access to heritage sites. This access includes in particular:

- what is needed to access the knowledge conveyed by objects; this is why this right is directly linked to the right to education and training – including training in conservation as a discipline and as a profession
- participation, which results from using this resource, sharing it, and participating in its interpretation and transmission to gain full access to the social connection that this knowledge enables.

The *Fribourg Declaration*, therefore, stresses that such an approach is of major importance not only for identity awareness by communities, but also for social integration and the development of a democratic culture. These two points are particularly relevant in the Congolese context; they also remain sensitive subjects, eminently political and therefore delicate to address during election periods. Our joint reflection on the articles devoted to heritage has led us to reflect together on the accessibility of these cultural rights, particularly in the field of cultural heritage in the DRC, whether in national museums or university collections. The link between theory and practice remains a crucial point. Realities on the ground sometimes thwart the most promising initiatives; adaptability to circumstances gives the best chance of bringing projects, or simply the objectives behind them, to fruition.

Accessibility of heritage and cultural rights in DRC

UNESCO Director-General Amadou-Mahtar M'Bow's stirring call in 1978 for the restitution of cultural heritage to Africa is still relevant (M'Bow 1978). Symbolic gestures have been made, but these are sometimes more posturing than commitments. In reality, there can be no global restitution without Congolese training in conservation. Otherwise, the deduction is obvious: the most precious and fragile objects have

to be conserved safely by experts and at suitable locations: in the West, that is.

Since 2013, Belgium has been working with the DRC to develop a diploma course on conservation in Kinshasa (Gesché-Koning 2021). This three-year course focuses on ceramics and wood, but there are other pressing areas not covered, including painting and contemporary art. A collaborative project, PICCo, is working to develop these skills and prepare for the introduction of a masters degree course to meet these needs. Access to a research doctorate will be planned later. The aim is that the DRC will one day be able to export the skills of its own heritage experts, including those being created today (Verbeeck and Mava 2023). This request for support in conservation training has been made by the DRC at the same time as requests for restitution.

It was within the framework of the PICCo project that the idea of exhibitions was born to raise public awareness of the conservation of cultural goods present in the territory. The authorities are aware of the important role played by heritage in consolidating Congolese identity and have been trying to promote it since the 1970s and President Mobutu's first 'recourse to authenticity' initiatives.[2] President Tshisekedi, for his part, has made this theme one of the spearheads of his presidency of the African Union, organizing a symposium held in 2021 with an unequivocal title: *Colloque sur la reconstitution des biens culturels et la Renaissance Africaine (Reconstitution of Cultural Heritage and the African Eebirth)*.[3] The title included 'reconstitution', not 'restitution': Africa's heritage needs to be reassembled from scattered objects (including in its own territory) and revitalized (this is the very meaning in French of the word *reconstitution*). In other words, a heritage that has been weakened by colonization but also by a lack of interest, desire, or the will to preserve it, needs to regain its potency.

The inauguration of the new National Museum in 2019 was a further step in this direction; however, this prestigious showcase, built with funds from the Korean International Cooperation Agency, must not mask under-resourcing for other establishments in Kinshasa or the provinces, several of which are closed (such as the Musée d'Art Contemporain et Multimédia in Limété) or remain only sporadically accessible (Bukavu, Goma). Public attendance at the national museum is hardly representative of the population of Kinshasa, and even less so of the whole Congolese population. The explanatory labels are in French and English (no national Congolese language was considered). The museum's open days and school visits attract only a tiny fraction of the 17 million inhabitants of Kinshasa and more than 95 million Congolese.

Pitfalls

In addition to the problems of access to heritage mentioned above, the main stumbling block to the exercise of cultural rights in the DRC is cultural. The concepts of 'conservation', or even 'museums' are foreign, and are not necessarily perceived well or understood. However, history is highly valued, and Congolese historians assist anthropologists in collecting traces of the past. History is linked to tradition: it is through tradition that it is possible to collect information, or better still, to involve the population in the memory of its heritage, and its conservation.

This is only possible if we consider the geographical and cultural mosaic and the predominant structuring role of national languages – the very languages that are absent from the National Museum. Few Congolese speak all four national languages; in general, they master one or two. Approximately 10% speak French, the official language of the DRC. This being the case, translating conservation terms is a priority, and this translation, including concepts, can only be performed by the Congolese.

Finally, let us look at the problem in context: the economic, social, political, and ongoing conflict situation sets priorities for the Congolese other than heritage. This is obvious when you visit this country. It is only by demonstrating the social utility of conservation work, and its role in building a common identity while respecting diversity, that we can generate national momentum. Without this, conservation will remain a foreign concept. Demonstrations must be practical and pragmatic: in this way, it intersects with the Congolese spirit, which is geared towards adaptation, repair, reinterpretation, and reuse rather than slavish copying.

Methodologies

The UNIKIN joined forces with the IMNC and the Conservation Department of the Academy of Fine Arts of Kinshasa to develop the project. UNIKIN also owns museum collections; however, its educational role has been gradually losing ground. In 2022, Antoine Tshimpi relaunched an ambitious project to develop the museum on campus and open it up to primary and secondary schools. In line with UNESCO's commitment to the development of digital skills in Congolese higher education, UNIKIN has considered the digitization of certain elements of its collections, and one of its members has attended an EPA workshop devoted to the virtual museum.

The first question asked before embarking on the project was: what do the stakeholders want? This was: to promote the training and profession of conservators among the general public; to involve them in

thinking about the conservation of objects; and to initiate dialogue and collaboration, in order to apply one of the principles of Muñoz-Viñas' *Contemporary Theory of Conservation* (2005): 'Conservation must be negociatory'.

Rather than addressing a wider audience as 'experts,' the stakeholders decided on a scenario that encouraged interactivity and the co-creation of knowledge by confessing ignorance.

The lack of information is the pretext, or more precisely, the opportunity to initiate a discussion, an exchange, to make the interlocutor feel that he or she is the repository of knowledge, and by the same token, competence. This can give rise to a feeling of responsibility and to the transmission of knowledge: of the object and its materiality, of knowledge, and last but not least, of meaning.

We have gaps

Nous avons des lacunes consists of an exhibition, to be hosted at different sites, of objects with losses or deterioration. In the first phase, the conservator explains the object, its fragility, and vulnerabilities using conservation terms, and invites the public to find synonyms in native languages and dialects. The conservator also explains the profession, what it can do, what should be avoided and why. Here, the presenters are in line with the objectives already cited as being at the heart of cultural rights: appropriation by the interlocutor; learning the necessary references; their conceptual translation; their linguistic adaptation; and explanations relating to training, curriculum, and profession. In the second stage, the conservator admits personal shortcomings: knowledge gaps, areas of doubt, what causes perplexity, and invites the interlocutor, through his questions, to communicate any relevant information. We are talking here about stimulating participation: the interlocutor is invited to interact with the heritage object to take part in its interpretation and transmission to activate the social bonding process that such knowledge enables.

The interlocutor's knowledge is transmitted, transcribed, and enhanced to leave its mark. Based on this scenario, each partner is invited to reflect on and propose a customized version of the exhibition, which will coordinate with those of the other stakeholders. The only constraint is the standardization of data collection methods for subsequent joint use.

Different sites, different audiences, different approaches

The exhibition will take place at several sites, in several phases, and will target different audiences. It will be relayed by the culturecongo.net website, an entrepreneurial and non – institutional partner; eventually, a website featuring 3D digitized models will perpetuate the project's achievements, allowing information to be added even after the project has ended (see below). The 3D survey of various objects has already been completed with the help of Prof. Pierre Hallot of ULiège, and training in photogrammetry and 3D modeling techniques is planned for a representative of each institution, to support their empowerment. For some of them, training took place in Belgium (September – December 2023), and for others *in situ* in Kinshasa (April 2024).

Institut des Musées Nationaux du Congo

The IMNC, a partner in the PICCo project, chose the Musée National de la République Démocratique du Congo (National Museum of the Democratic Republic of the Congo) in Kinshasa as the testing ground for the *Nous avons des lacunes* project. The National Museum is located in the heart of the capital, close to the Palais du Peuple, and has air-conditioning in its public spaces and stores; it welcomes a rather well-informed public and could provide showcases and museographic enhancement for the *Nous avons des lacunes* exhibition. The question arose whether the latter would confine the public to the role of passive spectators. Mediation is key to overcoming this problem. The museum's main asset is its modern, well-equipped conservation workshop staffed by a qualified conservator, who is enthusiastic about sharing information about her profession. It is conceivable that the exhibition will play the 'behind the scenes' card and that this is a real asset for initiating a dialogue based on curiosity.

Academy of Fine Arts of Kinshasa

The Academy of Fine Arts (ABA from its name in French) targets its version of the exhibition at students from all departments. In Kinshasa, as in many establishments in Europe, the conservation department is little-known and is even questioned as to why its requirements (notably the student/teacher ratio), increase operating costs. The Academy brings together 2,500 students in the plastic and visual arts, including just 25 studying conservation, spread over three years of study. This is an opportunity to showcase their training and work in conjunction with IMNC.

However, the *Nous avons des lacunes* exhibition extends far beyond the campus: the academy is a major hub of Kinshasa's cultural life and a showcase for contemporary art. Relations between the IMNC and the academy, and more specifically, the conservation department, are close. Professionals from both establishments who have taken the same training courses are closely linked. They worked together to

develop a scenario that would be implemented in both establishments.

For example, Colette Awomo (IMNC) and Francine Mava (ABA) worked together on the question of the accessibility of their discourse on conservation: what do the public understand about what we say? No member of the museum staff or conservation department spoke all four national languages. The conservators speak two languages, in addition to French, the official language. Therefore, they set about compiling a small lexicon of 'conservation words' and asked for help in translating them.

University of Kinshasa

This is where the junction is made with a third stakeholder, UNIKIN, whose museum collections were mentioned earlier, particularly that of the Anthropology Department. The collection has already been the subject of conservation studies, notably an anthropology dissertation (Véro 2018); and as part of the International Museum Day and Women's Month in 2021, curator Josée Madwika (Museum of Kinshasa) and conservator Colette Awomo (IMNC) worked together to explain the work of the conservator to an audience of students (Figure 1).

