CONSERVATION PERSPECTIVES

THE GCI NEWSLETTER

SPRING 2020

CONSERVATION SCIENCE

Getty Conservation Institute

A Note from the Director

Photo: Anna Flavin, GCI

As this issue of *Conservation Perspectives* was being prepared, the world confronted the spread of coronavirus COVID-19, threatening the health and well-being of people across the globe. In mid-March, offices at the Getty closed, as did businesses and institutions throughout California a few days later. Getty Conservation Institute staff began working from home, continuing—to the degree possible—to connect and engage with our conservation colleagues, without whose efforts we could not accomplish our own work. As we endeavor to carry on, all of us at the GCI hope that you, your family, and your friends, are healthy and well.

What is abundantly clear as humanity navigates its way through this extraordinary and universal challenge is our critical reliance on science to guide us. Science seeks to provide the evidence upon which we can, collectively, make decisions on how best to protect ourselves. Science is essential.

This, of course, is true in efforts to conserve and protect cultural heritage. For us at the GCI, the integration of art and science is embedded in our institutional DNA. From our earliest days, scientific research in the service of conservation has been a substantial component of our work, which has included improving understanding of how heritage was created and how it has altered over time, as well as developing effective conservation strategies to preserve it for the future. For over three decades, GCI scientists have sought to harness advances in science and technology to further our ability to preserve cultural heritage.

This edition of our newsletter examines how current scientific research is enhancing the conservation field with new techniques that enable us to get answers to conservation-related questions at a much higher level of detail than was previously possible. This development, in turn, is providing the field with a new range of approaches for practical application, a number of which are highlighted in our four articles. Each article is coauthored by a GCI scientist in collaboration with colleagues around the world.

In our feature, the GCI's head of Science, Tom Learner, Loïc Bertrand (formerly head of IPANEMA at the French National Centre for Scientific Research and now at the Université Paris-Saclay), and GCI associate scientist Catherine Schmidt Patterson offer an overview of some major developments in scientific analysis and testing that have been applied to the conservation field over the last ten years. Our subsequent articles delve into several specific areas where this advancement has occurred.

The scientific characterization of organic materials (used by artists for millennia in their creations) has been advanced with a variety of analytical instruments, a subject explored by the GCI's Michael Schilling, along with Chris McGlinchey (the Museum of Modern Art) and Jennifer Poulin (the Canadian Conservation Institute). Alick Leslie of the GCI, writing with Heather Viles (the University of Oxford), describes an array of cost-effective, simple, and field-portable equipment currently available that can provide reliable data on how historic structures are performing under today's environmental conditions and that can monitor the performance of preservation treatments. The last article, by the GCI's Michal Lukomski, with Emanuela Bosco (Eindhoven University of Technology) and Lukasz Bratasz (the Jerzy Haber Institute), examines several new and effective scientific techniques for monitoring and measuring changes in art objects, which can help define safer conditions for collections.

In our roundtable, three noted scientists—Julie Kornfield (Caltech), Brent Seales (the University of Kentucky), and Sam Webb (the Stanford Synchrotron)—talk with GCI scientists Karen Trentelman and Odile Madden about ways to encourage dialogue between researchers in conservation and scientists from outside the field—a dialogue that could lead to substantive collaboration in research of mutual interest. Such collaboration holds the potential for even greater advancement of science as a bulwark in support of heritage preservation.

Timothy P. Whalen
John E. and Louise Bryson Director

Contents

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ON THE COVER
Researchers at the Rijksmuseum in 2019 using macro X-ray fluorescence scanning to accurately determine the material composition and condition of Rembrandt's painting *The Night Watch*. This analysis is part of Operation Night Watch, the most wide-ranging research and conservation project in the history of the painting, all carried out in view of the public. Photo: Jan-Kees Steenman, courtesy of the Rijksmuseum.

Read this issue and more online at **getty.edu/conservation.**

ADVANCING SCIENCE

BY TOM LEARNER, LOÏC BERTRAND, AND CATHERINE SCHMIDT PATTERSON

The conservation field has seen astounding change in recent years in the applicability and accessibility of scientific analysis for generating knowledge and advancing research. The area of the profession now often termed "heritage science" historically relied on benchtop instruments to probe small, representative samples from cultural objects. Today, however, it engages in the full spectrum of chemical, physical, mechanical, and optical sciences, applied on a broad range of scales, from the macro level down to the nano. There have been significant advances in access to the most sophisticated multimillion-dollar instruments housed in dedicated facilities—as well as in the development of affordable, portable, and noninvasive techniques, which are being applied to more areas of heritage preservation and a wider range of conservation issues.

Scientific analysis informs the practices and outcomes of heritage preservation and interpretation in two broad ways: by accurately identifying the materials used in, or on, cultural objects, and by assessing those materials' properties. However, heritage studies have many constraints, most notably the severe restrictions on taking significant samples—or indeed any samples at all—from highly valued and unique objects or sites. Another common constraint is that the materials in question are seldom found in isolation. Instead, they are usually applied—by artists, creators, or conservators—in combination or in layers, or are modified with trace amounts of other materials (for example, additives contained in commercial products). Also, all materials change with age, environment, and conservation treatment; the associated changes in their chemistry and physical properties can affect their analysis. Of course, these challenges have existed since the advent of heritage science as a field and have consequently driven innovation, especially with regard to instrumental and methodological development.

So what has changed in the last twenty years? While there are many answers to this question, some of the most salient developments are:

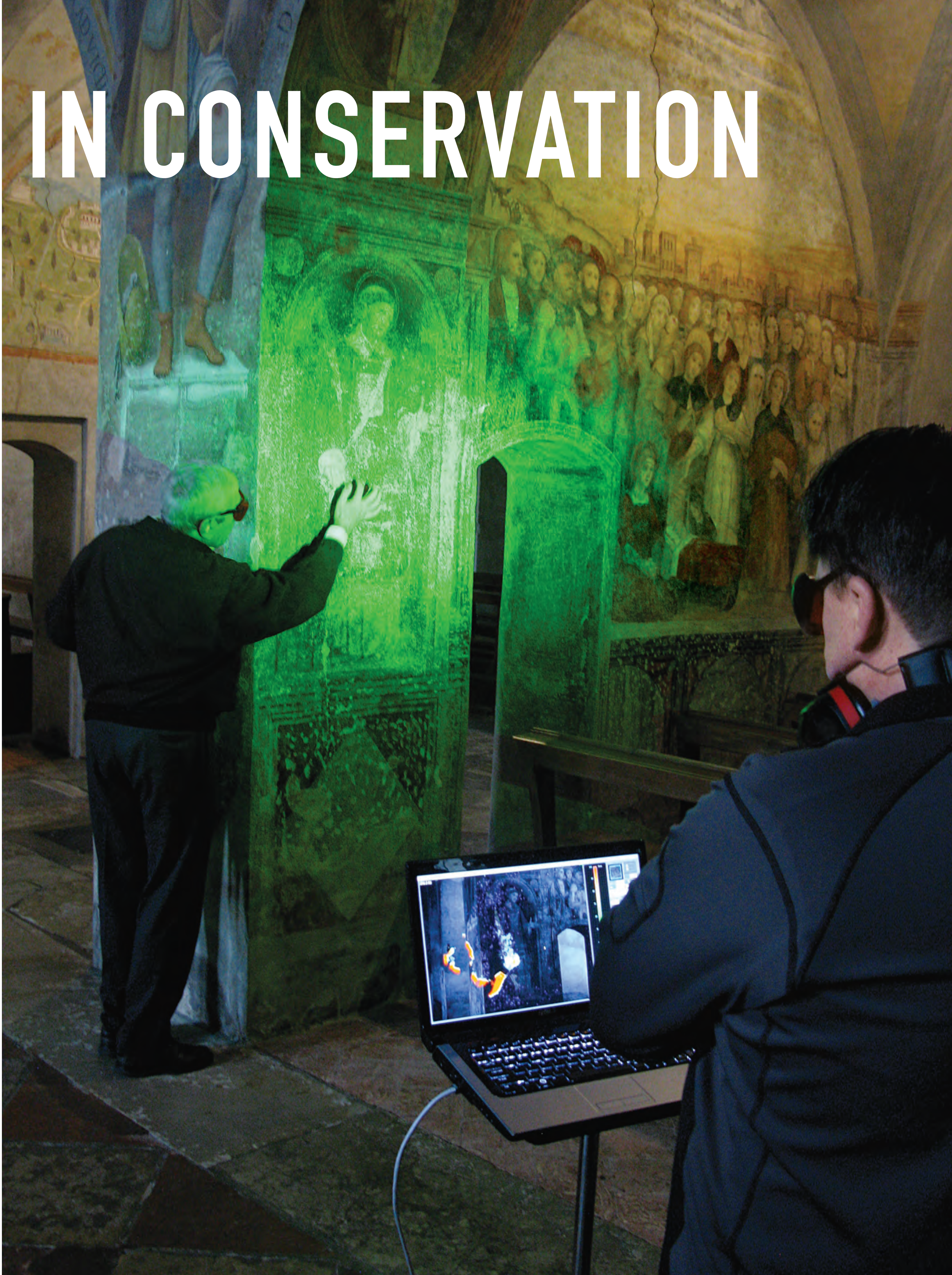
- increases in instrumental sensitivity, allowing much more information to be obtained from smaller and smaller samples;
- the maturing and broader availability of portable (or transportable) instruments, bringing analytical capabilities directly to collections and sites;
- improved contributions from large-scale facilities, such as synchrotrons, enabling analyses with a sensitivity and on a spatial scale not available elsewhere;
- the development of imaging and data technologies that provide new interpretation pathways and that produce data visualizations understandable to a far wider group of stakeholders;
- the emergence of many more cross-disciplinary research projects, where heritage scientists can collaborate and exchange scientific expertise.

MORE WITH LESS: PORTABLE INSTRUMENTS AND MOBILE LABORATORIES

Laboratory analysis is often not possible, because objects of study may be delicate or damaged, stationary and embedded in a site, unable to be sampled, or owned by an institution without in-house analysis capabilities. This challenge has encouraged a dramatic increase in the use of portable or transportable instruments—and indeed in fully mobile laboratories—that can travel to the art or site, conducting in-depth scientific analysis noninvasively and in situ. While instrument miniaturization often results in decreases in sensitivity or spectral resolution, as well as increases in spot size or instrumental noise, it extends the range of objects and sites that can be studied. Many laboratory-based instruments now have portable counterparts that allow researchers to collect elemental data (identification of the chemical elements present), molecularly specific

Laser speckle interferometry being used to assess structural conditions of wall paintings and plasters at the Church of Santa Maria degli Angeli in Lugano, Switzerland, with frescoes by the Italian artist Bernardino Luini. Photo: Francesca Piqué, for the GCI.

IN CONSERVATION



Participants adjust a portable XRF unit before taking a measurement during the GCI's XRF Boot Camp workshop held at the Bonnefantenmuseum, the Netherlands, in 2016. Photo: Stéphanie Auffret, GCI.

data (identification of chemical compounds), or physical properties (such as color or porosity). Portable instruments operate either in a point-based mode in which data stem from a discrete location, or in an imaging or scanning modality in which the data are collected over larger areas.

Portable X-ray fluorescence spectroscopy (XRF) is by far the most widely used form of in situ elemental analysis in heritage science. Even institutions without scientists on staff are willing to invest in this versatile "point-and-shoot" instrument, and there has been a subsequent rise in professional workshops and publications that provide focused training experiences for the expanding range of users. Recent enhancements to XRF instrumentation include decreased (or changeable) spot sizes and improved ability to detect "light" elements (such as aluminum and sodium). Increasingly, the ability to map elemental distributions over small areas (microscale mapping) is being introduced, with several new portable systems available. Laser-induced breakdown spectroscopy is less commonly used, but portable instruments are now available. This minimally invasive technique can remove small amounts of material sequentially, allowing elemental depth-resolved analysis without removal of a complete cross section.

Portable instruments for molecular spectroscopies used to rapidly identify a wide range of organic and inorganic materials, such as Fourier transform infrared (FTIR) and Raman, have also been developed and improved in recent years. A major advancement in portable FTIR has been the introduction of ATR (attenuated total reflectance) systems, which produce more easily interpretable spectra compared to reflectance systems. The development of curved ATR heads —which reduce the contact force with the area being measured down to the lightest touch—has made these systems more compatible with sensitive heritage materials and has proven particularly useful in analysis of polymeric material such as plastics. Raman, near-infrared spectroscopy, and fiber optic reflectance spectroscopy are also being used more frequently as improved instruments come onto the market, and they have expanded the number of materials that can be identified in situ. In recent years there has been an increase in portable instrumentation combining molecular and elemental methods at the same point of analysis—particularly X-ray diffraction (XRD) or Raman spectroscopy with XRF.

The rise in the availability and breadth of portable instrumentation has allowed the development of impressive and truly mobile laboratories that can provide analytical services to an increasing number of institutions and sites. In Europe, building on the success of MOLAB (the first mobile laboratory, established at the University of Perugia almost twenty years ago), there are now at least five such facilities—based in France, Germany, Greece, Italy, and Poland—that provide an impressive suite of analytical capabilities across the entire continent. And, of course, many institutional laboratories and individual researchers use portable and transportable instruments to extend the reach of their work to collections, objects, and sites beyond their home organizations. For example, the Center for Scientific Studies in the Arts in Chicago and the Network Initiative for Conservation Science in New York both partner with other institutions in the United States to provide analytical support to a wide array of research projects. Such programs would not be possible, or as successful as they have been, without continual advancement in portable analytical technologies.

MORE WITH MORE: SYNCHROTRONS AND LARGE-SCALE ANALYTICAL FACILITIES

Another move out of the traditional laboratory in recent years is evident in the increasing use of specialty, multiuser, large-scale facilities for in-depth analyses of objects, materials, and processes relevant to works of cultural importance. Perhaps the most widely used of these are synchrotron facilities. Synchrotrons—specialized particle sources that accelerate electrons in a tightly controlled fashion at very high, relativistic energies—produce superbright light across an extremely broad range of wavelengths to provide the light source for many analyses. The source characteristics offer unprecedented sensitivity and high tunability for chemical analysis, with far greater spatial resolution than is available in traditional lab-based instruments. Synchrotron facilities are research hubs for many fields of science and therefore create opportunities for cultural heritage scientists to interact with colleagues in allied professions.

The key areas in which synchrotron work has expanded in heritage science are spectral imaging (as discussed in the next section), X-ray microcomputed tomography (which provides 3-D reconstructed volumes of samples and small artifacts), and X-ray excitation spectroscopies—in particular, X-ray absorption spectroscopy (XAS), which identifies different chemical forms of an element. XAS has been particularly helpful for studies of pigments and their alteration products in paint layers, and in metallic surfaces and their corrosion; its scope has gradually been extended to almost the entire periodic table, allowing, for instance, the study of sulfur or chlorine in photographs or in wood and metal corrosion products, heavy elements such as chromium and lead in artists' pigments, and rare earths in metallic artifacts.

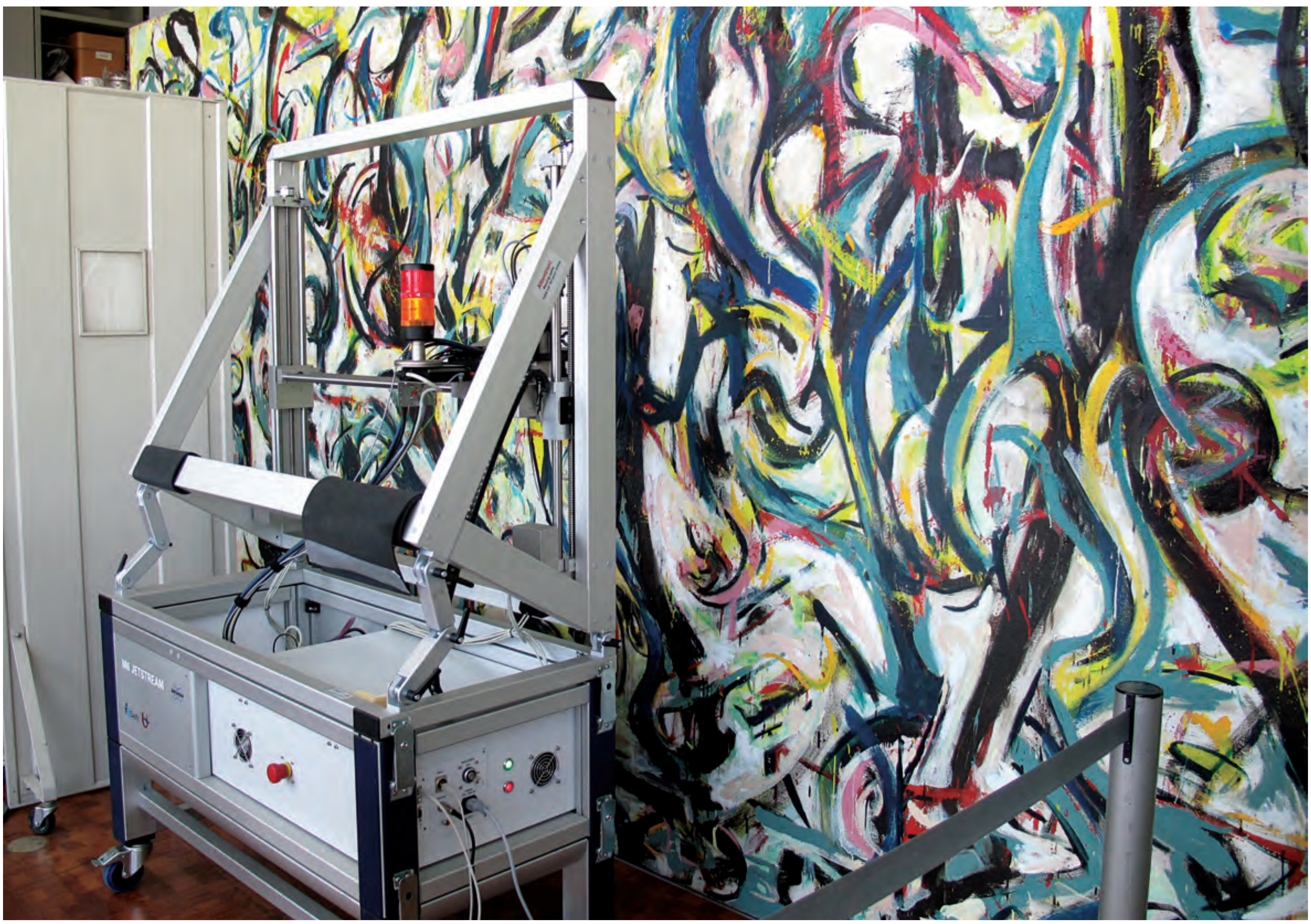
While many synchrotron-based analyses have focused on inorganic systems, methods for analysis of organic materials are also developing rapidly. For example, scanning transmission XAS has advanced greatly over the last fifteen years, and X-ray Raman spectroscopy now provides signatures that allow identification of carbonaceous compounds in a sample. These two approaches are complementary: the first offers nanoresolved information for cross sections that must be thinned down to a few hundred nanometers, while the latter allows compositional mapping of organic materials in two or three dimensions at scales on the order of 20 μm with much easier sample preparation.

Importantly, synchrotron professionals have always welcomed scientists from diverse fields. The FIXLAB program in Europe, which consists of four large-scale facilities in France and Hungary, gives access to conservation scientists, conservators, curators, art historians, and archaeologists from Europe and other countries who seek to deepen their studies through appropriate scientific techniques. The continued development of platforms dedicated to heritage applications (such as the IPANEMA platform at the Soleil Synchrotron) and the expansion of conferences dedicated to synchrotron analysis of heritage materials have contributed to a growing awareness of the research questions for which synchrotron-based methods are appropriate and transformative. This evolution and the consistent presence of heritage science projects and heritage scientists on large-scale instruments allow these researchers' voices to be heard and their needs considered when upgrading instruments. This further encourages cross-disciplinary work and funding at international, national, and even regional levels.

MORE TO SEE: SPECTRAL IMAGING AND VISUALIZATION

Spectral imaging has arguably seen the most striking developments in recent years in heritage science (it was the focus of the Spring 2017 edition of this publication). It has found its way into a wide variety of spectroscopic probes—from the hard X-ray to the infrared—and is transforming portable, laboratory, and large-scale facilities' instruments alike. Critically, examining data in image form often initiates and encourages dialogue among scientists, conservators, and curators. Spectral images provide essential clues about an artist's materials, techniques, and composition, past conservation interventions, and damage, to name just a few applications.

First developed at synchrotrons, XRF imaging recently has gained significant prominence, resulting in a number of new instruments, new research projects, and even specialty conferences focused



Setting up for macroscale scanning XRF analysis of an area of *Mural* (1943), by Jackson Pollock, during its conservation and technical study at the Getty in 2013. Painting: University of Iowa Museum of Art, Gift of Peggy Guggenheim, 1959.6. Reproduced with permission from the University of Iowa. Photo: Catherine Schmidt Patterson, GCI.

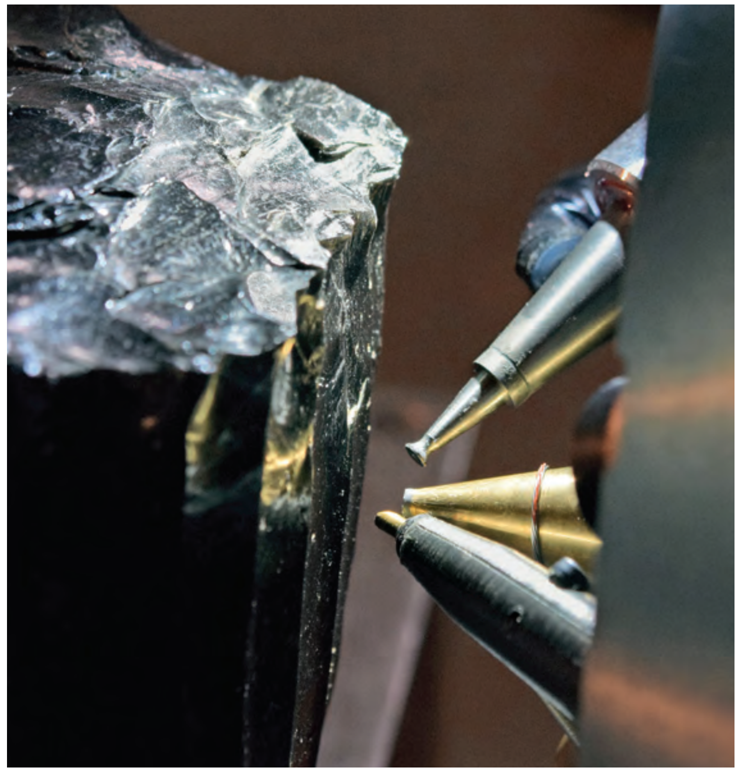
on the technique. Initially reserved for highly spatially resolved studies of the composition of microsamples, it has gradually been extended to the study of entire works of art, first using large-scale facilities (the end stations at synchrotrons), and more recently laboratory and even transportable sources (including handheld instruments). On a painting, the technique produces a series of element distribution images, allowing the inorganic pigments, ground, and driers present to be inferred. Beyond major public operations, such as the scanning of Rembrandt's *Night Watch* at the Rijksmuseum in Amsterdam, the acquisition of XRF scanners by museums around the world demonstrates that they are becoming desirable, if not yet standard, tools for conservators and curators. Commensurate with this interest, the technique currently is evolving through increasingly transportable equipment for use directly in galleries, faster data collection, and better extraction of information through image analysis.

Portable hyperspectral imaging has also risen in prominence. An imaging analogue of reflectance spectroscopy, hyperspectral imaging (also known as reflectance imaging spectroscopy) typically records wavelength-resolved images from around 400–2500 nm. Particularly informative at the molecular level, hyperspectral imaging is even more powerful when joined with elemental XRF imaging; combined analyses have become a recent trend.

Ultraviolet-visible (UV-vis) photoluminescence is another developing imaging method. It records the emission from fluorescence (or phosphorescence) following illumination of a sample or object with UV-vis light. Although data interpretation can be challenging, especially for the complex mixtures and impure compounds in heritage objects, photoluminescence probes are extremely sensitive, and the energy and time decay of these emissions provide critical information about chemical properties. Photoluminescence imaging can identify corrosion compounds and characterize their crystalline defects or trace impurities, which often play a critical role in their long-term reactivity and thus in their degradation mechanisms. Under excitation in the deep UV, organic materials autoluminesce and give rise to characteristic emissions; photoluminescence imaging allows their identification and study with submicrometrical spatial resolution and thus adds a new tool for identifying organic materials.

MORE WITH OTHERS: COLLABORATION, NETWORKS, AND SHARING

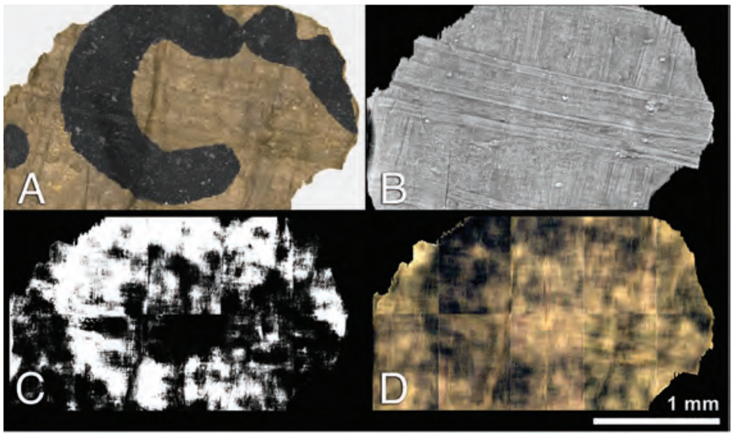
The heritage science profession continues to improve communication and collaboration within the field. A notable example is IPERION HS, a current European research infrastructure program for heritage science that includes twenty-four major research institutes, laboratories, and conservation centers in museums and universities from twenty-three countries; it coordinates research interests, access to instrumentation, education, and outreach. All European partners are funded by the European Union, and many are working toward opening key national research facilities of recognized excellence in heritage science. But the program is also open to non-European partners, and it includes research centers in Brazil, Israel, and the United States, helping facilitate communication and technology transfer within the field.



Ion beam analysis of an obsidian core for blade production from the Final Neolithic dwelling site of Sa Duchessa (Cagliari, Sardinia, Italy), dating from the beginning of the 4th millennium BCE. Photo: © C. Lugliè. C2RMF / Vanessa Fournier. Appeared in "FIXLAB Transnational Access: The Opportunity for Cultural Heritage Scientists to Access Large Scale Facilities," by Claire Pacheco, published in *Techne*.

The benefits of engaging professionals from other fields are also clear. Consequently, in recent decades efforts have been made to encourage dialogue among scientists in fields as diverse as medical research, geology, and computer science, and to take advantage of advancements in those fields. Specialty conferences (such as the Gordon Research Conferences on Scientific Methods in Cultural Heritage Research) and cultural heritage–focused symposia embedded in other scientific conferences help introduce a wide range of researchers to the unique challenges of cultural heritage conservation. Critically, they also stimulate transfer of knowledge and new technologies into heritage research.

For example, several teams have recently developed novel ^{14}C dating protocols of low-carbon-content inorganic materials that are applicable to materials in which environmental carbon is incorporated during manufacture. This is the case for materials as distinct as steels, synthetic carbonate cosmetics, and pigments (manufactured using "fresh" carbon sources). Carbon-14 has a half-life of 5,730 years, making it possible to date objects that are at most several times that age. These new protocols could pave the way for direct dating of objects such as paintings and metal objects, whose dating currently is generally based on indirect contextual or archival evidence. One application of this capability already in use is on works of art created after the late 1950s. The concentration of ^{14}C in the atmosphere doubled from then until 1963—a direct result of atmospheric testing of nuclear weapons in that period. Since radiocarbon is incorporated into all living things—including cotton and flax from which canvas is made, wood from a panel or stretcher, and even the paints made with natural binders—this



Application of a machine learning (ML) pipeline for the identification of carbon inks on papyrus to a fragment from a Herculaneum scroll (PHerc. Paris 2, Fragment 96, shown in A). The ML algorithm extracts information from micro-computed tomography (micro-CT) data (like that shown in B), to predict where carbon ink is located. The predictions (shown in C) are then rendered photo-realistically (as shown in D) for ease of reading. The close correspondence between A and D suggests that this pipeline can capture, enhance, and visualize text even in cases where the ink is *not* visible to the naked eye, as in rolled scrolls. Images originally appeared in "From Invisibility to Readability: Recovering the Ink of Herculaneum," by Clifford Seth Parker et al., published in *PLOS One*.

pulse is an isotopic chronometer of the past half century for canvas paintings. In some cases, the so-called "bomb peak" has been used to date paintings from this period to within a few years.

In another example, nonlinear microscopy techniques developed for examination of melanin in human tissue recently have been directed by Duke University researchers at the challenges of identifying pigments and their degradation in works of art, allowing noninvasive, depth-resolved material examination. The method has been used to image pigments in layered paints, identify organic colorants, and examine the firing temperature of pottery. European research groups have used the unique properties of nonlinear microscopy to study interfaces in varnishes and oils, and to examine parchment degradation. Other particularly exciting developments involve DNA or proteomic analysis, exploiting methods from molecular biology. The sensitivity of new spectrometers used in proteomics allows precise identification of animal species used to make objects (such as leather or parchment for manuscripts), with samples as small as the detritus on erasers used in routine cleaning of such objects.

The establishment of closer links with data sciences is another promising area of active technology transfer and interaction with heritage science. Work is underway on issues as diverse as image recognition, data mining, classification using artificial intelligence, and statistical processing of spectral imaging data. Practices of artists or workshops—such as the consistent use of particular pigment formulations, supports, or artistic gestures across an object or a collection—create specific spatial and spectral signatures in imaging data sets. Though these signatures are often weak and complex, they may provide clues that can inspire new studies. Similarly, when multiple imaging spectroscopies are fused—when the data from multiple techniques are considered as a single data set—new correlations may emerge. Sophisticated statistical analysis and deep machine learning techniques are particularly suited to uncovering such signals and subtle correlations, and they may ultimately support authentication, conservation research, and technical art history.

These techniques need not be limited to two-dimensional objects. For example, computer scientists at the University of Kentucky are exploring the use of neural networks to recognize carbon-based text in the composite layers of rolled, carbonized scrolls from Herculaneum, rendering the text readable without opening the scrolls—even when the chemical signatures of the text and support are very similar. Such areas of research will be invigorated as heritage science data become more accessible to data scientists.