Therefore, it is natural that these earlier collaborations should be reactivated. The conservators suggested that UNIKIN's linguistics department translated the lexicon from French into national languages and that the anthropology department helped design a questionnaire for interaction with the public. Anthropologists are no strangers to this exercise and practice it regularly. For their part, the academy and the national museum will lend the support of conservators, students, and graduates during exhibition days organized by the University. UNIKIN proposes to activate the *Nous avons des lacunes* project at three key moments: in December, during the University's open days; in February, as part of the open-air museum day; and finally in autumn, as part of a 'traveling museum marathon' (Figure 2). The objects to be used in the experimental project are two masks, one of which recently arrived in the collection and has no inventory records; the other's inventory sheet is very sketchy and questionable. So it makes sense to enlist the public's help in identifying and documenting them, as well as in understanding the causes of their deterioration (Figure 3).



Figure 1. Curator Lelo Mambu demonstrates the tools housed at the MUK before posing questions to the audience, with which she interacts. Image: Muriel Verbeeck.

During open days, the University will feature four musical groups, illustrating the four national languages, close to the Museum of Anthropology (where the masks are on display); the conservators hope on this occasion to bring together groups of students, according to their linguistic affinities, and to benefit from group dynamics in interactions; the questionnaire, which will be presented orally, has already been drafted.

The Museum Day will rely on the dynamism and enthusiasm generated in 2022, by a previous initiative: a chief's scepter was displayed on campus under a straw hut and students from different ethnic backgrounds spontaneously recognized the artifacts and submitted their identifications. This time, the masks will be exhibited on the open-air campus, looking to gain understanding from the public about their functionality, which has an impact on their deterioration, as well as their repair and restoration techniques. Replicas are envisaged, allowing participants to manipulate these artifacts, and even demonstrate their use.

In phase 3, UNIKIN's conservators plan to take objects on the road (in a semi-trailer van) to popular markets (Figure 4), craftsmen's stalls, and art dealers' shops in order to get stakeholders to interact. Of course, this initiative *a priori* raises the eyebrows of Western conservators concerned about the risks incurred by objects. However, it should be noted that the museum stores (apart from the National Museum) are not air-conditioned, and the objects experience 'natural' hygrothermal cycles in the sheds where they are stored (e.g. at Mont N'galiema). Of course, there are also risks associated with transport, but the creation of transport crates is an excellent preventive conservation exercise for conservation students, who have already had to deal with moving a large proportion of the 70,000 objects in the Mont N'galiema stores. Last but not least, these objects are essentially ethnographic and functional, and simply



Figure 2. The team of curators from the MUK in front of the 'Nous avons des lacunes' project stand in UNIKIN, April 2024. Curators will receive additional conservation training at the National Museum, starting in January 2025. Image: Muriel Verbeeck.



Figure 3. The curatorial team working together at UNIKIN with students, in front of the 'hologram box' donated by ULiège, April 2024. The two masks in the university museum have been modeled in holograms and can be used for numerous interactions. Image: Muriel Verbeeck.

looking at the objects (which is a very Western attitude) is not culturally the norm: people feel inclined to touch and manipulate these artefacts. Here again, the idea of replicas is envisaged, not to replace, but to accompany the original objects.

Panzi Hospital and the 'repaired women'

During the project, we noticed the under-representation of women (except in the case of conservators, which was a very positive development). Yet women are often heavily involved in repairing objects, particularly what Speranza (2007) has called 'wounded objects'. The ULiège has very close links with Panzi Hospital, run by doctor and Nobel Peace Prize winner Denis Mukwege. The 'man who repairs women' as he was nicknamed, has devised a 4-pillar healing model, in which psycho-social support and socio-economic reintegration play an essential role. Contacts are underway to see whether working on the vocabulary of repair and restoration would be a constructive element in the patients' recovery process, and whether the practice of conservation would be experienced as positive.

In the meantime, the project and several 'wounded objects' will be presented at the *Mukwege Chair International Congress* which was held in Liège in November 2023. Artifacts from the anthropology collection of ULiège will be on display, as well as 3D models of objects from the Kinshasa collections. The aim is to involve the large African diaspora from Brussels and Liège in the project. In the same vein, the Musée Royal d'Afrique Centrale (AfricaMuseum) in Tervuren, Belgium, was contacted, to consider moving or reconfiguring this 'Belgian' side of the exhibition within the museum. The diaspora's contribution to the project would be doubly interesting, as the social bonding process would be multi-layered.

The Waza Center in Lubumbashi

It was through the AfricaMuseum in Belgium that contact was made with the Waza Center for



Figure 4. In the 'value market' is where merchants sell cultural objects, mainly to tourists. They call themselves 'Antiquaires' (antique dealers), and they are the heirs of the main suppliers to Western collections in the 19th and 20th centuries. As such, they have in-depth knowledge of the provenance and authenticity of cultural goods. Image: Muriel Verbeeck.

Contemporary Art, in Lubumbashi, DRC. The AfricaMuseum is home to the website of the Verbeek-Mwewa collection (Figures 5 and 6), comprising several thousand objects, including numerous folk paintings. The collection has now been inventoried, and two curators from the École du Patrimoine Africain are drawing up a conservation plan. It is already apparent that several works require conservation, and the Waza Center is keen to receive professional training. The Center has experience in involving the public: several traveling exhibitions have been held, as well as interviews, podcasts etc. produced by young people. A link with the *Nous avons des lacunes* project is therefore envisaged.[4] It would raise awareness among artists and the public of the problems involved in conserving contemporary folk art; it could also raise awareness of the importance of oral archives, which are proving to be a very important source of information during conservation work.



Figure 5. Workshop on the conservation of the Verbeek-Mwewa collection, at the Waza Center for Contemporary Art, Lubumbashi, April 2024. Image: Muriel Verbeeck.

Since the 1990s, the Waza Center has accumulated an exceptional collection of artists' interviews, probably the only one of its kind: its ethnographic, cultural and social value is incomparable. These sources of information remain to be exploited in terms of conservation.

Autonomy and harmonization

The stakeholders in the PICCo project have a common goal but different audiences; they are completely autonomous in their creative approach and project implementation. However, they can rely on logistical and technological support from the ULiège, if required, for the management of the data collected and their exploitation.

This autonomous, internally developed, flexibly coordinated operation empowers participants before the public. Spontaneous interactions reveal the social utility of such a project: the social liaison processes are understood by the partners who evolve in the context they know and master. In so doing, they meet the ambitions expressed at the 2021 symposium, regarding: introducing the African cultural model into teaching, communication and practice, with particular emphasis on African languages; capacity-building for the appropriate management, animation and



Figure 6. An audience of curators from the Musée national de Lubumbashi, heritage professionals and young contemporary artists interested in safeguarding the Verbeek-Mawa collection, at the Waza Center for Contemporary Art, Lubumbashi, April 2024. Image: Muriel Verbeeck.

promotion of all these cultural assets; the transmission of endogenous knowledge through education and lifelong learning; promoting education and research in African languages as vehicles for culture, memory and African and diasporic integration.

Expected results

At this stage, we cannot yet say what the results will be (since the exhibitions are still in preparation) or how they will be used together.[4] Nevertheless, all stakeholders agreed on the following points:

- The public's contributions must be emphasized and highlighted. We can think about a specific mode of reference; the 'contributors of knowledge,' however humble, must feel recognized and valued. The question of 'how' has been raised.
- Investigators need to be attentive to the social bonding processes involved in such surveys of objects to be preserved. It is by experimenting with this 'resignation of knowledge by experts,' and this 'investment of knowledge by citizens,' that we can encourage the exercise of cultural rights in the DRC, about heritage.
- Information is collected to make it available in open access to both partners and the public. Conservators are responsible for annotating 3D models and transferring information on materiality, functionality, and repair techniques. Linguists and anthropologists, for their part, will value information relating to national languages and dialects in order to compile a lexicon of conservation terms and the semantics peripheral to the field.
- All of this should be exploited by African museologists within the framework of social museology; they have already been identified.

Conclusion

Openness, flexibility, and adaptation are key to this project, which, without any pre – constructed scheme, has been articulated and organized in an attempt to adapt to a particular context (election year, social unrest, and war in the east of the country). With modest means, *Nous avons des lacunes* attempts to meet the recommendations made by researchers from the African Union after the 2021 symposium. The place given to national languages is, of course, a sign of respect; but we can also emphasize the interest in the semantic field, and, underlying these, in the endogenous concepts that shed light on the interventions undergone by cultural goods, in their area of origin.

Empowerment in terms of cultural rights must not remain a theoretical concept; it can, via conservation, be embodied in concrete ways and manifested in social bonding processes (whether intergenerational or otherwise). Anything that adds value to cultural diversity and unites citizens in the desire to preserve and pass on plays the role of social cement. Cultural

rights are also expressed in heritage conservation, and their universalism does not contradict the claim of an African and Congolese identity.

Notes

1. The *Universal Declaration of Human Rights* (UDHR) is an international document adopted by the United Nations General Assembly on 10 December 1948 in Paris, France.
2. Western authors have referred to this process as 'Congolization'. It is a misnomer. Ex-president Mobutu favored what he called 'Zaïrisation' in economic terms, and 'recourse to authenticity' in cultural terms: it was with this in mind that works and artefacts were collected until recently in the stores of Mont N'Galiema.
3. See https://www.youtube.com/watch?v=VuJbKHH1I38. Accessed 10 October 2023.
4. After the presidential elections, the Belgian team was able to join Lubumbashi and Kinshasa (April 2024) to implement the project at the Waza center and UNIKIN. The results will be reported in the oral communication. The photos published in the article bear witness to these developments.

Acknowledgements

The authors would like to thank all those involved in the project: colleagues from IMNC, the Academy of Fine Arts of Kinshasa, UNIKIN and ULiège for their involvement, as well as Wallonie-Bruxelles-International, which is funding the PICCo project. They would also like to express their gratitude to Antoine Tshimpi, who laid the foundations for this project, and to thank Marie-Claire Yandju, UNIKIN's General Secretary for Research, MUK, and in particular the dynamic team of curators who were involved in the field. Last but not least, they acknowledge the two other members of the steering team, Monique Milivu and Théophile Mafuta, whose perseverance overcame many obstacles and made this project a success.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Muriel Verbeeck http://orcid.org/0000-0001-7271-9127

References

Gesché-Koning, N. 2021. "Sauvegarde du patrimoine culturel en RDC." *Mémoires du Congo* 57: 28–31.

M'Bow, A.-M. 1978. *Pour le retour, à ceux qui l'ont créé, d'un patrimoine culturel irremplaçable.* Appeal by M. Amadou-Mahtar M'Bow, Director-general, UNESCO, 7 June 1978. Accessed June 11, 2023. https://unesdoc.unesco.org/ark:/48223/pf0000034683_fre.

Meyer-Bisch, P., and M. Bidault. 2010. *Déclarer les droits culturels: Commentaire de la Déclaration de Fribourg*. Brussels: Bruylant, Schulthess.

Muñoz-Viñas, S. 2005. *Contemporary Theory of Conservation*. London: Routledge.

Speranza, G. 2007. *Objets blessés. La réparation en Afrique*. Paris: Musée du Quai Branly.

UNESCO. 2007. *Cultural Rights. Fribourg Declaration*. Accessed March 24, 2024. https://www.unifr.ch/ethique/en/research/publications/fribourg-declaration.html.

Verbeeck, M., and F. Mava. 2023. "A Sustainable Future for Endogenous Conservation in the Democratic Republic of the Congo." In *Working Towards a Sustainable Past*. ICOM-CC 20th Triennial Conference Preprints, Valencia, 18–22 September 2023, edited by J. Bridgland. Paris: ICOM. https://icom-cc2023.org/wp-content/uploads/2023/09/0408_818_VERBEECK_Paper.pdf.

Véro, M. H. 2018. "Conservation et restauration des objets aux Musées Universitaires de Kinshasa." Masters diss., University of Kinshasa.

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S369–S375
https://doi.org/10.1080/00393630.2024.2347108

ORIGINAL RESEARCH OR TREATMENT PAPER

Sustainable Cultural Preservation in Central Asia – Involving Local Communities as Caretakers of Archaeological Sites

Preservación Cultural Sostenible en Asia Central: Involucrar a las Comunidades Locales como Cuidadoras de Sitios Arqueológicos

Maruchi Yoshida[1], Natascha Bagherpour Kashani[2], Abolfazl Aali[3], Hamed Zifar[3], Shahrzad Amin Shirazi[4] and Hasan Ahmed Qasim[5]

[1]Iconyk GmbH, München, Germany; [2]Deutsches Bergbau-Museum Bochum, Leibniz Forschungsmuseum für Georessourcen, Bochum, Germany; [3]Zanjān Saltmen and Archaeological Museum, Zanjān Cultural Heritage and Tourism Organisation, Zanjān, Iran; [4]Research Institute for Cultural Heritage and Tourism (RICHT), Tehran, Iran; [5]Kurdistan Archaeology Organisation, Duhok, Iraq

ABSTRACT

This article presents cultural conservation projects in Iran and Iraq, in each of which the social context of the archaeological site and the collection were also considered, in order to develop long-term conservation planning. The objective of one project is to improve the water supply for the local village population near an ancient salt mine in Iran in order to retain them as stewards of the archaeological site. Another project shows how digital media and different narrative perspectives are intended to appeal to different target groups in Iran and worldwide to raise awareness of the so-called salt mummies recovered from the ancient salt mine. International experts are also addressed via online formats to discuss the challenges of the ethical handling of human remains for conservation and exhibition. In Kurdistan (Iraq), young archaeology students are introduced to the topics of archaeological heritage management in order to recruit them as future caretakers. What all projects have in common is that relationships and cross-sector networks are being established to build a crisis-proof local community that takes care of its cultural heritage. In this way, projects can be implemented that are primarily carried out by local actors, thereby building up expertise that will endure. These projects are the initial attempts to link cultural preservation and social well-being and thus to make a contribution to sustainable development in line with the UN's 2030 Agenda for Sustainable Development.

Este artículo presenta proyectos de conservación cultural en Irán e Irak, en cada uno de los cuales también se consideró el contexto social del sitio arqueológico y la colección, con el fin de desarrollar una planificación de conservación a largo plazo. El objetivo de uno de los proyectos es mejorar el suministro de agua para la población local de una aldea cercana a una antigua mina de sal en Irán para conservarlos como administradores del sitio arqueológico. Otro proyecto muestra cómo los medios digitales y las diferentes perspectivas narrativas pretenden atraer a diferentes grupos objetivo en Irán y en todo el mundo para crear conciencia sobre las llamadas momias de sal recuperadas de la antigua mina de sal. También se dirige a expertos internacionales a través de formatos en línea para discutir los desafíos del manejo ético de restos humanos en la conservación y exhibición. En Kurdistán (Irak), se introduce a jóvenes estudiantes de arqueología en temas de gestión del patrimonio arqueológico para reclutarlos como futuros cuidadores. Lo que todos los proyectos tienen en común es que se están estableciendo asociaciones personales y de confianza y redes intersectoriales para construir una comunidad local a prueba de crisis que cuide su patrimonio cultural. De esta manera, se pueden implementar proyectos que sean llevados a cabo principalmente por actores locales, generando así experiencia que perduren. Estos proyectos son los primeros intentos de vincular la preservación cultural y el bienestar social y así contribuir al desarrollo sostenible en línea con la Agenda 2030 para el Desarrollo Sostenible de las Naciones Unidas.

ARTICLE HISTORY
Received October 2023
Accepted April 2024

KEYWORDS
Cultural heritage; preservation; public participation; sustainable development goals

Patrimonio cultural; preservación; participación pública; metas de desarrollo sostenible

Introduction

Cultural preservation can be a valuable contribution to social development when directly connected to the specific targets of the *17 Sustainable Development Goals* (SDGs) set by the United Nations (UNESCO 2017). The link between archaeological sites to wealth and freedom of communities might not be visible at first sight in times of post-conflict recovery and social transformation. Nevertheless, culture is often the glue that holds together a crisis-ridden society.[1] Project examples in Central Asia show how cultural preservation is undertaken to strengthen

CONTACT Maruchi Yoshida maruchi.yoshida@iconyk.de Iconyk GmbH, Welserstr. 33, München 81373, Germany
© The International Institute for Conservation of Historic and Artistic Works 2024

local structures and to support students and young professionals.

The projects presented here are taking place in Iran and in the Autonomous Region of Kurdistan in northern Iraq. Both countries have in common that the population is experiencing various political and religious crises and their economic and social consequences. In addition, there are geographic challenges posed by heat, drought, water scarcity and natural disasters.

Facing these circumstances, cultural preservation must unfold its potential to strengthen social cohesion and be conducted to meet social needs, and to offer benefits and opportunities to local communities. Therefore, preservation plans and activities are developed in collaboration with local authorities and are implemented step-by-step with local partners whenever practicable. Long-term cooperation is intended, and the solutions developed should be appropriate for continuation and further development. Thus, building intersectoral networks and relationships of trust with key stakeholders are of great importance to overcome political tensions, economic crisis, and the effects of the global pandemic.

Preserving the saltmen of Iran in a local context

Social context of the ancient saltmine in Chehrābad

In 1993, the mummified head of a bearded man wearing a golden earring was unexpectedly found in the Chehrābad salt mine. Therefore, state authorities stopped the working of the mine and only allowed archaeological investigation while more mummified bodies came to light (Aali et al. 2012, 2014–2015; 2020; Stöllner 2020; Stöllner and Aali 2020). The researchers identified the bodies as salt miners, who had died in various accidents that occurred in the Achaemenid (c.550–330 BCE) and Sasanian (c.224–651 BCE) periods. Further research excavations and protection measures for the site have continued, with cooperation between the German Mining Museum and the Iranian cultural authority.

An important pillar of research and care of this site is the local population, living in the village of Hamzehloo at the foot of the salt mine. Villagers support international research teams with workers, and any necessary assistance. But what is even more valuable is that they take care of the site when research teams are not there (Yoshida, Bagherpour Kashani, and Amin Shirazi 2021). However, life in the region is challenging for the villagers because the salt deposits in this region also cause high chloride levels in the water, therefore making the supply of drinking water and the irrigation of the fields difficult (Bagherpour Kashani, Boenke, and Herd n.d.). In recent decades, Hamzehloo and other villages in the area have been affected by a decline in the younger population, and it seemed that the future 'stewards' of the salt mine were migrating to the cities.

Based on this situation the project *Water, Education and Tourism in the Rural Region of Mahneshan/Iran (Water Project)* was initiated[2] and funded by the Gerda Henkel Foundation in Germany (Bagherpour Kashani 2020), with the aims of finding new water sources, installing wells, building up technology to desalinate the water, and supporting the local authorities in developing new water management concepts (Figure 1). As of 2018, hydrological surveys have been conducted (Pfingsthorn 2020), water analyses have been carried out in local laboratories of the Regional Water Authority of Zanjan, the water supply infrastructure has been modelled (Hummel 2023), and test wells installed (Eichhorn 2020). Investing in the water supply in a water-scarce region stirs up various sensitivities, e.g. refusal to make land available for well construction, claims from neighbouring villages, or regulations imposed by local authorities. However, all obstacles were overcome in negotiations with the landowners, village elders and the local authorities.

Based on the *Water Project* current efforts by regional stakeholders are aimed at developing an education and community centre for regional and international visitors in Hamzehloo. There, information about cultural and natural resource management, and the cultural heritage of the saltmine itself, are provided. The Iranian Ministry of Cultural Heritage, Handicrafts and Tourism and regional travel agencies are working on a sightseeing route for tourists that connects the Chehrābād saltmine and the Zanjān Saltmen and Archaeological Museum (ZSAM) to the UNESCO World Heritage Sites of Qazvin and Takht-e Soleyman, all situated in the Province of Zanjan within a radius of 70 km. Developing the idea of an education and community centre has already initiated



Figure 1. Hydraulic engineer from the Technical University Darmstadt, Germany, testing one of the potential wells in Hamzehloo. © Natascha Bagherpour Kashani.



Figure 2. Exhibition of mummies from the salt mine, Zanjān Saltmen and Archaeological Museum, Iran. © Natascha Bagherpour Kashani.

further interest, which will open new economic opportunities for the residents. While the *Water Project* is still ongoing, these new perspectives are already attracting people back to their village.