MORE TO COME

It is, of course, impossible to give a full overview here of all the advances changing the field of heritage science. We hope that we have drawn attention to some key areas where developments have been significant.

The progress we have described is expected to continue into the foreseeable future. As more instruments are developed in portable versions, we should expect far greater application to smaller museums, private collections, and built heritage. The challenge of gaining better access to the third (depth) dimension will certainly be further addressed. There likely will be massive progress in advanced data analysis and machine learning technologies that help link scientific material evidence to artistic and conservation practice. Undoubtedly, there will be greater investment in novel ways of sharing data, both with other researchers and with the public, through exhibitions and social engagement, as well as through virtual and augmented reality experiences.

And there will be developments that redefine the field in ways we have not yet imagined. So long as there are researchers dedicated to building collaborative projects to understand and protect our shared cultural patrimony, the scientific community will advance that critical work.

Tom Learner is the GCI's head of Science. Loïc Bertrand is the former head of IPANEMA at the French National Centre for Scientific Research and is now at the Université Paris-Saclay. Catherine Schmidt Patterson is a GCI associate scientist.

Three handheld instruments—XRF, FTIR, and a digital microscope—packed into a 24 × 20 × 12 inch (approx. 60 × 50 × 30 cm) protective transport case prior to travel, allowing elemental, molecular, and visual data to be collected in situ. Photo: Art Kaplan, GCI.

BUILDING ON THE TRIED AND TRUSTED

Recent Advances in Organic Materials Analysis

BY MICHAEL SCHILLING, CHRIS McGLINCHEY, AND JENNIFER POULIN

Analysis of a wood sliver using DART (Direct Analysis in Real Time). Traditional methods for analysis of wood phytochemicals require large samples, tedious solvent extraction protocols, and long analysis times using GC-MS or LC-MS. DART overcomes these problems through its unique design and is being applied in wood species identification. Photo: courtesy of the National Fish and Wildlife Forensic Laboratory.

ORGANIC MATERIALS COMPRISE A DIVERSE RANGE of natural and synthetic products, such as drying oils, resins, waxes, proteins, plant gums, and polymers, as well as a vast number of dyes and organic pigments. Artists have used natural organic materials for millennia in their creations, and since the early twentieth century they have eagerly incorporated plastics and other synthetic organic materials into their work as chemical industries have made them available. Organic materials are also widely used in conservation—for example, as coatings, adhesives, consolidants, and in-painting media, utilized on all types of cultural heritage.

The analysis of organic materials has long been important in cultural heritage conservation. The information produced by analysis leads to improved understanding of how objects were made, how materials may have changed over time, and how to assess the performance of conservation treatments. Organic materials are also generally less durable than inorganics because exposure to light, pollution, heat, and humidity frequently leads to their degradation via a range of chemical reactions. Therefore, the ability to identify them can be a priority when assessing the relative stability of an artwork.

Unfortunately, organic analysis is notoriously difficult and often requires high-end and expensive instruments. The difficulty arises because the vast majority of organic materials contain just three elements—carbon, hydrogen, and oxygen—although a handful of others, such as nitrogen, sulfur, and the halides, also appear regularly. But this means that analytical techniques must differentiate between large numbers of molecules that might be extremely similar in composition. The process is further complicated by the nature of the materials themselves: natural products are highly complex in composition and typically comprise dozens if not hundreds of individual compounds. Commercial synthetic polymers can add another level of complexity in that they often contain a myriad of proprietary additives often present in only trace amounts that can be crucial to the performance and aging properties of that material.

In the last twenty years, a number of new techniques have appeared that build on "tried and trusted" techniques, including Fourier-transform infrared spectroscopy and a range of chromatographies, such as liquid, gas, and thin-layer variations. Because of the complex nature of organic materials and the technological limits of analytical equipment, most analyses are still carried out on microscopic samples removed from objects, although noninvasive techniques are coming into use.

The field has also benefited from advances that have vastly reduced the required amount of sample needed for these techniques, in some cases making the entire process acceptable to owners and curators. This article draws attention to some of the more recent developments already being applied to the field.

FOURIER-TRANSFORM INFRARED SPECTROSCOPY

In Fourier-transform infrared spectroscopy analysis (FTIR), a spectrometer measures the absorption of infrared radiation versus wavelength of a sample. Absorption bands in the infrared spectrum that relate to specific molecular structures are useful for identifying materials. Perhaps the biggest advances in FTIR have been the development of sophisticated sensors that allow imaging across samples, and handheld devices capable of producing high-quality, accurate results for noninvasive analysis. The imaging aspect becomes particularly powerful when comparing FTIR maps of materials to images from light microscopy, fluorescence microscopy, and scanning electron microscopy (SEM). For example, on a cross section from a painting, the comparison of images reveals an incredible depth of information on how a painting was made. Portable FTIR instruments are ideal for noninvasive analysis of objects for which removing samples would be challenging. They have been particularly useful for in situ analysis of diverse museum collections, such as the identification of animation cel paints and plastics, natural resin coatings on photographs, and plastics used for architectural models.

GAS CHROMATOGRAPHY–MASS SPECTROMETRY

Gas chromatography coupled with mass spectrometry (GC-MS) is a very versatile technique for identifying major, minor, and trace amounts of a range of organic compounds. It works best for relatively small organic molecules that have molecular weights below 1,000. Often, before analysis, samples are reacted with chemicals (called derivatization reagents) to improve compound detection by increasing their volatility. Many of the recent advances with this technique have improved GC-MS procedures for characterizing specific classes of organic compounds, and for data processing.

One recent advance is a qualitative procedure developed at the Canadian Conservation Institute for identifying natural and synthetic dyes on textiles, quills, feathers, wood, and leather. The methodology extracts and derivatizes dyes from their substrates with minimal extraction of those substrates. In faded areas of textiles, it is also now possible to detect colorless degradation compounds characteristic of the original dyes. Similar protocols have been developed and applied to the identification of pesticides and wax coatings.

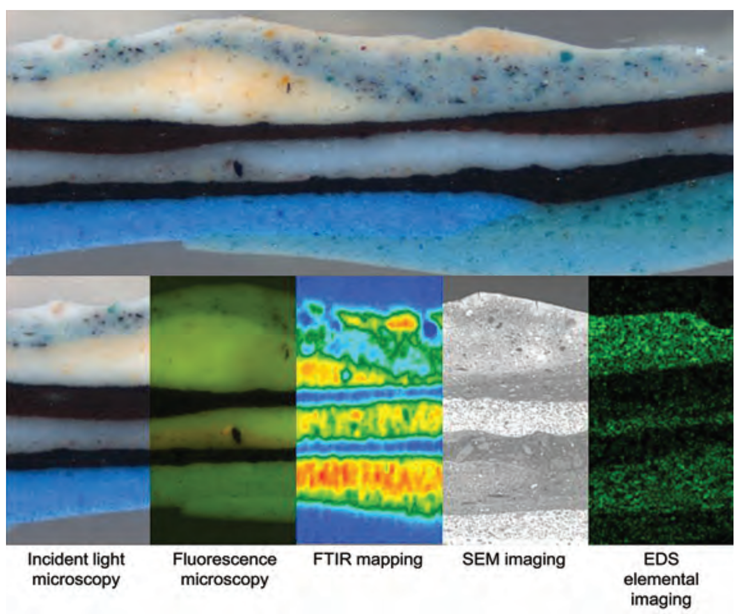
In addition, GC-MS can be used in procedures that identify materials based on quantitative measurements of specific marker compounds. For example, quantitative protocols for identifying proteins, plant gums, and drying oils developed by GCI scientists were used in APPEAR (Ancient Panel Paintings: Examination, Analysis, and Research project), an international research consortium studying the complex natural binding media in ancient panel paintings, particularly Romano-Egyptian funerary portraits. The GC-MS results revealed that most of the portraits were painted with an animal glue tempera medium, not with beeswax as had been expected. This new information is having a major impact on our understanding of these objects.

PYROLYSIS–GAS CHROMATOGRAPHY–MASS SPECTROMETRY

Pyrolysis–gas chromatography coupled with mass spectrometry (Py-GC-MS) is a close cousin to GC-MS analysis. In this variant, the pyrolysis step involves heating the sample to a high temperature (typically around 500ºC–600ºC), permitting GC-MS analysis of polymeric materials, such as plastics and synthetic paint media, which have much higher molecular weights. Data interpretation is the primary challenge in Py-GC-MS, as samples may produce hundreds of compounds when pyrolyzed, and experience is required to recognize and interpret the marker compounds.

One significant and recent advance has been the development of an interpretation tool known as ESCAPE (Expert System for Characterization using AMDIS Plus Excel), created at the Getty in collaboration with researchers from various institutions. In a two-step process, marker compounds are identified in the GC-MS results by AMDIS (Automated Mass Spectral Deconvolution and Identification System, a freeware program developed by the National Institute of Standards and Technology), using the ESCAPE library of reference materials, which currently contains more than 1,500 marker compounds for cultural heritage materials. A custom report template then aids in interpreting the list of marker compounds and presenting the results for the materials identified in the sample. ESCAPE has benefited from experts in Py-GC-MS who shared their knowledge and reference spectra of natural and synthetic paint binding media, decorative lacquers, and varnishes. The whole system makes accurate identification of sample materials possible even for users of Py-GC-MS with limited practical experience.

Developments with Py-GC-MS have also enabled a technique to improve the accuracy of detecting volatile organic compounds (VOCs) off-gassed by materials. The Oddy Test, the traditional method for testing display and storage materials, involves looking for evidence of corrosion on metal strips exposed to the materials for one month in an oven. However, an evolved gas analysis (EGA) method developed at the Indianapolis Museum of Art has proven to be a more rapid and sensitive means for detecting a wide range of VOCs, making it a far more useful and informative tool for museum professionals involved in the design and construction of display and storage cases for works of art.



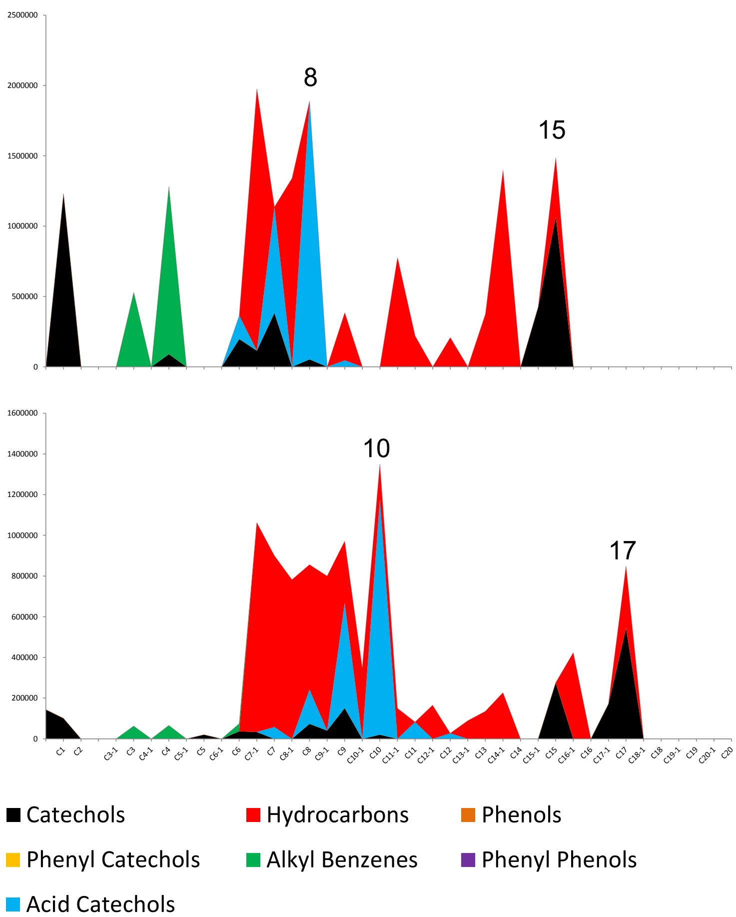
Imaging methods used for analysis of a paint cross section from *Nature morte à la mandoline* (1952) by Jean Dallaire. FTIR and other analytical techniques can produce maps of chemical information across paint cross sections; when these maps are overlaid, many rich details about pigments, binding media, and chemical degradation products are revealed. Image: © Government of Canada, Canadian Conservation Institute.

NONINVASIVE MASS SPECTROMETRIC TECHNIQUES

While it is difficult to imagine creating a noninvasive setup for an instrument that requires a high vacuum, such instruments are beginning to appear. The instrument currently in use for cultural heritage research is DART (Direct Analysis in Real Time) mass spectrometry and is essentially capable of noninvasive "point and shoot" analysis. With DART, an object or a sample is brought up toward the instrument's inlet, and ions are emitted and then recovered from the instrument. The technique is proving particularly promising at distinguishing between previous conservation treatments on a range of substrates—for example, on parchment. In a recent study of parchment, the technique was able to distinguish between castor oil and glycerol parchment treatments. Because of its high sensitivity and simplicity—and since it does not require sample preparation—the methodology can help conservators in the challenging analysis of unidentified treatments on cultural heritage objects.

Although it works best for detecting specific compounds of interest, the DART methodology has also been used to analyze complex samples, such as wood. Genus-level identification is commonly performed by experts in wood anatomy who look for characteristic microanatomical features within wood thin sections under a microscope. However, much practice is required to maintain proficiency with the technique, the procedure is time consuming, and relatively large samples are needed. DART has been shown to be capable of differentiating protected *Dalbergia* species, such as rosewoods, from their tropical hardwood look-alikes by using multivariate statistics to process the complex DART mass spectra and compare sample results to a mass spectral library of vouchered wood specimens. With a method that bridges cultural heritage and forensic science, there is interest in expanding the DART database to include other wood species.

In the conservation studio at the Getty Research Institute, Julia Langenbacher of the GCI conducts FTIR analysis of an architectural model of a proposal for Disney Hall by architect James Stirling. Analysis using portable FTIR instruments can be carried out without the need for sampling, greatly expanding the range of objects that can be studied. Photo: Scott S. Warren, for the GCI. With permission of the Canadian Centre for Architecture, Montreal.



A Gestalt graph of two tree saps used in decorative Asian lacquers. This graph, a key part of the ESCAPE report generated from Py-GC-MS analysis, illustrates the composition differences between marker compounds for the species. This way of reporting data is beneficial for interpretation, enabling a better understanding of regional workshop practices, trade routes, and the extent of chemical degradation. Image: the GCI.