Preventive conservation and sustainable refurbishment of the ZSAM

The mummified saltmen and the organic finds recovered from the excavations are extremely well preserved (Figure 2) and are important sources for technological, sociological and cultural information. They are now presented in the ZSAM. To all project members it was clear that a sustainable prevention strategy was needed to achieve effective results in the long term at the ZSAM, in order to preserve the mummies and also make the museum, an historical building from the Qajar period (1779–1924), a welcoming place for visitors and staff. Preventive conservation was therefore the guiding principle for a holistic approach regarding the building envelope, the environmental and lighting conditions in the rooms, establishing integrated pest management, and improving fire safety and security protocols (Waentig et al. 2014).

In the project *Saltmen of Iran*, also funded by the Gerda Henkel Foundation, an interdisciplinary workshop series was organised in which archaeologists, architects, conservators, and engineers from various institutions were invited to discuss and agree on priorities for preventive conservation[3] (Figure 3). During this phase, the outdated electrical system in the museum building was classified as a major fire risk and was renewed with the help of the Prince Claus Fund[4]. Alongside the refurbishment measures, parts of the building were restored with traditional building techniques which have been revitalised as a result, and are now increasingly being applied to restore the old town.

The most important outcome of the first workshop series was the common understanding that a stable environment and pest prevention form the basis for collections care in the museum. Together, monitoring and inspection plans were developed and tested in practice in the building. Based on this data and its interpretation, measures have since been developed and implemented to improve the physical properties



Figure 3. (a–b). Workshop on preventive measures, Zanjān, August 2019. © Natascha Bagherpour Kashani

of the building envelope and to provide a ventilation system. Regular environmental and insect monitoring are carried out by the museum team and evaluated regularly by the project team (Yoshida, Bagherpour Kashani, and Amin Shirazi 2021, 46).

International visibility and awareness building for the saltmen of Iran

Considering the challenges involved in long-term preservation of the saltmen and the salt mine, international visibility and awareness is of great importance. All parts of society should know the saltmen, their heritage and their value for the people – not only at a national but also at an international level. Therefore, communication channels have been chosen: a digital exhibition, an open lab accessible by social media and on site, and participation at international conferences.

The exhibition *Death by Salt* at the German Mining Museum in Bochum has chosen a graphic novel to convey the tragedy of the saltmen, reconstructed by complex archaeological and multidisciplinary investigations to a wide audience (Stöllner 2020, 356–368). Reaching audiences on different levels and catching their interest by means of multi-faceted topics achieves high visibility for the saltmen and their heritage, which raises social awareness of the value of this cultural heritage. The exhibition has been made accessible as a virtual exhibition. Created in response to the pandemic, digital access is proving to be a great advantage, as it allows us to reach many more target groups than would have been possible with a physical exhibition (Yoshida, Bagherpour Kashani, and Amin Shirazi 2021, 50).

In the same period during the pandemic, the saltmen project was granted further funding from the German Ministry of Foreign Affairs.[5] Within the project *Conserving the Saltmen of Zanjān in Iran,* conservation of and research into the saltmen could be continued. But instead of taking them to off-site laboratories, a laboratory was set up in the exhibition hall, called OPEN LAB. Due to the pandemic the team opened up the lab in a virtual room, using social media. Within four months, the saltmen of Iran (Instagram: @saltmen_of_iran) would attract over 900 followers all over the world, but mostly in Iran, showing how interested young Iranians are in their cultural heritage (Yoshida, Bagherpour Kashani, and Amin Shirazi 2021, 50). A special book for young people has also been written and illustrated to familiarise young people with the cultural heritage (Zifar and Aali 2021).

Long-term preservation is a challenge because experience and knowledge about the correct treatment of human remains preserved in salt is lacking: these mummies are the only ones of their kind anywhere in the world. Due to the combined effects of the pandemic, political reasons, and budget constraints, personal meetings of the international scientific community were and still are difficult. Therefore, an online ethical discussion forum *From underground to the limelight: the saltman as information carrier and storyteller* was organised in 2021 to connect interdisciplinary experts from Iran and Europe, and discuss the challenge and responsibility of treating human remains with respect while also preserving them as cultural heritage.[6]

The international discussion forum, related conference contributions and publications have increased the worldwide visibility of the saltmen, so that now a professional network is growing and helping to find good solutions for the long-term preservation and dignified presentation of the saltmen. The conference contributions and outcomes of the discussion forum have been published (Bagherpour Kashani, Yoshida, and Stöllner 2021; Yoshida, Baghanpour Kashani and Amin Shirazi 2021; Bagherpour Kashani and Yoshida 2024).

Pilot project for awareness raising: Qishla Dohuk (Iraq)

In 2012 in Dohuk Bazaar, in northern Iraq which is today in the Autonomous Region of Kurdistan, an urban development project brought to light one of the oldest archaeological remains in the city (Figure 4). Excavations uncovered the remains of vaulted storage rooms, mills and bathrooms dating from the Mitanni dynasty as the earliest period, through the Assyrian, Hellenistic and Islamic periods, to the Bahdinan period, a particularly important epoch for the region.[7] The site called Qishla Dohuk has now been 'preserved' within a newly-built shopping centre, where it is visible as an open trench below basement level. It is planned to preserve the important features and to keep them visible for future visitors. However, plans to make the historic remains accessible and understandable for the citizens of Dohuk and other visitors such as tourists, and how to use them for the benefit of local people, have not yet started.

In spring 2023 an initial project with funding from the Gerda Henkel Foundation launched a programme to involve students from the recently-founded Archaeological Department of the University of Dohuk in planning for the preservation and sustainable use of Qishla Dohuk.[8] This region in northern Iraq, which until a few years ago was fighting Islamic State, now wants to train its own archaeologists. With the Qishla Dohuk pilot project, topics such as archaeological heritage management and cultural heritage conservation will now be added to the general curriculum.

The first phase of the project therefore focussed on documenting the ceramics from the site as they are an important source of information for chronological and cultural contextualisation. To draw and interpret pottery shards from excavations forms a basic and



Figure 4. Students of the University of Dohuk at the archaeological site Qishla Dohuk in May 2023. © Kurdistan Archaeology Organization.

important method of the evaluation of archaeological sites. The students could thus contribute to further research on Qishla Dohuk, and they gained valuable skills for their future careers as archaeologists.

For the second phase a 4-day participatory learning format was organised to introduce the students to heritage preservation. Starting with a 'learning circle', students learned the basics of cultural heritage preservation and reflected their role and function as future archaeologists and as caretakers for national and international cultural heritage (Figure 5). In a 'future workshop', students created their own vision for the preservation and presentation of the Qishla Dohuk site without regard to any limitations. The students prepared their ideas on a poster for a competition. Representatives of the official authorities and the university were invited to attend and to discuss ideas with the students, to give them their first experience of negotiation.

Participatory formats turned out to be a new method, both to teachers and students. The students were not used to being confronted with complex tasks to solve without being instructed by the teachers. However, working in small teams in a protected space enabled the students to bring in their own interpretation of cultural heritage and ideas for its preservation and use, without being limited by any lack of professional background. They got a first impression of how dialogue processes work and became aware of 'ownership', not only in a material sense but as an expression of identification with their own cultural heritage and their sense of responsibility towards it.

As the ideas are based on local perspectives and are discussed with representatives of the local authorities, the results are suitable as a basis for further project applications. Future projects in cultural preservation might provide young archaeology students with professional access to the field of cultural heritage management to activate and inspire them for their future careers.

Achieving sustainability with temporary projects in post-conflict areas

Solutions adapted to local conditions and needs

The projects in Iran and Kurdistan (Iraq) take the social and economic circumstances of the countries and the



Figure 5. (a–b). Students of the University of Dohuk taking part in a learning circle in October 2023. © Natascha Bagherpour Kashani.

needs of the population into account to develop *sustainable solutions for conservation*. These projects should also convey understanding of a cultural site or collection as a resource that belongs to the community, and that its preservation goes hand in hand with sustainable uses that benefit the community.

Sustainability in preservation projects also means that if specialists with the relevant qualifications are not available locally, the focus should be on training and promoting young talents rather than on a quick fix by flying in experts from abroad. External experts are used specifically for consulting and coaching to support local stakeholders in achieving the best results with the resources available locally. Even if one solution initially only meets the minimum requirements it opens the possibility of a continuous improvement process that can be implemented step by step.

Establishing strong local networks and reliable international partnerships

Particularly in countries such as Iran and Iraq, communities and different social entities play a crucial role as active caretakers of their heritage. The projects discussed here relied strongly on the successful implementation by local partners in Iran and Iraq. Thus, financial and material resources are mainly assigned to the local partners to generate the greatest possible benefit in the host country. Therefore, trusting and reliable partnerships between the project coordinators and contact persons at partner institutions are needed.

In Iran, long-lasting cooperation with the cultural heritage authorities over the past 20 years has seen several crises come and go. In Kurdistan, our partner is a non-governmental organisation that is well connected in both political and economic circles at the regional level. In any case, the local contact persons have a key role to play in involving local partners and supporters necessary to the success of the project, and for addressing potential critics positively, thus ensuring their acceptance. Close cooperation between the various parties involved will be consolidated and stabilised over the course of the project so that conservation and maintenance concepts, once developed, can be continued beyond the funded project period (Bagherpour Kashani, Yoshida, and Stöllner 2021).

Contribution to SDG 2030

It is important that cultural preservation is not merely an end in itself, but that it generates benefits for the local population – both in a social and economic sense. We must not lose sight of the fact that, as foreign conservation professionals, we are entering a society that has experienced wars and suffering in recent years. Cultural preservation must help to heal these wounds, restore cultural identities, and open up prospects for future prosperity and stability. These are ambitious goals that cannot be achieved through the conservation of cultural sites alone.

These projects are the initial attempts to link cultural preservation and social well-being and thus to contribute to sustainable development in line with the UN's 2030 Agenda (UNESCO 2017). Besides the explicit SDG target 11.4 to 'strengthen efforts to protect and conserve the world's cultural and natural heritage' other SDGs such as *SDG 1 No Poverty*, SDG 6 *Clean Water and Sanitation, SDG 8 Decent Work and Economic Growth*, and also *SDG 16 Peace, Justice and Strong Institutions* and *SDG 17 Partnerships for the Goals* are addressed by these projects. Future projects will focus more on explicit targets, and indicators to document and evaluate the impact of cultural preservation on local communities and their well-being. The Culture for Development Indicators developed for this purpose are to be used in future projects in order to demonstrate the multidimensional function of culture for social development and to pave the way for further projects (UNESCO 2014a; 2014b).