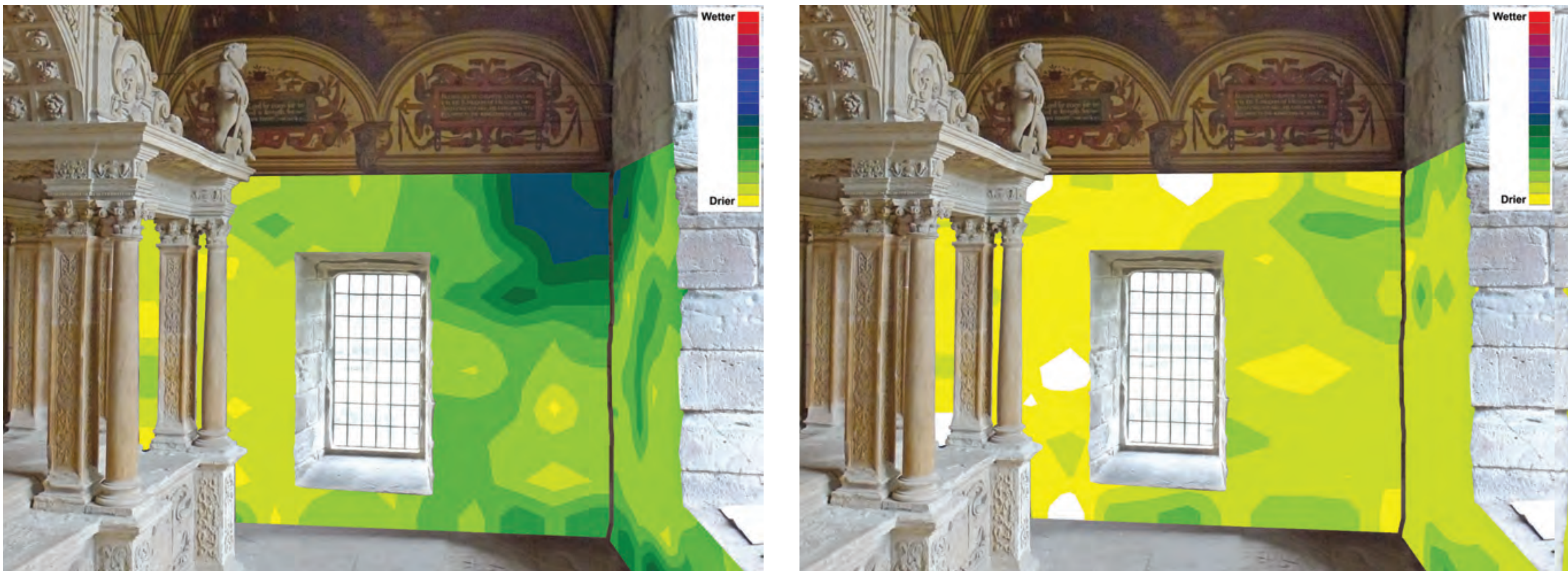
LOOKING AHEAD

If technological advances over the past ten years are any indication, there are indeed exciting new horizons ahead in the area of organic analysis. We can anticipate smaller instruments, enhanced levels of sensitivity, more devices that operate noninvasively, and improved statistical methods for processing complex results. As analysis with noninvasive, portable instruments does not rely on samples, their use expands the amount of information that can be obtained in studies of objects, leading to better assessments of their condition and how they were created. Ultimately, collaborations between scientists and conservators promote data sharing, provide opportunities for dialogue that enhance our understanding of the data provided by analysis, and result in improved approaches to conservation.

Michael Schilling is a senior scientist at the Getty Conservation Institute. Chris McGlinchey is a conservation scientist at the Museum of Modern Art in New York. Jennifer Poulin is a senior conservation scientist at the Canadian Conservation Institute.

THE HANDHELD LABORATORY

Analyzing Building Materials Out in the Field



BY ALICK LESLIE AND HEATHER VILES

AROUND THE WORLD THERE ARE THOUSANDS OF historic buildings in need of preservation to maintain their heritage values and ensure their survival for future generations to experience and enjoy. Many are still in use, including churches, cathedrals, mosques, synagogues, and other religious buildings. Some are abandoned and in ruins, while others—for example, many former industrial buildings—have been repurposed and now have new lives. All face challenges, such as traffic and pressure from tourism, air pollution, and extreme weather events, including storms, floods, and droughts. Many of these structures, built centuries ago, show signs of old age and the wear and tear from long histories of environmental stress.

Numerous institutions are addressing the challenges to preserving such heritage buildings, and many of these are turning to a wide array of scientific instrumentation to help us know more about the materials used within them and about any past interventions or attempts at preservation. These scientific techniques are also required to properly determine how buildings are performing under today's environmental conditions, and to monitor the performance of preservation treatments or repairs in order to evaluate their success. Given the urgent global need to gather this information, the conservation field requires cost-effective, simple, and field-portable equipment that can provide reliable data. A wide array of such techniques is now available, and below we highlight a few of those that are proving particularly useful.

FIELD-PORTABLE DEVICES

What makes an ideal field-portable device for investigating built heritage? In a perfect world, it would be quick and easy to deploy, usable by nonexperts, affordable, rugged, of sufficient power for a day's work, and able to provide reliable data. Also preferable are field-portable devices that do not damage the materials under investigation (such as noncontact instruments and devices that do not require holes drilled in walls). If they are small and light enough to be easily portable, can be left in situ to collect data automatically, and are smart—that is, can send data back to the users and be reprogrammed without the need for repeated site visits—they are even more advantageous.

Unfortunately, we are not in a perfect world with perfect devices, and compromises must be made. To get the very best information, research is now needed into the performance of different field-portable measurement techniques and how they compare with specialized, laboratory-based equipment. As field-portable equipment is often designed with very different purposes in mind (e.g., for mainstream industry), its use in built heritage conservation commonly necessitates testing and careful calibration to ensure that the data generated are of maximum value. In this article, we focus on field-based methods now available for determining material properties, environmental

Microwave moisture maps of a wall inside Skelmorlie Aisle, Scotland. The image on the left shows the relative water content of the wall before repairs in 2013, and, on the right, the reduction in water content in 2017 after repairs were carried out. Images: courtesy of Maureen Young, Historic Environment Scotland.

influences on deterioration (notably moisture dynamics), and the performance of surface treatments (especially on surface permeability).

Characterizing the properties of materials used in the construction and repair of historic buildings usually requires obtaining small samples, taking them back to the laboratory, and subjecting them to a series of often-destructive techniques to measure their chemical constituents, porosity and permeability, compressive and tensile strength, and other key indicators of their nature, provenance, and durability. Ideally, many samples should be taken and analyzed to get a representative picture, but taking even small samples from many heritage sites is often a contentious issue; furthermore, it is time-consuming to get all the analyses done in the laboratory. However, there are now many field-based alternatives that can provide relevant information. For example, microscopes can be attached to the USB port of a laptop and offer a very detailed view of the surface of building materials, enabling preliminary identification of minerals, paint layers, and other constituents.

One type of device that has proven particularly promising for field-based characterization is the rebound surface hardness tester (sometimes called a portable hardness tester or durometer). The hardness is calculated from the ratio of rebound to impact velocity—harder materials have higher ratios. Surface hardness is a good predictor of material strength and can also be used to infer the degree of deterioration on surfaces that have been exposed for long periods. The test is nondestructive, quick, and easy to perform, allowing mapping of surface hardness across large areas of the surface.

To look at properties deeper in a building or stone, Ultrasonic Pulse Velocity (UPV) and ground-penetrating radar (GPR) can be used. UPV sends a pulse of sound through a material, and the speed of the sound waves can indicate the consolidation or strength of the stone, so that damaged areas can be identified. GPR also uses a pulse of energy, but the way in which this energy is reflected deep within the building gives information about its structure.

ANALYSIS AND MONITORING

Apprehending the decay currently affecting historic building materials usually involves understanding their interaction with moisture, as water is involved in the great majority of decay processes. Standard meteorological monitoring equipment is not designed to measure rainwater hitting building surfaces, nor how it gets transported into the surface, runs over it, or evaporates from it. However, a range of inexpensive and simple handheld devices can provide a decent understanding of moisture dynamics across and within historic walls. Such devices do not measure water directly, but rather assess properties of porous materials that are themselves influenced by water contents—such as electrical resistivity and capacitance.

One promising method—microwave moisture measurement—is based on sending a pulse of microwaves into a porous material and measuring how the microwaves are reflected at different depths within the material. The water content of the porous material affects the microwave reflection, and thus the wet and dry areas in the material can be detected. The method is noninvasive and generates data quickly, and the equipment is easily portable. It is particularly good at mapping near-surface moisture content and can be used, for example, to monitor moisture ingress and drying after storms.

Monitoring the performance of surface treatments over short or long periods involves repeated measurement of key aspects of the material properties, such as permeability, water repellency, surface roughness, and color. Ideally, surface treatments should prevent or reduce loss of material while at the same time allowing water and air to pass through the material. If a surface is treated and becomes impermeable, this can speed up decay of the untreated material beneath, with serious consequences for the structure's longevity. Therefore it is important to know how permeable a surface is before and after treatment.

Air permeability can be assessed on-site with a range of field-portable permeameters, although their measurements can be influenced by surface conditions. Moreover, the data are not as reproducible as data gained from larger, laboratory-based systems. Nevertheless, the advantage that these devices can be used easily, quickly, and nondestructively more than compensates for their data drawbacks.

While portable analysis equipment is being developed and improved, there remains an increasing need to coordinate analysis and research to maximize the benefits to built heritage. How will this be achieved? The first coordinated efforts were truck-based mobile heritage laboratories, which now exist in some countries in Europe. Such mobile laboratories, often called MOLABs, can carry a wide range of equipment, much of which is nondestructive, that can be taken to sites where sampling cannot be carried out.

Researchers at the Getty Conservation Institute and the University of Oxford are making good progress in evaluating the usefulness and performance of a range of field-portable devices deployed on-site by professionals. But they—and many others in the field—are also starting to think a bit bigger. Is an entire mobile research facility for built heritage feasible? What would it look like, and what equipment would it contain?

In Spain, for example, researchers from the University of Granada are collaborating with colleagues from Europe and the United States to provide analytical equipment to assess consolidation work at the World Heritage Site of the Alhambra, much of which was built from unfired earth. Consolidation of the structures at this historic palace and fortress presents particular challenges, and novel techniques using calcifying bacteria to stabilize walls are being trialed, with tests using a range of nondestructive analysis methods.

WHAT'S NEXT?

Across the world, academics and conservators are finding innovative ways to generate data that help in the conservation of important architecture, while at the same time minimizing disturbance to the historic materials. It is now commonplace to carry out analysis without having to take samples. With improvements in communications and instrument design, it soon might be possible to analyze and monitor building performance without having to leave the laboratory at all.

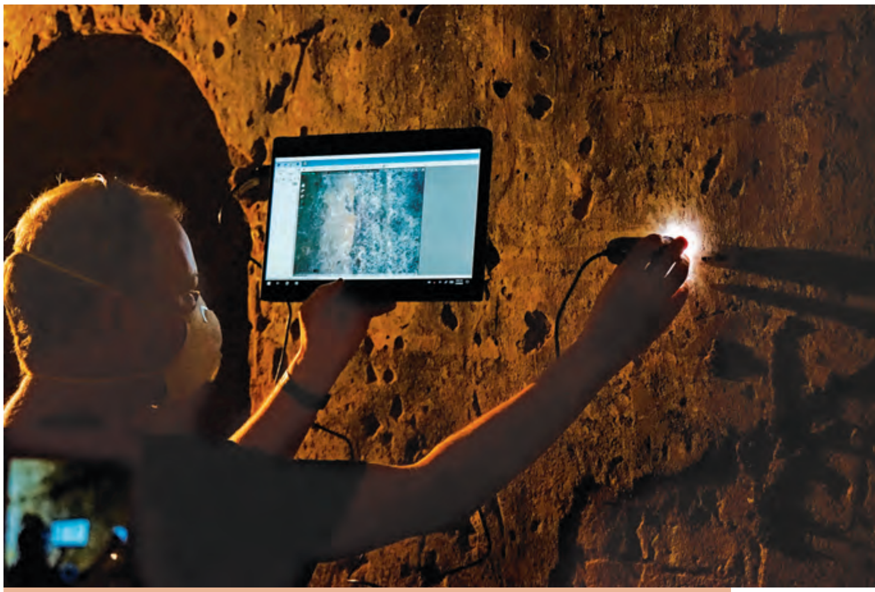
Maybe "smart heritage" is the future for built heritage conservation research.

Alick Leslie is a senior scientist at the Getty Conservation Institute. Heather Viles is a professor of Biogeomorphology and Heritage Conservation at the University of Oxford.

FIELD-PORTABLE DEVICES are being employed in a variety of situations around the world. Below are just two examples—the first, a project that has already lasted decades, and the second, a long-term initiative just getting underway.

At the Fraunhofer Institute for Building Physics in Holzkirchen, Germany, a number of complex-geometry sandstone samples were created as part of a long-term trial begun in the 1980s. These samples—known as "Asterixe" because of their resemblance to the face of the French cartoon character—were exposed to the environment as part of a German government-funded project to understand the deterioration and conservation of key historic building materials. Today, they form an invaluable archive of samples with known environmental histories encompassing over thirty years. Analysis of the samples using a range of field-portable devices, including an air permeametry device, is providing critical data on the decades-long performance of sandstone. As the Asterixe were kept for prolonged periods in different places (a heavily polluted urban area and a rural setting close to the Alps), the effects of different environments and pollutants can also be assessed, making these carved stones a significant resource for research into stone decay.

Davide Gulotta of the GCI testing a field-portable air permeametry device at Holzkirchen, Germany, where sandstone samples were exposed to the environment as part of a German government-funded project to understand the deterioration and conservation of historic building materials. Photo: courtesy of Katrin Wilhelm, University of Oxford.



Alick Leslie of the GCI using a USB microscope and laptop to examine decorative surfaces in a temple at Bagan in Myanmar. Photo: Davide Gulotta, GCI.

In early 2020, the GCI's Built Heritage Research team joined the recently launched Bagan Conservation Project, a ten-year initiative between the Getty Conservation Institute and Myanmar's Department of Archaeology and National Museum (see p. 26). The project aims to develop a holistic and sustainable approach to the complex conservation and management challenges facing the vast Bagan archaeological site, which is home to over 3,500 temples, stupas, monasteries, and archaeological remains, many of which are decorated with wall paintings, sculpture, and stucco. The initiative includes repair and seismic retrofitting of monuments; conserving decorated elements; recording, documentation, and information management; site management; and the training of local professionals. The contributions from the Built Heritage Research team will be varied, including documentation of original materials, assessment of historic repairs, and monitoring of new interventions. The work will primarily involve nondestructive analysis using field-portable devices—the most practical analytical devices that can be utilized at a site like Bagan.

HELPING TO SAFEGUARD COLLECTIONS

Measuring Mechanical Behavior at the Microscale

BY MICHAL LUKOMSKI, EMANUELA BOSCO, AND LUKASZ BRATASZ

SLOWING OR PREVENTING PHYSICAL CHANGES IN art objects is a fundamental, and often challenging, aim for collections preservation. Deterioration factors such as light, temperature, humidity, pollutants, shocks and vibrations, and material fatigue all must be understood, quantified, and mitigated.

Until relatively recently, most of the analytical techniques available for the evaluation of physical and mechanical properties required extremely large samples and moreover resulted in the total destruction of the sample—clearly a problem for assessing the properties of an actual artwork.

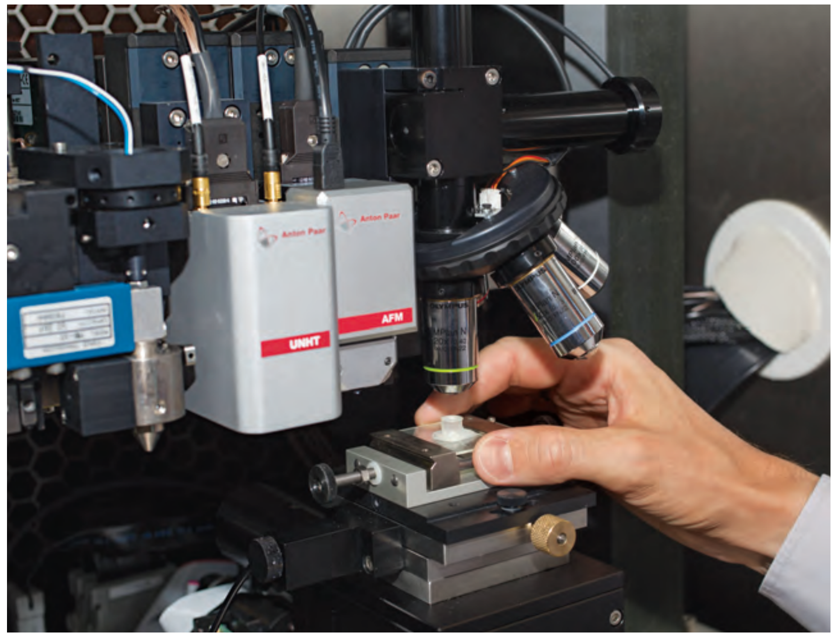
In the last decade, however, new and effective scientific techniques for monitoring mechanical response and measuring physical properties have appeared, and many of these are now being applied specifically to works of art. These techniques include a number that can be directly employed on objects, such as acoustic emission, and others that can utilize small sample sizes, such as atomic force microscopy and nanoindentation. These two high-resolution techniques allow the measurement of detailed mechanical behavior and characterization at the micro- and nanoscale directly on historic material, such as paint cross sections, that can be correlated with accompanying chemical analysis.

NEW TECHNIQUES

Applied to any investigation into the effects of environmental conditions experienced during exhibition, storage, and transportation, these new monitoring and measuring methods can help reveal how changes in the preservation state of art objects may have been caused by specific agents of deterioration, and thus they help define safer conditions for art collections. Furthermore, even though the process of deterioration is largely driven by chemical reactions, these usually result in changes to material properties at the microscopic scale. Mapping these material properties at a microscale resolution can aid in the development of models simulating deterioration.

Acoustic Emission

Acoustic Emission (AE) monitoring is a method of tracing micro damage in situ for objects exposed to potentially harmful conditions.



From left to right: microindenter/scratcher; ultra nanoindenter; atomic force microscope; and optical microscope, inside a climatic chamber. A cross-sectional sample is under the optical microscope. Photo: Evan Guston, for the GCI.

The brittle cracking of any material triggers the release of energy in the form of ultrasound waves. These waves propagate through the material and can be recorded by piezoelectric sensors positioned on their surfaces. The technique is robust and highly sensitive, capable of operating in harsh environments and detecting crack initiation and growth at a micrometrical scale. It offers high temporal resolution, whereby individual AE events lasting several microseconds can be digitally captured and processed in real time.

AE has been applied in industrial and academic research to investigate crack propagation, yielding, fatigue, corrosion, and stress corrosion when monitoring objects of critical importance, such as liquefied natural gas storage tanks, bridges, and airplanes. The noninvasive character of the measurement, together with its high sensitivity, makes the method extremely attractive for directly monitoring damage on heritage objects. Crucially, it has the potential to act as an early warning system, informing staff that environmental events may be contributing to microdamage in the collections they care for *before* an actual crack appears. Furthermore, AE monitoring results can be used to inform the development of environmental control strategies by verifying the validity of models that predict object damage.

An experimental program aiming to explore the response of historic objects to changes in relative humidity was recently conducted at the Getty Conservation Institute as part of its Managing Collection Environments Initiative. The study combined the application of AE monitoring with physical measurements and photographic documentation of various historic, nonmuseum wooden objects subjected to controlled environmental stresses. Rather than using mock-ups, the study utilized wooden objects representative of a museum collection but purchased from antique stores or donated to the project.

One striking result of this test was the very low level of AE activity for objects previously exposed to large climatic variations. It clearly supported the "proofed fluctuation" concept, which states that there will be no further mechanical damage to an object if the environmental fluctuations are kept within those previously experienced.

Atomic Force Microscopy

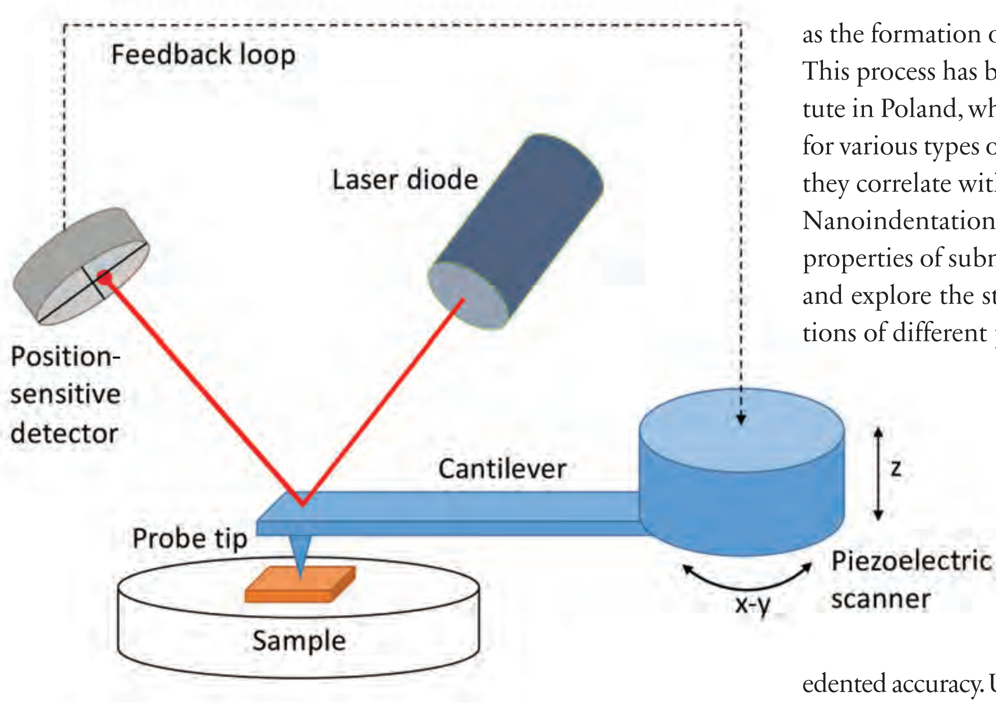
Atomic Force Microscopy (AFM) is a technique that allows the measurement of surface characteristics of a material at the nanoscale. It is a type of microscopy that scans a surface with a probe instead of light, resulting in a resolution in the order of fractions of a nanometer—more than a thousand times smaller than that of an optical microscope. Essentially, it works by scanning a surface with a cantilever with a very sharp tip. As the tip approaches the surface, the close-range forces between the surface and the tip cause the cantilever to deflect very slightly. These tiny deflections can be detected by a laser beam, and properties such as hardness and stickiness are then measured across the surface.

AFM can be particularly useful for assessing the adhesion of materials. The technique was recently employed to analyze the adhesion of paint to the plastic substrates used in painted animation cels to help formulate recommendations for storage conditions. These cels, used in the production of animated movies, consist of gum-based paints applied to thin, transparent sheets of cellulose acetate plastic. The paint on these cels exhibits a range of conservation issues, such as cracking and delamination. By analyzing the pull-off adhesion force at the nanoscale when exposed to a range of relative humidity conditions, it was possible to demonstrate that the adhesion properties for the paint surface exhibit a dramatic change above 65 percent relative humidity. A major advantage of AFM is that the material properties of submillimeter samples taken from artwork can be analyzed in a virtually nondestructive way—no chemical alteration and minimal physical impact—allowing the sample to be used for subsequent testing.

AFM is also an ideal tool for analyzing the topography of a sample surface by scanning a region of interest with the cantilever in contact with the surface. By combining force measurements and topographical imaging, AFM can inform us about the distribution, size, and mechanical properties of different materials within a sample. Such information can also be used in the modeling of chemically induced changes on the sample surface.

The technique was recently employed to study the growth of metal soaps in oil paints. Metal soaps are formed by chemical reactions between certain metal ions present in pigments and the saturated fatty acids found in the oil binder. Initially amorphous, these compounds ultimately crystallize into relatively large protrusions that can deform and crack the surrounding paint layers. Much effort in the field has gone into understanding the chemistry of this process, but until recently it was not possible to correlate this chemistry to physical phenomena, such as crack formation and propagation. Metal soaps have been observed to form around preexisting crystal nuclei that undergo chemically induced growth, building up stress fields in the paint layer. When local stresses are higher than a critical value, they cause crack formation and propagation. This process has now been modeled by scientists from Eindhoven University of Technology in the Netherlands. The simulation of this fracture process enables the description of developing complex crack patterns at the surface of the painting. The high resolution of AFM allows it to localize soap protrusions on a sample surface and measure their size and mechanical properties, such as stiffness and viscosity.

Michal Lukomski and Vincent Beltran at work on a study by the GCI exploring the response of historic, nonmuseum objects to changes in relative humidity. The study combined acoustic emission (AE) monitoring with physical measurements and photographic documentation of the objects, which were subjected to controlled environmental stresses. **Detail: Close-up of the AE sensor on one of the objects**. Photo: Evan Guston, for the GCI.



A diagram of Atomic Force Microscopy, a technique that allows measurement of surface characteristics of a material at the nanoscale. Graphic: Michal Lukomski, GCI.

Nanoindentation

As its name implies, nanoindentation operates at the same size scale as AFM, but it has significant advantages with respect to the accuracy and precision of the results. Because of the high stiffness of the measuring frame and precise control of the force and deformation, nanoindentation can provide, to a much greater extent than AFM, quantitative information about measured surface properties. It is essential when exact values are needed to model the behavior of an object at the macroscale. Standard nanoindentation tests press a probe with a well-defined geometry into a sample in a controlled manner. The force-displacement curve produced by this indentation serves as a "mechanical fingerprint" of the material, from which quantitative properties such as stiffness and viscosity can be determined.

Although typically used to examine nonviscous homogeneous media, nanoindentation can record changes in material properties for soft materials such as paints or plastics. These changes in material behavior can result in the cracking and deformation of art objects. An example of this process is the rapid and extensive deformation of Marcel Duchamp's *Little Large Glass*, owned by the Yale University Art Gallery. This object's deterioration was modeled by assuming a cross-sectional stiffness gradient in the cellulose acetate film (due to the migration of plasticizer toward the surface of the film). As a consequence of this gradient, temperature and humidity variations result in nonuniform swelling and shrinking, and this, in turn, leads to severe deformation of the object. To refine this model, nanoindentation was used to quantify the stiffness gradient in a submillimeter cross-sectional sample taken from this Duchamp artwork.

Micromechanical material characterization can also play an important role in understanding different damage processes, such as the formation of craquelure patterns on the surface of paintings. This process has been the focus of research at the Jerzy Haber Institute in Poland, which has sought to elucidate the formation factors for various types of craquelure patterns in order to understand how they correlate with the material properties of these cracking layers. Nanoindentation can be employed to determine the mechanical properties of submillimeter cross-sectional samples from paintings and explore the statistical variability of these properties for collections of different provenance or history.

ADVANCING THE FIELD

Novel techniques for micromechanical characterization are advancing the field of art conservation by providing a more thorough understanding of the physical properties of artistic media and enabling the evaluation of new conservation procedures with unprecedented accuracy. Using techniques such as Acoustic Emission enables direct monitoring of micro damage development in art objects, while Atomic Force Microscopy and nanoindentation have provided the capability to directly characterize the mechanical properties of small-scale samples, to a degree that was previously unattainable.

Investigating the use of these techniques is ongoing, with particular emphasis on the combination of all three. The best means of quantifying the risk of environmentally induced damage is to couple correlations with external conditions (provided by AE) with insights into the mechanical properties of the materials present (provided by AFM and nanoindentation) that make the object vulnerable to change.

These breakthroughs facilitate the exploration of numerous research questions, including the effect of aging on the materials found in cultural objects and the impact that changing environments have on the mechanical behavior of these materials. It is expected that use by the field of these micro- and nanoscale techniques will increase in the near future, finally allowing heritage scientists to measure, monitor, and correlate chemical changes with mechanical properties of materials. These advancements have the potential of adding a completely new dimension to our understanding of the materials that make up our cultural heritage.

Michal Lukomski is a senior scientist at the Getty Conservation Institute. Emanuela Bosco is an assistant professor in the Chair of Applied Mechanics and Design at Eindhoven University of Technology. Lukasz Bratasz is a professor at the Jerzy Haber Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences.

DIALOGUE AND COLLABORATION

A Conversation about Science and Conservation

JULIE KORNFIELD is professor of chemical engineering at the California Institute of Technology. A fellow of the American Physical Society, American Association for the Advancement of Science, National Academy of Inventors, and National Academy of Engineering, her work ranges from fundamental research on the molecular basis of polymer structure and properties to commercialization of polymers that improve health and safety.

BRENT SEALES is professor and chairman of the Department of Computer Science at the University of Kentucky and a 2019–20 Conservation Guest Scholar at the GCI. His research includes applying data science and computer vision to challenges in the digital restoration and visualization of antiquities.

SAM WEBB is a staff scientist in the X-ray imaging program at the Stanford Synchrotron Radiation Lightsource (SSRL), a directorate of the SLAC National Accelerator Laboratory. His work involves developing the microscale imaging beam lines at SSRL and ways these micro X-ray techniques can be applied to research projects in the biological, medical, environmental, and heritage fields.

They spoke with GCI senior scientists **KAREN TRENTELMAN** and **ODILE MADDEN**, and **JEFFREY LEVIN**, editor of *Conservation Perspectives, The GCI Newsletter*.

JEFFREY LEVIN One of the things that researchers in conservation have increasingly sought to do is to engage scientists from outside the field in research of mutual interest. How can cultural heritage scientists and other scientific researchers best develop collaborations that are beneficial to both?

JULIE KORNFIELD My colleague Kathy Faber, who worked with the Art Institute of Chicago to establish a collaboration with scientists at Northwestern University, said it was through dialogue. The scientists were actually surprised at some of the ways they could contribute. The more they got into it, the more they were fascinated, and the more they collaborated. Conversation between conservators and scientists allows ideas to grow organically. People do not anticipate going into a meeting what will come out of a meeting.

SAM WEBB My job at the Stanford Synchrotron is essentially collaborative research. I find interesting projects and interesting collaborations where someone has an idea to try to examine something with a particular material, and that often just builds and builds. A whole new area of development can grow from one painting or pigment sample.

KAREN TRENTELMAN In your work, what are the challenges in bringing about collaboration between people at universities and people in cultural heritage institutions?

WEBB Being with the Department of Energy, it's often difficult to say where a cultural heritage sample fits into the National Lab's portfolio of interest. But a lot of what we're doing in cultural heritage is looking at material and chemical properties, which is often independent of a specific field of study. My collaboration with battery developers from Germany has actually dovetailed into my work on sulfides in lapis. It's natural that the work we do helps both the battery scientist and the cultural heritage scientist. As the person in the middle, I see people in different fields working on common problems, and I can say, "I looked at this problem two weeks ago with these battery people, and we approach the solution this way." Being that middle person, I get experience from the material science community, the cultural heritage community, and the biological community—and that's how we find beneficial solutions for all those communities.