Acknowledgments

We would like to thank the following people for their great support: Hamed Zifar (IR, Book Production and Water Project) and Maryam Aali (IR, Book Production), Alireza Rahmani (IR, Social Media), Mohammed Taha Mohammed (KRG/IQ, Translation), Akhink Omer Abdullah (KRG/IQ, Translation), Dr. Zhyar Doski (KRG/IQ, University of Dohuk).

Notes

1. In September 2023 within the Cáceres declaration the Ministers of Culture of the European Union stated that: 'Culture is rights, culture is freedom. Culture is progress and, above all, democracy … Because life without culture is mere survival'. See: https://spanish-presidency.consilium.europa.eu/en/news/caceres-declaration/. Accessed 4 April 2024.
2. Project 2019–2025 led by Dr Natascha Bagherpour Kashani (NBK), German Mining Museum (DBM) and Dr Abolfazl Aali, Zanjān Cultural Heritage and Tourism Organization (ZCHTO), with partners: Chair of Raw Material and Resource Management, Technical University Cottbus-Senftenberg; Institute IWAR, Technical University Darmstadt; and Regional Water Authority of Zanjān. See video: https://lisa.gerda-henkel-stiftung.de/klimawandel_wassernot and https://lisa.gerda-henkel-stiftung.de/the_water_project_a_cultural_heritage_site_dries_up?nav_id=11055. Accessed 4 April 2024.
3. Project 2018–2025 with coordinator NBK, and workshop and preventive conservation consulting conducted by Maruchi Yoshida (MY), with supporting institutions: Research Center for Conservation of Cultural Relics (RCCCR), Teheran; and ZCHTO. See: https://lisa.gerda-henkel-stiftung.de/patrimonial_projects, https://lisa.gerda-henkel-stiftung.de/die_geheimnisse_der_salzmaenner_von_zanjan_the_open_lab_project_or_the_secrets_of_the_salt_men?nav_id=9486, https://lisa.gerda-henkel-stiftung.de/saltmen_of_iran_

de and https://lisa.gerda-henkel-stiftung.de/saltmen_of_iran_en. All accessed 4 April 2024. Small museums like ZSAM in particular often lack knowledge and staff (Bagherpour Kashani 2022), so the workshop was essential for the implementation of the conservation measures.

4. https://www.tod-im-salz.de, https://www.bergbaumuseum.de/forschung/forschungsprojekte/tod-im-salz. Accessed 4 April 2024.
5. Project June 2020 – April 2021 managed and coordinated by Maruchi Yoshida and Dr Natascha Bagherpour Kashani, with partners DBM and ZCHTO.
6. https://lisa.gerda-henkel-stiftung.de/einladung_zur_diskussion_kulturerbe_mumien_und_wuerde?nav_id=9744. Accessed 4 April 2024. See Deutscher Museumsbund und Bundesverband Museumspädagogik (2021); Fuchs et al. (2021); ICOM 92023).
7. Mitanni dynasty c.1550–1260 BCE. Assyrian period beginning of the 18th century BCE until around 609 BCE. Hellenistic period: c. 330 to 30 BCE. Islamic period: since the 6th century CE. Bahdinan dynasty: c.1200–1843 CE. The Kurdish principality is located in today's Iraqi governorate of Dohuk. See: https://lisa.gerda-henkel-stiftung.de/qishla_dohuk. Accessed 4 April 2024.
8. *Qishla Dohuk. An Archaeological Site for the People*, Kurdistan Archaeology Organization, University of Dohuk, General Directorate of Antiquities, Erbil. Funded March–October 2023. Project coordination: Dr Hasan Ahmed Qasim and Dr Natascha Bagherpour Kashani.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Aali, A., and T. Stöllner. 2020. "Die Salzmänner von Chehrābad: Eine Spurensuche." In *Tod im Salz. Eine Archäologische Ermittlung in Persien*, edited by T. Stöllner, A. Aali, and N. Bagherpour Kashani, 133–146. Bochum: Nünnerich-Asmus.

Aali, A., and T. Stöllner, eds. 2014–2015. "The Archaeology of the Salt Miners. Interdisciplinary Research 2010-2014." *Metalla* 21 (1–2): 1–141.

Aali, A., T. Stöllner, A. Abar, and F. Rühli. 2012. "The Salt Men of Iran: The Salt Mine of Douzlākh, Chehrābād." *Archäologisches Korrespondenzblatt* 42 (1): 61–81.

Bagherpour Kashani, N. 2020. "Herausforderungen, Entdeckungen, Chancen." In *Tod im Salz. Eine Archäologische Ermittlung in Persien*, edited by T. Stöllner, A. Aali, and N. Bagherpour Kashani.

Bagherpour Kashani, N. 2022. "Kleinere Museen – ein Stimmungsbild." *Zeitschrift des Deutschen Museumsbunds* 1: 4–21.

Bagherpour Kashani, N., and M. Yoshida. 2024. "Ein digitales Restaurierungslabor als Lernort für Wissenschaftler, Ausstellungsmacher und die diverse Öffentlichkeit. Der Umgang mit menschlichen Überresten in Museen am Beispiel der iranischen Salzmumien." In Wo Wissen entsteht: Orte der Forschung, des Austauschs und des Lernens in den Altertumswissenschaften, Cluster 5, Geschichte der Archäologie. Berlin: Deutsches Archäologisches Institut (in the press).

Bagherpour Kashani, N., M. Yoshida, and T. Stöllner. 2021. "Die Salzmänner von Iran. Kulturerhalt als Treiber und Ermöglicher einer nachhaltigen Entwicklung." *Fachzeitschrift für die Museumswelt* 1: 34–42.

Bagherpour Kashani, N., N. Boenke, and R. Herd. n.d. "Water Resources, Climate Change and Resilience at Douzlākh." In ResourceScapes in the Iranian Highlands: Water, Wind and Minerals as Factors of Appropriation and Integration" held 12–13 September 2022. [Publication forthcoming].

Deutscher Museumsbund und Bundesverband Museumspädagogik. 2021. *Leitfaden Umgang mit menschlichen Überresten in Museen und Sammlungen*. Berlin: Deutscher Museumsbund und Bundesverband Museumspädagogik.

Eichhorn, C. 2020. "Development of a Concept for the Water Supply of the Village Hamzehlu as Well as a Visitor Center at the Salt Mine Chehrabad (Iran) with Process and Drinking Water." Masters dissertation, Technische Universität Darmstadt, Darmstadt. Accessed April 2, 2024. https://iranhighlands.com/wp-content/uploads/2023/11/MA_Eichhorn_Wasserprojekt_2021_kompr.pdf.

Fuchs, J., D. Gabler, M. Markert, C. Herm, and S. Mühlenberend. 2021. *Menschliche Überreste im Depot, Empfehlung für Betreuung und Nutzung*, version 2. Accessed April 2, 2024. https://wissenschaftlichesammlungen.de/files/4416/2140/5696/Menschliche_berreste_im_Depot_V2.pdf.

Hummel, J. 2023. "Softwaregestützte Modellierung der Wasserversorgungsinfrastruktur des iranischen Dorfes Hamzehloo." Unpublished masters dissertation, Technische Universität Darmstadt, Darmstadt.

ICOM. 2023. *Ethikkodex für Naturhistorische Museen*. Accessed April 2, 2024. http://icom-oesterreich.at/publikationen/icom-ethikkodex-fuer-naturhistorische-museen.

Pfingsthorn Olivares, M. 2020. "Geoelectric Investigations of the Detection of Groundwater Sources in the Area of Hamzehlooh, Zanjan, Iran." Unpublished bachelors dissertation, Brandenburg University of Technology, Cottbus.

Stöllner, T. 2020. "Von Salzmumien und anderen Besonderheiten. Theoretische und methodische Aspekte einer Salzbergbauarchäologie." In *Tod im Salz. Eine Archäologische Ermittlung in Persien*, edited by T. Stöllner, A. Aali, and N. Bagherpour Kashani, 47–59. Bochum and Oppenheim: Nünnerich-Asmus.

Stöllner, T., and A. Aali. 2020. "Chehrābad: Ein antikes Salzbergwerk und seine bergbauarchäologische Erforschung. Von Produktionsverfahren und Unglücken." In *Tod im Salz. Eine Archäologische Ermittlung in Persien*, edited by T. Stöllner, A. Aali, and N. Bagherpour Kashani, 117–130. Bochum and Oppenheim: Nünnerich-Asmus.

UNESCO. 2014a. *UNESCO Culture for Development Indicators, Methodology Manual*. Accessed April 2, 2024. https://unesdoc.unesco.org/ark:/48223/pf0000229608/.

UNESCO. 2014b. *UNESCO Culture for Development Indicators, Implementation Toolkit*. Accessed April 2, 2024. https://www.unesco.org/creativity/en/activities/cdis/.

UNESCO. 2017. *UNESCO moving forward the 2030 Agenda for Sustainable Development*. Accessed April 4, 2024. https://unesdoc.unesco.org/ark:/48223/pf0000247785.

Waentig, F., M. Dropmann, K. Konold, E. Spiegel, and C. Wenzel. 2014. *Präventive Konservierung: ein Leitfaden*. Berlin: ICOM Deutschland.

Yoshida, M., N. Bagherpour Kashani, and S. Amin Shirazi. 2021. "The Saltmen of Iran: Preserving Cultural Heritage and Securing Livelihoods in Times of Social Transformation and Volatile Political Climate." *News in Conservation* 38: 41–58.

Zifar, H., M. Aali, et al. 2021. *Dream of Immortality*. Teheran: Iran National Museum. [In Farsi and English]

STUDIES IN CONSERVATION
2024, VOL. 69, NO. S1, S376–S384
https://doi.org/10.1080/00393630.2024.2358592

ORIGINAL RESEARCH OR TREATMENT PAPER

APOYOnline: A Sustainable Approach to Heritage Preservation Across the Americas

APOYOnline: Un enfoque sostenible para la preservación del patrimonio en las Américas

Beatriz Haspo[1], Amparo Rueda[1], Nathália Pamio Luiz[2], Gabriela Lúcio[3], Cristina Lara Corrêa[2], Irene Delaveris[4] and Sarah Sequeira[5]

[1]APOYOnline, Association for Heritage Preservation of the Americas, Rockville, MD, USA; [2]Universidade Lusófona de Humanidades e Tecnologias, Lisbon, Portugal; [3]Universidade Federal do Estado do Rio de Janeiro, Rio de Janeiro, Brazil; [4]APOYOnline - Association for Heritage Preservation of the Americas, Greece; [5]APOYOnline - Association for Heritage Preservation of the Americas, Brazil

ABSTRACT

For 35 years, APOYOnline – Association for Heritage Preservation of the Americas has been building bridges of communication and promoting professional development in the field of heritage preservation, strengthening, empowering, and transforming our community, increasing inclusion and access, and reducing social inequalities in the Americas and in Portuguese- and Spanish-speaking countries. As a grassroots, volunteer-based, non-profit organization, we listen to the community and work to address needs caused by widely recognized discrepancies in working conditions, adverse climate conditions, social inequalities in training, and other factors that directly impact heritage preservation and to provide access to specialized technical resources. This paper presents the voices of APOYOnline and the impact of the organization's catalyzing work in improving resource accessibility and connecting people. This work has mobilized regional and global networks, providing equal opportunities through translation of reference materials in multiple languages, professional development grants for students and emerging professionals, and training and regional networking events in underserved territories in the region. It also addresses our special community-based initiative *Manos a la Obra*, which strengthens long-term community engagement as a collaborative knowledge-sharing process, based on learning through participation and dialogue. The program improves access to technical information and fosters the long-term sustainability of local and regional cultural heritage preservation efforts, and has served as a model for similar activities in other countries. APOYOnline pursues sustainability through volunteer-based networking showing that communication and horizontal interaction with local communities creates awareness and better opportunities for our professionals and positively impacts heritage preservation in the region.

Durante 35 años, APOYOnline-Asociación para la Preservación del Patrimonio de las Américas ha construido puentes de comunicación y ha promovido el desarrollo profesional en el campo de la preservación del patrimonio cultural, fortaleciendo, empoderando y transformando la comunidad, aumentando la inclusión y el acceso, a su vez reduciendo las desigualdades sociales en las Américas y en países de habla hispana y portuguesa. Como organización sin fines de lucro de base voluntaria, escuchamos a la comunidad y trabajamos para abordar sus necesidades causadas por discrepancias en las condiciones de trabajo condiciones climáticas adversas, desigualdades sociales en la capacitación y otros factores que impactan directamente en la preservación del patrimonio, y el acceso a recursos técnicos especializados. Este documento presenta las voces de APOYOnline y el impacto del trabajo catalizador de la organización que mejora la accesibilidad a los recursos y la conexión entre las personas. Este trabajo ha movilizado las redes de comunicación regionales y globales, brindando igualdad de oportunidades a través de la traducción de materiales de referencia en múltiples idiomas, facilitando el acceso a becas de desarrollo profesional para estudiantes y profesionales emergentes, y organizando eventos de capacitación y creación de redes regionales en territorios desatendidos de la región. También aborda nuestra iniciativa comunitaria especial Manos a la Obra, que fortalece el compromiso comunitario a largo plazo como un proceso colaborativo de intercambio de conocimientos, basado en el aprendizaje participativo y en el diálogo. El programa mejora el acceso a la información técnica y fomenta la sostenibilidad a largo plazo de los esfuerzos de preservación del patrimonio cultural local y regional y ha servido como modelo para actividades similares en otros países. APOYOnline busca la sostenibilidad a través de redes de voluntariado que muestran que la comunicación y la interacción horizontal con las comunidades locales crean conciencia y mejores oportunidades para nuestros profesionales e impactan positivamente la preservación del patrimonio en la región.

ARTICLE HISTORY
Received November 2023
Accepted May 2024

KEYWORDS
Networks; *Manos a la Obra (Helping Hands)*; volunteering; community engagement; training

Redes; *Manos a la Obra*; trabajar como voluntario; participación de la comunidad; capacitación

CONTACT Beatriz Haspo beatriz.haspo@apoyonline.org APOYOnline, 11712 Stonewood Lane, Rockville, MD 20852, USA

© The International Institute for Conservation of Historic and Artistic Works 2024

Introduction

In regions of great social, economic, environmental, and cultural inequities, such as Latin America and the Caribbean, the work of professional networks is vital to enhance efforts to recognize the value of cultures, ancestries, and heritage, empowering the dedicated professionals engaged in these tasks, and the institutions and companies that support these activities.

APOYOnline – Association of Heritage Preservation of the Americas Inc., formerly APOYO, is a grassroots non-profit organization that has grown over the past 35 years to become a major presence in the field of heritage preservation. Our mission is to promote communication, exchange, and professional development in the field of heritage preservation in the Americas, the Caribbean, and Portuguese- and Spanish-speaking countries. We foster connections and knowledge-sharing among professionals responsible for safeguarding our invaluable cultural heritage. Our robust network has increased to over 6,000 people to date, and continues to connect people across continents, supporting each other to solve problems and overcome challenges. Over 1,200 professionals from 31 countries have received specialized training through multi-lingual events organized by APOYOnline. All activities have been carried out solely with the remarkable efforts and unwavering commitment of volunteers. This level of volunteer engagement makes our organization unique in the sector.

The longevity and impact of APOYOnline may be explained through the organization's priority: *people*. Our mission and activities have been driven by our community. We believe that sustainable preservation of cultural heritage depends exclusively on people, and we dedicate our efforts to support those who treasure, preserve, and work with cultural heritage.

APOYOnline: history and vision

The organization was founded in 1989 after a group of 30 visionaries met to identify the needs of their colleagues in Latin America and propose ways to support them. To gain a holistic understanding of the state of conservation in the region, a survey was distributed to 150 Latin American professionals and institutions. The small number of questions inquired about their affiliation to an institution or private practice; conservation specialty; what was the heritage conservation situation in their country; if they were able to use and/or if conservation materials were accessible; if there were any local conservation training and research opportunities; and what their greatest challenge was as a conservator? The survey received an overwhelming response rate of 85%. Of the 128 responses, most of the answers (95%) were very similar. All suggested materials specialties were selective, reflecting the impossibility of specialization; they identified difficulty in purchasing conservation materials, due to lack of funding and knowledge of what and where to buy; lack of training opportunities; and their main obstacles were the lack of timely information in Spanish and Portuguese and their isolation from other professionals in the preservation field. To fill this gap, an association called APOYO was established by Amparo Rueda and José Orraca, and a database of names was compiled through word of mouth with the objective of creating a network of Spanish- and Portuguese-speaking cultural heritage professionals.

One of APOYO's initial efforts was the establishment of a newsletter that was first published in 1989 in Spanish, Portuguese, and English. The newsletter was a pioneering publication in Latin America, and included translations of important articles, reference materials, and news from the region. While the internet was not widely available, the APOYO newsletter was printed and mailed twice a year until 2003, with the support of the Smithsonian Institution in the US and ICCROM in Italy. It is today available on the APOYOnline website: www.apoyonline.org.

The first APOYO website was developed in 2003 and countless volunteers have helped to maintain it to this day, later adding a presence on social media platforms including Facebook, Twitter, Instagram, Threads, and YouTube. In 2023, APOYOnline carried out the *Webpage Content and Revamping* project with renewed focus on providing news and resources for cultural heritage professionals with emphasis on digital accessibility. Part of this project resulted in the publication *Guidelines for Digital Accessibility* (APOYOnline 2023) created in collaboration with award-winning expert in digital accessibility Desiree Nobre Salasar, which is available free of charge in three languages on the webpage.

In 2009, to respond to the continuously evolving needs of the community, APOYO reorganized and incorporated in the U.S.A. as a non-profit organization named APOYOnline – Association for Heritage Preservation of the Americas Inc. As a result, we increased our fundraising activities, expanded special initiatives and professional development at the regional level and created two scholarship programs for students and emerging professionals in heritage preservation.

Through collaborations and bilateral agreements with institutions around the world, APOYOnline has translated, and continues to translate, foundational conservation and preservation literature into Spanish and Portuguese, and makes them widely available. An example is the Canadian Conservation Institute's *Framework for the Preservation of Collections* first published in English in 1995 (CCI 2023) (Figure 1). This seminal publication was revised by the CCI in 2015 and APOYOnline obtained authorization to translate



Figure 1. Left: Amparo Rueda (APOYOnline President) and Beatriz Haspo (APOYOnline Executive Director) with the translated CCI *Framework for Preserving Heritage Collections*. Right: versions in Portuguese and Spanish. Image: APOYOnline.

and publish the poster in Spanish and Portuguese with APOYOnline as the rights holder.

Since 2015, APOYOnline has expanded bilateral agreements and fundraising activities to promote multilingual conferences and workshops in Latin America and to offer scholarships to participants (APOYOnline 2019a). In 2019, as part of our 30th anniversary celebration, APOYOnline established two scholarship programs for professional training: the Toby Raphael Memorial Fund and the José Orraca Memorial Fund, in memory of these two pioneering professionals who played a vital role in APOYOnline's history. APOYOnline develops and provides professional development activities including workshops, master classes, opportunities to present at conferences, and technical visits held in several countries, such as Brazil, Colombia, Cuba, Guatemala, the Dominican Republic, and in more than ten states in the USA. Participants represent national and regional museums, libraries and archives, universities, regional centers, government institutions, independent professionals, students, and professionals in related fields, who demonstrate a desire for learning, inspiring engagement, and regional leadership. For many of them, it was the first opportunity offered for technical training (Haspo 2020).

As one example of collaboration, APOYO (and later APOYOnline) formed an alliance with the American Institute for Conservation (AIC), the AIC Foundation (FAIC), and the Getty Foundation in 1997 to establish the Latin American and Caribbean Scholarship (LACS) Program. Up to 2023 this program has invited more than 400 professionals from 27 countries to participate in bilingual training workshops organized by APOYOnline and others during AIC annual meetings and to disseminate their work through papers and poster



Figure 2. 2023 APOYOnline/FAIC grantees in Jacksonville, Florida participating in the AIC annual meeting. Image: APOYOnline.

presentations. In other words, APOYOnline has continuously helped to fund and mentor Spanish-, Portuguese – and English-speaking preservation professionals from Latin America, the Caribbean, Portugal, and Spain, empowering the next generation of cultural heritage professionals.