KORNFIELD I find it fascinating that someone who's the master of certain measurement techniques can cross-pollinate from different areas of technology to cultural heritage.

BRENT SEALES The computing field has matured over the last fifty years, and the frontier in computing is really the diffusion of these techniques into other areas. That's premised on collaboration and dialogue. Computer scientists learn where there's overlap and where there are new problem areas by talking to heritage scientists, so dialogue is important. I've seen computer scientists become well versed in conservation science, and this blend becomes its own kind of field. That's how these things organically emerge. It's exciting to watch the diffusion of computer science into different fields,

Photo: Charles Ng, Time on Film.

> I think when a scientist hears that there's a need and they're able to help link it to a solution, they actually experience a moment of joy and excitement. They want to get involved.
>
> JULIE KORNFIELD

including heritage science, imaging science, machine learning, and artificial intelligence.

ODILE MADDEN Do all of you find that that addressing a cultural heritage question can sometimes spark ideas about your other projects? That it works the other way?

WEBB Definitely. Cultural heritage material analysis can feed back into new research in other areas. I wasn't involved in this, but there was research on Egyptian blue—a great pigment, but also a really good infrared re-emitter. It's actually being used for green building materials. That's a cultural heritage material that is now feeding back into modern technology and building materials. On the computer side of things, from the perspective of our large-scale user facilities, we have all these massive data sets, and we spend 99 percent of our time with the human eye trying to extract all the information out of them. Now we're turning more and more to different computing techniques to sort through this data, and it's amazing what we can learn.

KORNFIELD I'm wondering if some of the progress that's being made would allow you to do things like accelerated aging on computer, where you otherwise may not be able to assess a hypothesis that requires a thousand years to test.

SEALES The way computing resources have matured over the last five years to do what we're calling "at-scale computing" is going to open up all kinds of simulations if we can get the models right. But that's where the collaboration is so important—talking with material scientists who understand what the model should be and then with the computing scientists who can make that happen in a cloud-computing kind of environment, for example.

WEBB The grand challenge, across many disciplines, is how to make a model that can capture the chemistry or the environment we want to look at from a cultural heritage aging sense or from a reactive transport and geological materials standpoint. We're working on understanding the material on the nanoscale, the microscale, and the macroscale. There are so many scales of interest that we see phenomena occurring on. And they're all critically important. To model that properly, you need a massive computing environment to capture all of those scales and processes.

SEALES We've done pretty well at modeling phenomena within one of those areas, but how do you connect them all together to see certain macroscale effects in a realistic way? It's hard.

TRENTELMAN Computing is obviously at the forefront of technology. What about new materials?

KORNFIELD My perception of the post–World War II period—and this is from someone who's not an expert at all—is that after World War II artists became very interested in expressing themselves. They adopted new materials, unconcerned whether or not the work survived after their lifetime. Whereas if you were to wind the clock back, art was driven by patrons who might think in a grandiose way, like a pharaoh, whose attitude was, "Make me beautiful art, and it better be here a million years from now." As a result, we had centuries of stonework and paintwork and glasswork that were meant to last far beyond a human lifetime. How those people could do it without having survived more than one lifetime themselves, I do not know! But when conserving post–World War II art, it's difficult because some artists chose materials that weren't intended to last a hundred years, much less hundreds of years. It raises the whole question of whether we should conserve the aging of the material. Should we allow people two hundred years from now to see what two hundred years of aging does to the material and how it alters the artist's initial conception?

MADDEN With something that's been around, say, from the time of the pharaohs, the materials have self-selected. What was going to go is gone, and we conserve the survivors. Now we deal with new material, such as synthetic polymers, that are expected to improve through an iterative process in which failures reveal themselves. Because we have to conserve the older aged artworks and the recently made ones—the unstable and the stable alike—we are stewarding in a way that conservators of ancient material are not. I do wonder if artists, when working with new materials, think about their permanence.

SEALES With all we know about materials, I wonder if we should be more prescriptive to the people who are making art, so that it can last—and also catching the process using digital means. How much influence should the materials and the digital issues have on the people who are making art, and then expecting it will last a long time—or not? Because there is the Banksy-inspired mindset that self-destruction is also art. You're not going to stop that, but for work that people are commissioned to do to create truth and beauty in art, we probably could be more prescriptive. And the artists themselves may not be aware, right? It's an interesting point.

MADDEN There are some who think the idea that we should offer to consult with artists about their technique is an inappropriate intrusion into the artistic process. Of course, there are certainly many art traditions over the ages that have evolved into standardized practice.

WEBB When we talk about technology and conservation, I think about modern art and digital media. We may no longer have the ability to read or display art produced using technology from ten years ago. We have to think about how we conserve that work in the future and keep it going in more modern digital material or keep it as the artist intended. It boggles my mind as to where we go with the very vast open-ended questions related to technology and conservation.

SEALES The digital has the same problems, although we can be a little more prescriptive on the computing side because we have standards that people may more readily accept, such as the storing of an image in a standardized and portable way so that it can be transferred into social media.

MADDEN What time horizon do you see when you're talking about preserving your own data in the lab or the concept of an image being stable?

SEALES When you walk into a museum, you can see things that are two thousand years old. And then you go back to your desk and type on something that's going to be obsolete in a year—or even sooner. And then you store your files with a company that in six months is going to go IPO and be a new company. It's hard to get your head around that! I think of preservation on a pretty short timescale because I'm a computer scientist, and things have moved so quickly for my entire career. It's a continually changing landscape. The conservation horizon is very short in my field, but then I sit down with somebody who is the fifth custodian in the last one hundred years of an important collection that has existed for five hundred years, and their mindset is completely different about what preservation means.

KORNFIELD I was indoctrinated with the idea that I'm responsible for keeping my data accessible for twenty-five years, so my students freak out when I insist they use archival notebooks and ink. They think, "God, twenty-five years is a long time!" The artists I know who are in their thirties also think twenty-five years is a long time. There's no way they're thinking about the next generation, in part because they think the world's going to end. There are major disconnects with artists thinking about timescale. Perhaps we should give them guidance, saying, "Please digitally archive your methods, because the process influences the properties and the stability, and we'll need that information when you're eighty—and ninety—and one hundred—and dead."

LEVIN How interested do the three of you think your scientific colleagues would be in engaging in a dialogue and even a collaboration with the cultural heritage field?

KORNFIELD I think when a scientist hears that there's a need and they're able to help link it to a solution, they actually experience a moment of joy and excitement. They want to get involved. For example, a scientist who has a method that might have been developed for an entirely different purpose—a medical purpose, an environmental purpose, a military purpose—discovers through discussions that the method could be very beneficial in conservation. I don't know many examples that go in the other direction, but I'm sure there are some. But in my world, there's only a very tiny amount of this dialogue going on.

WEBB A lot of us in science have the same appreciation of a work of art as a layman, so it's very interesting for us to be able to contribute scientifically to conservation. If I go home and tell my mom I'm working on some eclectic chemical compound, she'll doze off. But if I tell her we're looking at a paint chip from a famous painting, she'll suddenly be very interested in what I have to say. It can be the same experiment, but one application allows a scientist to interface with something that's widely appreciated. It's exciting to see how science can help museums and conservation, and artists themselves, too.

TRENTELMAN So we know some of the benefits of collaboration—it's exciting and you feel great—but how do we get more people in academia to work actively in the cultural heritage realm?

KORNFIELD When you're a scientist in a system that's in decline or just extremely flat—and the population of scientists is going up—it's hard to get people's attention, because they feel like they're starving. This is especially true for young scientists. Someone like George Rossman, a fabulous geochemist at Caltech, has the bandwidth to take on new things now, because he doesn't care if he never gets another grant. He can do science with people who happen to walk in his door and want to work with him. So, there are stages of a career where you might find people more receptive. To get more academia scientists involved you have to be sensitive to the fact that people are worried about having a job. You have to create programs that entice someone who is not a George Rossman to come into this endeavor.

TRENTELMAN You're talking about the elephant in the room—money.

WEBB Scientists who are established are excited to do these collaborations, and graduate students and others who work on them are also really excited. We have lots of students who are very interested in applying science to cultural heritage materials. But there aren't always conservation science jobs available for my younger colleagues who'd like to work in conservation. This is where it often comes down to funding. That's one barrier to keeping these young scientists in the conservation field.

TRENTELMAN Could academia absorb them? And if so, is funding their research in academia viable in the current economic climate?

WEBB Funding as a whole is a big question mark in this day and age. Where do you get that funding? How do you apply it? It's a creative twist to say "Oh, I'm working on this material that has an application in something else," but how do you get funding for heritage science and conservation science in particular?

TRENTELMAN As we all know, the National Science Foundation had a program for a few years specifically funding collaborations between academia and cultural heritage institutions. But that no longer exists.

SEALES We're working on an AI and cultural heritage and imaging science program, but very few of the initiatives over the last twenty years at the NSF that I've seen have ever became a core program. Until we get people to acknowledge that this could be a core part of a research program that isn't going to come and go, it'll be hard to see faculty members sustain a career only in heritage science. I know a lot of established people moving in that direction because they're passionate about it, but they're in the part of their career where that's possible. Or perhaps they're at a university where you don't have to compete for funding because you have an endowed position that allows you to work with a few students funded through that endowment. Endowments might actually be a way. It works for some of the heritage science institutions like the Getty. Maybe endowments at universities could provide that stability.

KORNFIELD One of the things I perceive as extremely important is for a person like Tom Learner [head of GCI Science] and the Getty Conservation Institute to be points of contact that can become a hub of an activity that otherwise would not be sustainable. That's absolutely essential. But there are only a handful of those, right? Having an endowed institution that has a core value in conservation science is the anchor that makes it possible to grow and disseminate, and potentially get more and more scientists involved. I also like the idea of thinking about art exhibitions that show the relevant science next to the painting or sculpture. You can imagine this ten-year-old kid who thinks, "Oh my God, I can see the painting under the painting!" That sort of thing can spark a whole career.

TRENTELMAN Could each of you talk a little bit about how dissemination might be changing—in particular, dissemination with regard to work that is cross-disciplinary with cultural heritage?

WEBB We have the old-fashioned traditional way of publishing results and putting them out for display—and there's always a need for that, at least in terms of conventional funding agencies. But papers are isolated to our field. When it comes to heritage science, I think about museum displays where you can show to a wider public how science and cultural heritage can help each other. A display with thousands of people a year walking through it helps educate the public about how important this is. Obviously, as a scientist, some of my most enjoyable art displays have been those where they've shown the science behind it. In Europe there are much larger cultural heritage funding agencies that have money to go to institutions, museums, and research scientists—and they have many nations actually collaborating together. Is it because they have that much more art and that people spend more time in museums? The point is to get more people worldwide interested in how science and cultural heritage serve each other and show more examples of these dialogues.

MADDEN A mechanism lacking in the United States is a ministry of culture. The absence of that matters a lot for how these things are funded. In Europe, they do have them, and they are powerful when banded together.

KORNFIELD And they had them even before the EU. Each country prided itself on subsidizing studios for people creating visual arts and subsidizing opera tickets for students so they could have a taste of opera before their careers started. In the US, interest in the arts oscillates between being absent and being hostile. The US is a hard case. We need the equivalent of the Gates Foundation for conservation science.

SEALES Public dissemination is a problem because you're competing with technology, social media, entertainment, and sports. Where do you find a place for people to be interested? That's why I think we need a required curriculum at the university and maybe even in schools with young children. As a Getty Conservation Guest Scholar, I ride up the hill on the tram with schoolkids, and I love it because of the excited voices of the kids. I once said to a teacher, "They realize this isn't Disneyland, right?" She said, "Oh, they're really looking forward to this." We can't lose a handle on

Photo: Eva Kelety.

It's all about your own creativity at noticing something, figuring out something, being delighted by an idea that you've reapplied, and then seeing the excitement drive you forward. When you talk to an artist about a piece that they're making, they describe all the same feelings.

BRENT SEALES

the energy of those kids and the opportunity for them to experience art and culture. We just can't. That's our future. And that's true of dissemination. My writing a technical paper can feel frustrating, because sometimes all it seems to inspire are a few citations from other experts who already know my work.

KORNFIELD I'm reminded of the GCI's exhibition of De Wain Valentine's *Gray Column*, in which the artwork was displayed in a very engaging way. You could walk around the art and view informational videos about the artist and the chemistry he developed to make that sculpture possible. There was also a hardcover book and information accessible on the web. In terms of dissemination, it had a very multipronged approach.

TRENTELMAN How do we communicate our work to other scientists we want to inspire to join us in doing cultural heritage science? Is there a way we can do this rather than publishing a paper that only six people see?

SEALES Whenever you have a new field emerging and a new set of collaborations between scientists, say, and heritage scientists, you have an opportunity to set some new standards. We could move away from the way we disseminate our results and just refuse to write that paper that actually abstracts away all the stuff we really want to show. With papers, you can't have a video and you can't interact with the data. Maybe we can build a platform for storing all the assets, and on top of that do some storytelling of the actual results. Instead of downloading a PDF of a paper, why not download a way more robust thing that allows you to follow links, see pictures, and hear voices? We have the ability to do all that. If you're really talking about inspiring delight and wonder, why not use every tool available to try to do that? We're creating a new field, so we can create a new way to disseminate, too.

TRENTELMAN What's the barrier?

SEALES In academia, you used to publish papers by giving all your information to a staff member who put the paper together for you. Now *you're* responsible for building a camera-ready copy of the paper. If we're going to ask somebody to do that with all this multimedia—in all its many variations—it's probably not going to happen. But if you had a group you could send everything to that could produce it, that would work.

WEBB We've had the art communications department at Stanford occasionally do some sort of media thing, like a five-minute science spot that gets on the local news or a Facebook Live thing that showed experiments running and interviews with the scholars, scientists, and conservators who were there. But that just goes off into the ether and disappears. Maybe we need to think about doing this on a more regular basis, particularly when you have high-impact pieces of research—piece together, in a multimedia way, a product that can be exhibited, searched for, or at least referenced, and create an interesting, appetizing combination of both the science and the cultural heritage.

SEALES I know journalists are struggling with the change in technology and the fact that people just don't want to read an article anymore. *The New York Times* and *The Atlantic* have online pieces that are much more interactive, with panoramic photos and short audio clips, and with every one of those I've come to, I've read the whole thing. It's pretty compelling.

WEBB When I'd get a journal when I was young, I'd flip through all the articles. Now I rarely even go to the journals I like and read the table of contents. I just don't have the bandwidth to do that anymore. If I can't find it on a Google search or my proper indexing location, it doesn't exist. Maybe someone would look at this information if they were really excited by it. But so much more of this could be in an interactive web-based format where you could actually interact with the data in some way and maybe even discover something that was missed. You've interpreted it, and now other people can look into it as well, apply a new algorithm to it that we didn't have access to five years ago, and find something new with it.

Photo: Fanny Dubray.

As I've matured as a scientist, I see more of that creativity in how I can create an experiment that can be performed more easily by my broad user base, which includes biologists, physicists, geochemists, geologists, and professionals in cultural heritage.

SAM WEBB

LEVIN Scientific inquiry involves imagination and creativity. How do imagination and creativity figure into your work—and are there parallels with the creation of works of art?