Josefa Orrego (Chile), a first-time grantee in 2023 (Figure 2) wrote:

> As a first-time attendee it was an excellent opportunity to network with colleagues worldwide. I was thrilled to meet in person some of the authors I referenced in my research and learn from their experiences in the field of conservation. As an emerging professional, it was truly inspiring to connect and share with colleagues who have been in the sector longer, reassuring me that I am not alone on this journey. It was a delightful opportunity to meet colleagues from Latin America and make new friends. It was an experience I would love to repeat!

Some of the next steps for APOYOnline in recent years have been facilitated primarily by two generous grants from the Mellon Foundation in 2020 and 2022 which have allowed us to increase our organizational capacity and programming activities and to ensure future sustainability. APOYOnline developed its vision statement 'Connect, Empower, Transform' stemming from the idea that the organization works to connect heritage preservation professionals, to empower anyone charged with preserving cultural heritage, to transform the field, and to continue evolving and transforming the organization and the community we serve.

In 2021 APOYOnline completed its first Strategic Plan (2021–2026) by gathering quantitative and qualitative feedback from our stakeholders and community using surveys, one-on-one interviews, individual statements, and focus groups, which required nearly 300 hours of work dedicated to this task (APOYOnline 2021a). In 2022, as part of rebranding efforts, we launched a new logo developed with the help of an emerging professional designer. The new logo (visible in Figure 1) represents achievements of the past and the open connections we continue to pursue into the future.

Initiatives

While APOYOnline has evolved over three decades, many foundational initiatives have remained constant. Our main programs include professional training, access to technical information through translations of reference texts, strengthening regional connections through professional development, regional conferences, special initiatives, and the scholarship program. This has been possible through the hard work of hundreds of volunteers.

Translations

APOYOnline's translation team includes over 30 dedicated volunteers from different countries in Latin America, Spain, and Portugal, including conservators, restorers and experts in chemistry and biology and other specialties. The team has translated many resources related to topics like emergency preparedness and response, photographic conservation, and risk management, among others. During the Covid-19 pandemic, we translated important pandemic-related information into Portuguese and Spanish to help our colleagues safely reopen their institutions (APOYOnline 2019b; 2020). APOYOnline is honored to witness how these translations have contributed to the safety of our Portuguese- and Spanish-speaking community. Our workshop and master classes always include teaching material in three languages, including topics such as leadership, fundraising and advocacy, communication, team building, and photographic conservation.

Professional development

APOYOnline promotes professional training at national and regional levels in Latin America and the Caribbean, through technical workshops on a wide range of topics related to heritage preservation such as: copyright in heritage preservation, risk management, leadership and advocacy, networking, among others. To date, nearly 50 in-person and virtual workshops have been carried out, with many more planned for the future. These courses strengthen sub-regional networks, through the empowerment of engaged professionals and the institutions and companies that collaborate in these activities. APOYOnline initiated the development of a distance learning platform for professional development training to amplify the options for specialized training in the region. To date, participants in the professional development activities and APOYOnline grantees from 1997 to 2023 represent 31 countries.[1]

Tricia Lawrence Powell (Jamaica), a first-time grantee in 2022, wrote:

> The experience was exceptional. It allowed for networking, knowledge sharing, personal and professional development. More importantly, it allowed me to export for implementation, to my home country Jamaica, the lessons learnt to improve upon our preservation and conservation agenda. This undertaking would not have been achieved without the support of APOYOnline team led by Beatriz Haspo, who made every single second of the day a worthwhile experience. This was significant for me as a non-Spanish speaker; they made it absolutely seamless. The care, support and guidance coupled with the sponsorship will certainly yield the return on investment at the National Library of Jamaica and similarly the warm customer engagement for APOYOnline

> will forever be etched as an indelible memory in my history.

Masterclasses

Since 2021, APOYOnline has organized several virtual masterclasses to allow a more direct interaction between participants and instructors, which was particularly lacking for those seeking professional development opportunities during the pandemic. In June 2023, we organized the webinar *Introduction to Digital Accessibility* given by Desirée Nobre Salasar who introduced the challenges associated with accessibility, inclusive communication, and Universal Design in cultural institutions (APOYOnline 2023). The August 2023 Masterclass *Why our collections matter: connecting heritage collections and sustainable development* with José Luiz Pedersoli offered useful guidance on utilizing tools to implement *Our Collections Matter* (OCM) protocols. APOYOnline is proud to be one of the partner institutions of the *Our Collections Matter* initiative by the International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM).

Regional conferences

After many years of bringing professionals from Latin America to the USA through the LACS program, we decided to expand the number of beneficiaries organizing regional events in Latin America. The first APOYOnline regional conference took place in Medellin, Colombia in 2016 and centered around the theme *Practical exchange and future projects*. Since then, we have organized conferences in Latin America every other year. These have taken place in La Antigua, Guatemala in 2018 as *Managing emergencies in cultural heritage*; a 30th anniversary conference in Rio de Janeiro, Brazil, in 2019, *30 years building bridges and paths to preserve cultural heritage in the Americas*; and most recently a virtual conference for students and emerging professionals in 2021, *Connect, Empower, Transform: a virtual conference for students and emerging professionals*.

The 2021 conference was the first ever dedicated primarily to students and emerging professionals in the heritage preservation field in Latin America, we are very proud of that. It was a massive challenge as our first virtual event, but overall, it successfully encouraged a wide range of students and emerging professionals to share their work. The program discussed four main topics: vision and trends in cultural heritage; diversity/ equity/ inclusion/ accessibility in cultural heritage; global connections and opportunities; and sustainability in cultural heritage, with two keynote speakers, 24 panelists, 60 papers, 24 posters, 38 sponsors and 30 digital volunteers. The conference included a full day with seven workshops on various topics. It is important to highlight the massive presence of students and emerging professionals (62%) and we are proud to have awarded registration scholarships to all of them.

Conference participants over the years have included curators, archivists, historians, conservators in museums, libraries, archives, historical homes, collections care professionals, teachers, administrators, and scientists, as well as experts in allied professions, such as leadership, marketing, science and technology, and engineering, among others.

Dunia Caridad Rodriguez Pérez (Cuba), first-time attendee at the 2021 4th Regional Conference, wrote:

> The 4th Regional Conference [of APOYOnline] was a valuable experience for me as a professional in charge of Cuban heritage. It provided the possibility of exchanging knowledge and broadening the cultural horizon of the participants. Reflections on the new challenges for future work in cultural institutions, especially in museums, are varied and complex. The master lectures of the specialists (workshops) on the last day of the event contributed to strengthening knowledge and shortening distances. In this sense each of the participants of the 4th Regional Conference APOYOnline became goodwill ambassadors of cultural heritage of the people of our America.

Other activities

APOYOnline is proud to engage in regional social justice initiatives. In 2020 we created a webinar series *Iberoamerica Conversa* about legal recognition of the conservation profession that included 13 Latin American countries in collaboration with the Assembly of Conservators-Restorers of Argentina (ACRA). The impact of the series generated additional discussions at a country level in Argentina and Brazil in 2021 and the videos are available on the APOYOnline YouTube channel (APOYOnline 2021b). For 35 years, we have built a very active network to support professionals in the region, and it continues to grow and generate more networks in each country. This is very gratifying, because APOYOnline is the 'godmother' of many of these networks and new connections, which were born during our activities.

Paid internship program

APOYOnline created a paid internship program in 2020, to respond to the temporary interruption of in-person internships and study projects for undergraduate and graduate students due to the pandemic. Since then, this program has grown and has awarded six internships to students from various schools in the U.S.A. and elsewhere with the support of the Mellon Foundation.

Sarah Hesler (U.S.A.), 2021 intern wrote:

> Participating in APOYOnline as an intern was a tremendous experience that fostered my skills in research, survey-writing, and data analysis. The skills I gained through my internship made me a more desirable candidate for jobs and contributed to me receiving a job offer before I graduated with my masters degree. My internship with APOYOnline served as an extremely valuable experience that helped to jumpstart my career, and I hope to continue working with APOYO in the future!

Special Initiatives in times of crises

APOYOnline has led other special initiatives to help Latin American and Caribbean institutions in times of crisis. For four years, the *Supply Award Initiative* donated materials to select projects in the region with support from US suppliers of preservation materials. More recently, social media has helped APOYOnline coordinate various campaigns in response to natural disasters and emergencies, including supply drives for cultural institutions in Puerto Rico, Cuba, and Brazil. In these instances, we worked with local networks to assess the immediate needs of our colleagues before conducting donation drives to aid in the recovery of damaged collections and personally collected and distributed the materials in the affected areas. We continue to keep in touch with institutions to determine how we can best deploy our community of heritage professionals.

Manos a la Obra

To foster community engagement and participation, APOYOnline created a special community initiative called *Manos a la Obra* (*Helping Hands*) which consists



Figure 3. APOYOnline 30th Anniversary Conference held in Rio de Janeiro, Brazil, 23–27 September 2019. Above: volunteers involved in *Manos a la Obra*. Below: Photography conservation practice during *Manos a la Obra* activities. Image: APOYOnline team.



Figure 4. *Manos a la Obra* at the 2nd Regional Conference held in La Antigua, Guatemala, 23–27 October 2018. Above: Volunteers involved in *Manos a la Obra*. Below: Paper conservation practice during *Manos a la Obra* activities. Image: Beatriz Haspo.

of a call to voluntary action to participants in our regional conferences to assist local institutions in the preservation of their collections. Basic preservation activities are performed working on selected collections and using materials specifically donated to this initiative. Participants have so far carried out tasks like surface cleaning and packaging books, photographs, and negatives, drafting emergency and risk management plans, among other efforts (APOYOnline 2018) (Figure 3).

In 2018, during the 2nd Regional Conference in La Antigua, Guatemala, with the theme *Managing emergencies in cultural heritage* we worked with the Municipal Historical Archive of the City of Antigua (Figure 4). In 2019, during the 3rd Regional Conference, the 30th Anniversary Conference of APOYOnline in Rio de Janeiro, 40 people volunteered at the Public Archive of the State of Rio de Janeiro, working with books, photographs, and negatives (Figure 4).

In 2021, during the 4th Regional Conference, *Manos a la Obra* was carried out virtually for the first time. We worked with technicians from the Biblioteca Ateneo Amantes de la Luz in Santiago de los Caballeros, Dominican Republic, and in collaboration with the Assembly of Conservators and Restorers of Argentina (ACRA) (Figure 5). Over 50 volunteers from the conference participated in the event and shared expertise in surface cleaning, rehousing, preparation for digitization and establishing emergency plans. According to Edwin Espinal, President of the Biblioteca Ateneo, it ' … was the first time the technicians of the library received training in preventive conservation' (Espinal 2021). Testimonies received from participants make it clear that the love for preserving memories knows no boundaries.