WEBB You don't understand that as an undergraduate, because you're worried about your courses and stuff like that. But by the time you're in the field, you can see a very strong parallel. You have to be creative, particularly when it comes to cultural heritage. We can't just take a sample or dissolve a painting to figure out what was below it. We're very creative in how we explore and make these measurements. As I've matured as a scientist, I see more of that creativity in how I can create an experiment that can be performed more easily by my broad user base, which includes biologists, physicists, geochemists, geologists, and professionals in cultural heritage. There's a lot of creativity that goes into how I can make this platform accessible to a large group of interested scientists—designing the facilities and experiments and accessibility so people can really utilize something in their research.

KORNFIELD One thing that comes to mind for me is the role of emotion. I've always felt ashamed that I am a hedonistic scientist. If it doesn't feel exciting and beautiful, I don't go there. I just don't. Nevertheless, I do feel it's worth telling young people—especially kids in high school, because often the way we shove science down their throats is not pleasant—how much fun science is, how exciting it is, and how connected with other people it is. And those are things we associate with a creative endeavor where you're going to invent the characters, dream what it's going to look like, and make it with your hands. We don't tell people that if you look at a day in the life of a scientist, it's like that.

SEALES It's not just the dry scientific method you learn in elementary school. There's a lot more excitement and fun.

KORNFIELD I talk to students who are joining my group or our department, and I tell them, "My dream for every one of you is that at the end of your thesis you look back and can say that your thesis could not have happened had it not been you. I want you to feel as if you're composing a symphony or sculpting a sculpture. This is you. It's a reflection of your values and sense of beauty, and the difference you want to make in the world. That's what I want for your PhD. After that, you've got to make a living. But for this brief window—this last little bit of childhood at the brink of adulthood—I will be your patron."

SEALES I came to science and to my training through problem-solving. That was how everything was always described, and not always in a positive way. You have a problem—that's maybe presented even as a negative thing—and you have to find a way to solve it. But lately I've been thinking about problem-solving as a form of storytelling, because the path that you take to solve a problem is its own narrative. From there it's not much of a stretch when you're thinking about problem-solving as storytelling to think about it as self-expression—which is exactly what you're talking about. In order to tell that story, to get that outcome, it's all about your own creativity at noticing something, figuring out something, being delighted by an idea that you've reapplied, and then seeing the excitement drive you forward. When you talk to an artist about a piece that they're making, they describe all the same feelings. We may be doing the scientific community a disservice by framing everything as dry problem-solving using the scientific method. It might be better to use this lens of telling a story. How are you going to get to the end of the story? What's that story going to be? It's exciting to see it unfold. You're expressing yourself and a lot of who you are as a person through that process. Those are different lenses—and artists get the self-expression lens right from the beginning. I wish that the scientists could get that, too.

RESOURCES **CONSERVATION SCIENCE**

HERITAGE SCIENCE CENTERS & NETWORKS

Center for Scientific Studies in the Arts, Chicago
scienceforart.northwestern.edu

Centre de Recherche sur la Conservation (CRC), Paris
crc.mnhn.fr

Getty Conservation Institute
getty.edu/conservation

Heritage Science Research Network
heritagescienceresearch.com/

International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM)
www.iccrom.org/section/heritage-science

International Council of Museums, Committee for Conservation, Scientific Research Working Group
icom-cc.org/37/working-groups/scientific-research

Netherlands Institute for Conservation+Art+Science+ (NICAS)
nicas-research.nl

Network Initiative for Conservation Science (NICS), New York
bit.ly/3dq8cUD

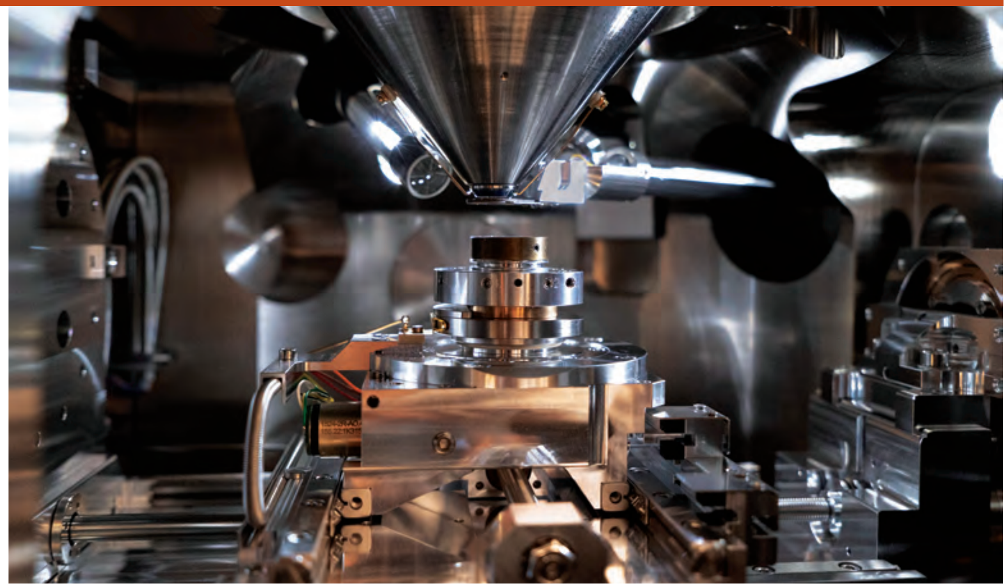
Oxford Resilient Buildings and Landscapes Lab (OxRBL)
oxrbl.com

SCIENTIFIC TECHNIQUES

AATA Online. A free research database.
aata.getty.edu

Chemical Analysis in Cultural Heritage, edited by Luigia Sabbatini and Inez Dorothé van der Werf (2020), Berlin: De Gruyter.
https://doi.org/10.1515/9783110457537

Chemistry and Materials Research at the Interface between Science and Art: Report of a Workshop Cosponsored by the National Science Foundation and the Andrew W. Mellon Foundation, July 6–7, 2009, Arlington, Virginia (PDF).
bit.ly/3gLxOgM



Inside the sample chamber of a variable pressure scanning electron microscope. Photo: Andrzej Liguz, for the GCI.

Handheld XRF in Cultural Heritage: A Practical Workbook for Conservators by Anikó Bezur, Lynn Lee, Maggi Loubser, and Karen Trentelman (2020), Los Angeles: Getty Conservation Institute.
gty.art/3a7Mjaa

Heritage Science. An open-access journal publishing original peer-reviewed research.
https://heritagesciencejournal.springeropen.com/articles

Science Advances Special Collection—Studying Heritage Art
sciencemag.org/collections/advances/heritage

Science and Art: The Painted Surface, edited by Antonio Sgamellotti, Brunetto Giovanni Brunetti, and Costanza Miliani (2014), London: Royal Society of Chemistry.
https://doi.org/10.1039/9781839161957

Scientific Methods in Cultural Heritage Research: Gordon Research Conference
grc.org/scientific-methods-in-cultural-heritage-research-conference/

MOBILE LABORATORIES

MOLAB. European mobile laboratories.
www.iperionch.eu/molab/

SYNCHROTRON ANALYSIS

Ancient Materials Research Platform
ipanema.cnrs.fr

"FIXLAB Transnational Access: The Opportunity for Cultural Heritage Scientists to Access Large Scale Facilities" by Claire Pacheco, in *Techne* 43 (2016), 26–31.
journals.openedition.org/techne/591

"Rings of Fire: Research at Synchrotron Facilities" by Catherine Schmidt Patterson, in *The Iris: Behind the Scenes at the Getty* (December 12, 2013).
gty.art/2MmhtBr

Synchrotron Radiation and Neutrons in Art and Archaeology, 9th International Conference, 2021.
sr2a2021.org

SPECTRAL IMAGING

Conservation Perspectives, The GCI Newsletter: Imaging in Conservation (Spring 2017).
gty.art/2BoMfYb

Operation Night Watch. Rijksmuseum.
rijksmuseum.nl/en/nightwatch

Special Issue: First Workshop on Macro X-Ray Fluorescence (MA-ARF) Scanning, 24 September 2017, Trieste, Italy, *X-Ray Spectrometry* 48, no. 4 (July/August 2019), 247–318.
bit.ly/2zRZfoz

For more information on issues related to conservation science, search AATA Online at aata.getty.edu

Tribute

Photo: Getty Trust.

DEBORAH MARROW 1948–2019

Deborah Marrow, who retired as Getty Foundation director in 2018 after more than three decades of leadership in various roles at the Getty, including two stints as interim president, died October 1, 2019.

"No one has contributed more to the life and mission of the Getty than Deborah, and we will miss her deeply," said James Cuno, president and CEO of the J. Paul Getty Trust. "She provided inspiring leadership in almost every aspect of the Getty, in roles including director of the Getty Foundation, acting director of the Getty Research Institute, and interim president of the Getty Trust. She brought clarity, vision, and selfless dedication to her work, and made loyal professional friends around the world."

As Foundation director, Deborah oversaw grant-making activity locally and worldwide in the areas of art history, conservation, and museums, as well as grants administration for the programs and departments of the Getty Trust. One of her proudest accomplishments was the creation of the Getty's Multicultural Undergraduate Internship program, which, over twenty-seven years, has supported more than 3,400 internships at 160 local arts institutions in an effort to increase staff diversity in museums and visual arts organizations. In 2018 the program was renamed the Getty Marrow Undergraduate Internship program in her honor.

Deborah joined the Getty in 1983 as publications coordinator. Beginning in 1989, as a director, she guided the Trust's philanthropic activity, then known as the Getty Grant Program. In 2004 she became director of its successor, the Getty Foundation. In 2000 she assumed the additional role of dean for external relations for the Getty. In 1999–2000 she was acting director of the Getty Research Institute. And she twice served as interim president of the Getty Trust—in 2006–7 and again in 2010–11.

During Deborah's tenure, the Getty Foundation awarded nearly 8,000 grants in over 180 countries. Those who knew Deborah may recall her fondness for noting that these grants reached all seven continents—including Antarctica, thanks to a conservation grant to preserve Shackleton's Hut. With all the conservation grants, priority was placed on planning and research as pillars of sound preservation practice.

Under Deborah's leadership, the Foundation partnered with the Getty Conservation Institute on several major initiatives, among them the Panel Paintings Initiative, which trained a new generation of conservators to preserve works of art created on wood panels, protecting some of the most valued masterpieces of art for future generations. Also under Deborah, the Foundation collaborated with the GCI and external partners on MOSAIKON, a multiyear effort to improve the care and presentation of ancient mosaics across the Mediterranean Basin. In connection with the Foundation's Keeping It Modern initiative—which focuses on preserving twentieth-century architecture around the world—staff of the GCI's Conserving Modern Architecture Initiative have presented workshops on conservation management planning to grant recipients. In recognition of her stewardship of these initiatives and many earlier grants supporting conservation of both movable and immovable heritage, Deborah was awarded the American Institute of Conservation's President's Award in 2019.

Deborah held a PhD in art history from the University of Pennsylvania; her original scholarly research was on seventeenth-century European art and patronage. She began her career at the Philadelphia Museum of Art and taught art history at universities in Pennsylvania, New Jersey, and Southern California. She was active for years in professional organizations in the fields of art history, museums, preservation, and philanthropy, and served as a trustee of the University of Pennsylvania and of Town Hall Los Angeles.

Deborah's extraordinary dedication to the goals and the work of the Getty, as well as her collegial spirit, was appreciated by the staff of the GCI, many of whom worked closely with her for a number of years. We will very much miss her presence.

We extend our condolences to Deborah's husband Mike McGuire, and to her children Anna and David for their loss.

GCI News

Project Updates

BAGAN PROJECT LAUNCHED

On November 6, 2019, the GCI and Myanmar's Department of Archaeology and National Museum formally launched a multiyear collaborative project to conserve the ancient site of Bagan, a complex of over 3,500 temples, pagodas, and monasteries.

Set in a vast cultural landscape, Bagan's monuments house an extensive array of wall paintings, sculptures, decorations, and inscriptions that are the surviving traces of a powerful empire—Bagan was the first kingdom to unify the regions that later became modern-day Myanmar. There is archaeological evidence at the site dating back to the second century CE, but the surviving monuments were built during Bagan's golden period between the eleventh and thirteenth centuries. Bagan remains an important and active place of pilgrimage and worship.

Getty will partner with local officials to address a variety of conservation issues across the vast Bagan Archaeological Zone. Work will include developing methods to repair buildings damaged by earthquakes and improve resistance to future seismic events; identifying means of conserving the site's decorative elements; developing conservation principles and approaches to manage the range of conservation challenges across the site; and training local professionals to sustain conservation efforts.

Bagan has been plagued by earthquakes, the latest of which in 2016 damaged over four hundred structures. The region also suffers from regular flooding, made more frequent by climate

Members of the Bagan conservation team at Myin-Pya-Gu temple as part of sonic and dynamic testing at the site. Photo: Tim Webster, for the GCI.

change and development. A large-scale conservation project became critically important after Bagan was named a UNESCO World Heritage Site in July 2019. While the World Heritage designation will bring welcome attention to the region, increased numbers of visitors will compound the conservation challenges, with hotel construction and even more international interest creating additional pressures on the site.

"We really appreciate the efforts and goodwill of the Getty Conservation Institute team to make Bagan more sustainable," said U Kyaw Oo Lwin, director general of the Department of Archaeology and National Museum. "We will work together long term for the best protection of cultural heritage in Myanmar."

The project will include case studies and model projects that can be used to inform future conservation efforts in Bagan and elsewhere. One of the first buildings to be studied will be Myin-Pya-Gu, an expansive and picturesque temple with extensive decorative elements.

"Bagan is a treasure," said Tim Whalen, John E. and Louise Bryson Director of the GCI. "This site is significant not only to the people of Bagan, but to people around the world, as evidenced by its recent inscription on the World Heritage List. We look forward to this long-term partnership with our Bagan colleagues to conserve this magical place and together build the professional capacity necessary to preserve it into the future."

The first major campaign of the project, in January 2020, included documentation and assessment of case study monuments, structural repair research, investigation of decorative elements, and training for seventy-five DOA staff from Bagan and other areas of Myanmar in conservation principles and processes.

The GCI envisions that other regions of Southeast Asia will be able to learn from the conservation experience in Bagan. The project is part of Getty's Ancient Worlds Now: A Future for the Past, a new global initiative to promote a greater understanding of the need to protect and save the world's cultural heritage for future generations.

Medieval Indian sculpture section at the Chandigarh Government Museum and Art Gallery. Photo: Tim Webster, for the GCI.

PROJECT IN CHANDIGARH

Members of the GCI's Managing Collection Environments and Conserving Modern Architecture initiatives were in Chandigarh, India, the week of January 6, 2020, to work with colleagues at the Government Museum and Art Gallery. The museum, which opened in 1968, is one of only three museum buildings designed by the modernist architect Charles-Édouard Jeanneret, better known as Le Corbusier. (The others are the Sanskar Kendra Museum in Ahmedabad, India, and the National Museum of Western Art in Tokyo.)

The Government Museum and Art Gallery was designed for passive environmental control. But in the five decades since its construction some interior spaces have been modified, and mechanized climate control has been introduced in several areas. While in Chandigarh, the GCI team worked with museum colleagues on a risk assessment of the museum's collection, regarded as one of the most significant in India. The team also initiated a yearlong campaign to monitor and better understand the environment of the museum and its impact on both the building and the collection.