The collaboration necessary to develop *Manos a la Obra* events facilitates sharing of knowledge among all participants, with learning through participation and dialog. It makes access to technical information more inclusive, fostering local and regional development and sustainability in preservation of cultural heritage. It transforms individuals and the social perspective provoked by the connections made, empowering all involved. These occasions have encouraged collaboration between specialists in cultural heritage from all backgrounds and increased knowledge of the practical measures that may be taken to assist collections in need.

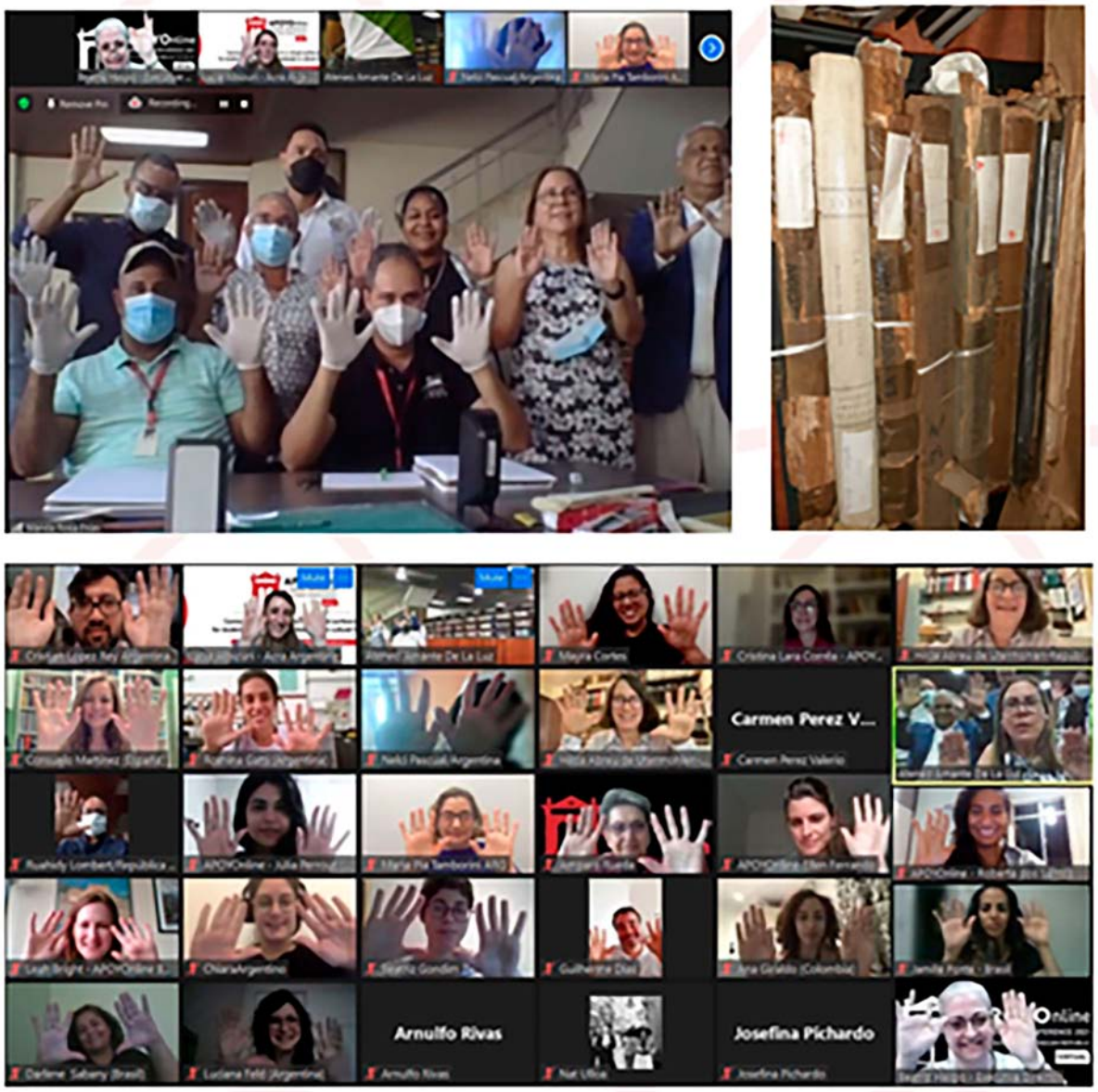


Figure 5. *Manos a la Obra* at the 4th Regional Conference held online 12–15 November 2021. Above: Technicians from the Biblioteca Ateneo Amantes de la Luz in Santiago de los Caballeros. Below: Volunteers involved in the virtual *Manos a la Obra*. Image: APOYOnline.



Figure 6. Experience as APOYOnline grantee in one word (2021), written in the grantees' native languages.

The impact of *Manos a la Obra* goes beyond the institutions benefited in Guatemala, Brazil, and the Dominican Republic. This model of community engagement has served as inspiration for other local initiatives in various Portuguese- and Spanish-speaking countries. It was the inspiration for the award-winning workshop held at the Casa de Monte Redondo Museum in Portugal, carried out by masters and doctoral students in museology from the Universidade Lusofona. This project received the 9th IBERMUSEOS Education Award.[2]

Conclusions: looking forward

APOYOnline work continues to be relevant. It is increasingly evident that the Latin American region continues to be a territory of great cultural inequities,

with some countries making successful efforts for preservation, in contrast to others with scarce opportunities for training, lack of specialized training at local level, and the possibility of direct contact with conservation suppliers. There are many social, cultural, and economic challenges that have a direct impact on museums, libraries, archives, and other institutions that care about memories and the people involved in preservation.

> The work of regional networks enhances the impact of professional development in preservation and allows regional and transatlantic collaborations between professionals from different countries and cultures. While we are feeding the network, we are, in turn, being fed by it and its members, who are living testimonies that the appreciation and love for preserving memories knows no geographical boundaries. (Haspo 2020)

APOYOnline stands as a beacon of sustainable, versatile, and volunteer-driven empowerment in the realm of cultural heritage preservation. Over the past three decades, APOYOnline has conducted successful initiatives including regional conferences, workshops, technical translations, supply donation campaigns, and community-based volunteer initiatives at small institutions. These activities have been achieved through the efforts of our over 250 volunteers who tirelessly contribute their expertise and passion, including the work of the Executive Director. This level of multi-lingual engagement sets us apart in the sector, showcasing the power of collective action (Figure 6). Today, our network encompasses over 6000 members spanning the Americas, Portugal, and Spain, and our training programs have connected and benefited more than 1,200 grantees. Through strategic partnerships, APOYOnline continues to forge connections, uplift communities, and catalyze positive change in our sphere of influence (Figure 6).

We encourage active participation with APOYOnline and use of our network as your platform to connect with colleagues in Latin America, the Caribbean, and Portuguese- and Spanish- speaking countries, expand collaborations, promote professional development, and encourage greater diversity, equity, inclusion, accessibility, and sustainability in cultural heritage preservation. There are limitless opportunities for collaboration to preserve our history and keep connections alive. There is much more to be done and the mission of APOYOnline remains current and necessary.

> Together, the APOYOnline community is shaping a more sustainable and vibrant future for our invaluable cultural patrimony. Through regional partnerships and collaborations, APOYOnline has carried out tangible and successful work to connect, empower, and transform communities and professionals in its area of expertise. And our work continues to be *from* the community, *with* the community and *for* the community!

Notes

1. Argentina, Bahamas, Belize, Bolivia, Brazil, Canada, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Egypt, El Salvador, Guatemala, Haiti, Honduras, Italy, Jamaica, Mexico, Netherlands, Panama, Peru, Portugal, Puerto Rico, Spain, St Lucia, Nevis, United States, Uruguay, and Venezuela.
2. BERMUSEOS is the main cooperation program for museums in Ibero-America, which aims strengthen the more than 10,000 institutions in the region. Since 2010, the Ibermuseos Program has been dedicated to acknowledging and promoting the educational potential of museums by presenting awards that inspire initiatives to enhance the role of museum engagement in Ibero-America. See http://www.ibermuseos.org/en/.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

APOYOnline. 2018. *Manos a la Obra*. Accessed 8 October 2023. https://apoyonline.org/en_US/programs/initiatives/manos-a-la-obra/.

APOYOnline. 2019a. *Scholarships and Grants*. Accessed 8 October 2023. https://apoyonline.org/en_US/scholarships-and-grants/.

APOYOnline. 2019b. *COVID-19*. Accessed 8 October 2023. https://apoyonline.org/en_US/resources/translations/covid-19/.

APOYOnline. 2020. *REALM Project*. Accessed 8 October 2023. https://apoyonline.org/en_US/2021/06/10/realm-project/.

APOYOnline. 2021a. *APOYOnline Strategic Plan (2021–2026)*. Accessed 8 October 2023. https://apoyonline.org/en_US/about/what-is-apoyonline/strategic-plan/.

APOYOnline. 2021b. *Iberoamerica Conversa: Camino hacia el reconocimiento de la profesión en Latinoamérica*. Accessed 8 October 2023. https://www.youtube.com/watch?v=d9sE5NRRkaQ&t=16s.

APOYOnline. 2023. *Guidelines for Digital Accessibility*. Accessed 8 October 2023. https://apoyonline.org/en_US/resources/guidelines-for-digital-accessibility/.

CCI. 2023. *Framework for Preserving Heritage Collections*. Canadian Conservation Institute. Accessed 8 October 2023. https://www.canada.ca/en/conservation-institute/services/preventive-conservation/framework-preserving-heritage-collections.html.

Espinal, E. 2021. Personal communication. 1 November 2021.

Haspo, B. 2020. "Redes de Partilha, Educação e Preservação Patrimonial: 30 anos construindo pontes e abrindo caminhos de integração nas Américas." *Cadernos de Sociomuseologia* 60 (16): 101–115. https://doi.org/10.36572/csm.2020.vol.60.06.



TRU VUE®

ISSN 2047-0584

YSIC 69_S1 Cover_OBC_Mac.indd 1 30/08/24 2:55 PM