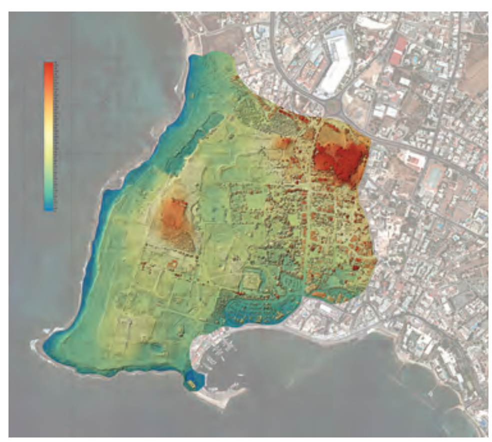
The GCI's efforts complement work already being carried out by colleagues in India to create a conservation management plan for the museum building and its site. Development of the conservation management plan is being supported by a grant to PEC University of Technology (now Punjab Engineering College) in Chandigarh by the Getty Foundation's Keeping It Modern grant initiative. As the monitoring advances, the GCI team will work with the India-based team of architects, engineers, and museum personnel to produce a conservation strategy that integrates the longer-term preservation needs of this iconic museum building and the collection it houses.

PAPHOS CONSERVATION AND MANAGEMENT PLAN

The Getty Conservation Institute and the Department of Antiquities (DoA), Cyprus, have been collaborating on a project to develop a conservation and management plan for the archaeological site of Nea Paphos. Mapping the site has been a priority over the last two years, one of the first steps in the development of the plan.

In November 2019, consultants from the Carleton Immersive Media Studio of Carleton University, Ottawa, and DoA staff undertook field checking of the mapping. Additionally, a second training workshop was given for DoA staff in the use and application of the site Geographic Information System (GIS) that is being created. With the final development of the GIS and production of maps of the site—including topographical maps, digital surface models, and plans of all buildings and underground features—the site, which encompasses 1.36 square kilometers, has now been fully mapped.

Another major component of the project that was advanced is the development of a prototype shelter to protect the site's most significant mosaics. The areas of the site for the initial shelter prototype were delineated, and a call for Expressions of Interest was subsequently developed and disseminated in December, thus announcing the intent to the architectural community.



Digital surface model of the Paphos site showing elevation of topographical and archaeological features, with red indicating the highest level and blue indicating the lowest. Image: Carleton Immersive Media Studio, for the GCI.

Members of the Rock Art Network visiting Lascaux IV, a replica of the Lascaux rock art site in France. Photo: © Noel Hidalgo Tan.

2019 ROCK ART COLLOQUIUM

In October 2019, the GCI organized a third colloquium of the Rock Art Network (RAN), established in 2017 to address the challenge of global rock art preservation as identified in the 2015 GCI publication *Rock Art: A Cultural Treasure at Risk*. One pillar of preservation is for public and policy engagement with the values of rock art, which is addressed significantly at French and Spanish Paleolithic cave art sites, where RAN members met for twelve days to discuss ongoing Network activities, projects, and collaborations.

The title of the colloquium, "Replication as Conservation," references the reproduction cave art sites visited. At Chauvet, Lascaux, Ekain, and Altamira, full-scale facsimiles of large painted portions of each cave site are presented to visitors. Dramatically illuminated, and with trained guides, each reproduction is unique in its techniques of production and presentation. The juxtaposition of these reproductions, along with group visits to seven other original cave sites, provided compelling examples of how rock art can be presented and interpreted to inspire visitors and cultivate a sense of global patrimony for this unique heritage.

Beyond visiting and discussing these sites, network members built on momentum from previous colloquia. Collaborative projects between network members and their institutions were highlighted, including an exhibition on South African rock art hosted by the Altamira Museum, which the group toured. Future activities were also proposed and debated. A principal discussion focused on RAN's financial and programmatic sustainability. After refining the network's vision, mission statements, and target audiences, action plans were developed. These include inviting new participants with more geographic and professional diversity to join RAN—in particular those with experience in fundraising and with media experience for promotional outreach; disseminating RAN members' work more efficiently through the network's website, hosted by the Bradshaw Foundation; and developing further working groups within RAN to bolster its organizational strength.

Recent Events

NEW INTERFACE FOR AATA ONLINE

A new user interface for the GCI's AATA Online launched on April 1, 2020. This database—which contains citations, abstracts, and indexing terms that conservation and heritage professionals have relied on for years—now provides vastly improved search features and functionality. Some of the notable enhancements include linked author names and indexing terms, additional search result filters, links to full-text articles that have digital object identifiers, and a more intuitive look and feel. AATA Online researchers will also be able to more easily save and share records, generate citations and bibliographies, and export records to reference management programs.

Initially developed in 1932 as a community effort within the nascent field of fine arts conservation, AATA Online has grown over nearly ninety years from a print publication (*Art and Archaeology Technical Abstracts*) to a comprehensive database of abstracted literature related to the preservation and conservation of material cultural heritage. The vast array of topics covered—from plastics to concrete, marquetry to feathers, chapels to industrial landscapes, paint pigments to textile dyes, and microscopy to GPS—would not be possible without the dedication of volunteers, specialized language abstractors, and subject field editors. Their submissions and expertise have ensured the breadth, depth, and accuracy of AATA Online's citations and abstracts. Getty, which became the publisher of this invaluable resource in 1983, continues its investment in and support of AATA Online with this new and improved user interface.

GCI-ASOR WORKSHOP

The GCI, in collaboration with the American Schools of Oriental Research (ASOR), organized a workshop on conservation and archaeology for selected directors of excavations and members of ASOR following its annual meeting in November 2019 in San Diego.

The workshop grew out of the Archaeology and Conservation Education Roundtable organized by the GCI and hosted by the Getty Villa and the GCI in 2017, an initiative itself rooted in the Institute's long-term work in archaeological conservation. During the roundtable, faculty in archaeology and conservation, from universities where both fields are taught, identified the need for better knowledge of conservation by archaeologists and better knowledge of archaeology by conservators, to improve collaboration and best practices in fieldwork. One proposed action was delivering workshops or "boot camps" on conservation for archaeologists, and on archaeology for conservators, in association with their respective professional meetings. This GCI-ASOR collaboration was

Heather Hurst, associate professor of anthropology at Skidmore College, speaking at the GCI-ASOR workshop. Photo: Juliette Raffaelli, GCI.

the first of the proposed workshops to be conducted.

The one-day workshop was attended by twenty-four midcareer and senior excavation directors in the ASOR region and selected staff from the American Center for Oriental Research in Amman, Jordan. It included an introduction to archaeological materials and their deterioration causes and mechanisms, followed by a discussion of ethics in archaeology and conservation. Subsequent presentations by conservators with extensive experience on archaeological excavations focused on the conservation process and the importance of pre-excavation planning. Case studies of best practices in collaborative fieldwork were presented, forming the basis for discussions on planning, budgeting, and funding. This last topic was of particular importance to some participants, who identified it as a primary obstacle to integrating conservation in their research and excavation plans. One potential follow-up of the workshop will be for the GCI to convene a meeting of archaeological organizations and principal funders of archaeological research to advocate for including funding for conservation and a conservator in their research grants.

WINTERTHUR MEETING ON T AND RH TOOLS

Collecting temperature (T) and relative humidity (RH) data is fundamental to collection management for many cultural heritage institutions. Analysis of this information supports decision-making for collection assessment, loan considerations, and developing environmental management strategies. Several tools have been developed (or are forthcoming) that improve understanding of T and RH data. However, their effective use requires sufficient training, budget, and staff time, and can benefit from interdisciplinary involvement.

In December 2019, the GCI convened a meeting at the Winterthur Museum, Garden & Library to create a framework to support use and development of T and RH analysis tools. Of particular interest was supporting collection management activities of small institutions with limited resources. Participants represented users and developers of tools from various disciplines, including conservation, engineering, architecture, data science, and building physics.

Discussion initially focused on specific T and RH tools and on themes such as the motivation for development, general awareness of the tools, and their utility for communicating collection risk and environmental management strategies. The meeting subsequently aimed to identify gaps among the capabilities of the tools. Topics included more advanced analysis and visualization of T and RH data, highlighting correlations between the environment and recorded events, integration of building and site-specific information, and improved dissemination about tools. An initial outcome of the Winterthur meeting will be a report summarizing discussion of the application and advancement of T and RH analysis tools. Such a document can help bridge the communities of tool users and developers, and promote interdisciplinary collaboration for further tools education and development for the heritage field.

BIZOT GROUP PRESENTATION

In November 2019, at the Boston Museum of Fine Arts, Joel Taylor and Michal Lukomski of the GCI presented work of the Institute's Managing Collection Environments (MCE) initiative to the Bizot group—an international collective of museum directors from large collecting and lending institutions, who meet to exchange ideas and discuss current events.

In their presentation, they outlined the scientific, educational, and outreach activities of MCE, including its contributions to new guidance for engineers and conservators on environments in museums for the *ASHRAE Handbook* (the handbook for the American Society for Heating, Refrigerating and Air-Conditioning Engineers); its nine-month international training course on sustainable approaches to climate management for museum professionals; and its use of novel techniques to characterize material properties in order to understand their responses to changes in relative humidity. The presentation referenced the Bizot Green Protocol of 2015, which called for closer ties between the principles of sustainability and museum activities, such as loan agreements, building design, and conditions for storage and display.

Staff Update

KATHLEEN DARDES DEPARTS THE GCI

Kathleen Dardes, who was head of the Getty Conservation Institute's Collections department for over a decade, retired from the GCI on March 31, 2020.

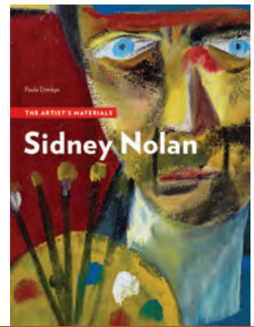
Kathy began work at the Institute in 1988—first in what was then the Training department and subsequently in Field Projects, before taking on the leadership of Education (now called Collections) in 2007. During her long and varied career, Kathy worked on a broad array of projects and contributed significantly to the development of the GCI's mission, especially in the areas of preventive conservation and conservation education, in many ways the connecting threads of her career.

In her early days at the GCI, Kathy launched the Institute's first series of interdisciplinary courses on preventive conservation along with a number of projects that promoted a holistic approach to caring for museum collections and the buildings that house them. She field-tested this approach by undertaking conservation assessments at a number of museums, including the Bardo Museum in Tunis and the Museum of Sacred Art in Salvador, Brazil, working with interdisciplinary teams of conservators, architects, and engineers. Somewhat later, in collaboration with ICOM and ICCROM, she launched the Teamwork for Integrated Emergency Management project, designed to encourage the integration of emergency planning and preparation in museums, with a particular focus on the Asia-Pacific region and Southeastern Europe.

After becoming head of Education and then Collections, Kathy continued to demonstrate her strategic thinking skills, intellect, and creativity in further advancing these areas of work. She worked with colleagues in GCI Science to launch the Research into Practice series of workshops to facilitate the transfer of promising new research into conservation practice. Throughout her career, the professional development needs of colleagues and institutions in underserved areas of the world had been a priority for Kathy, and this was exemplified by her contribution to the Middle East Photograph Preservation Initiative, a partnership of the Arab Image Foundation, the GCI, the University of Delaware, and The Metropolitan Museum of Art. Her work in preventive conservation came full circle with the launch of the GCI's Managing Collection Environments (MCE) initiative, a collaboration of the GCI's Collections and Science departments. MCE's innovative course and field activities combine to promote new thinking about sustainable museum environments and how to adapt it to a range of museum contexts, including those in challenging climates.

Kathy has been a wonderful, collaborative colleague these many years and will be missed greatly. Nevertheless, we know that she is excited about this next chapter in her life, which will bring a return to her East Coast roots and, it is expected, new professional and personal opportunities.

Print & Online Publications



Values in Heritage Management: Emerging Approaches and Research Directions
Edited by Erica Avrami, Susan Macdonald, Randall Mason, and David Myers

In the last fifty years, conservation professionals have confronted increasingly complex political, economic, and cultural dynamics. This book, with contributions by leading international practitioners and scholars, reviews how values-based methods have come to influence conservation, takes stock of emerging approaches to values in heritage practice and policy, identifies common challenges and related spheres of knowledge, and proposes areas in which the development of new approaches and research may help advance the field.

This open-access catalogue is available for free online and in multiple formats for download, including PDF, MOBI/Kindle, and EPUB. A paperback edition is also available for sale.

Erica Avrami is James Marston Fitch assistant professor of Historic Preservation at Columbia University. Susan Macdonald leads the Buildings and Sites department at the GCI. Randall Mason is an associate professor in the Graduate Program in Historic Preservation at the University of Pennsylvania School of Design. David Myers is a senior project specialist at the GCI.

Herculaneum and the House of the Bicentenary: History and Heritage
Sarah Court and Leslie Rainer

This volume for general readers vividly recounts the history of Herculaneum, the Roman town buried by the Mount Vesuvius eruption in 79 CE and uniquely preserved for nearly two thousand years. Initial chapters provide an overview of the town in antiquity, the riveting story of its rediscovery in the eighteenth century, its excavation in the nineteenth and twentieth centuries, and its cultural significance in modern times. Subsequent chapters offer an interpretive tour of the ancient town and then focus on one of Herculaneum's grandest and most beautifully decorated private residences, the House of the Bicentenary. Its original rooms, magnificent wall paintings and mosaics, and remarkable documents illuminate daily life in the ancient world. Final chapters discuss recent discoveries about the site and its famous papyrus manuscripts, as well as ongoing conservation initiatives.

Sarah Court is an archaeologist at the Herculaneum Conservation Project. Leslie Rainer is a senior project specialist at the GCI and coauthor of *Palace Sculptures of Abomey: History Told on Walls* (Getty Publications, 1999).

Sidney Nolan: The Artist's Materials
Paula Dredge

Sidney Nolan (1917–1992) is renowned for an oeuvre ranging from views of Melbourne's seaside suburb St Kilda to an iconic series on outlaw hero Ned Kelly. Working in factories from age fourteen, Nolan began his training spray-painting signs on glass, followed by a job cutting and painting displays for Fayrefield Hats. In 1939, having given up his Fayrefield job to pursue an artistic career, Nolan became obsessed with European abstract paintings he saw reproduced in books and magazines. With little regard for his work's longevity, he exploited materials such as boot polish, dyes, secondhand canvas, tissue paper, and old photographs, in addition to commercial and household paints. He continued to embrace new materials after moving to London in 1953. Oil-based Ripolin enamel is known to have been Nolan's preferred paint, but this study reveals his equally innovative use of nitrocellulose, alkyds, and other diverse materials.

Paula Dredge is head of paintings conservation at the Art Gallery of New South Wales in Sydney, Australia.

Museum Lighting: A Guide for Conservators and Curators
David Saunders

David Saunders explores how to balance the conflicting goals of visibility and preservation under a variety of conditions. Beginning with the science of how light, color, and vision function and interact, he offers detailed studies of the impact of light on a wide range of objects, including paintings, manuscripts, textiles, bone, leather, and plastics. With analyses of the effects of light on visibility and deterioration, *Museum Lighting* provides practical information to assist curators, conservators, and other museum professionals in making critical decisions about the display and preservation of objects.

David Saunders is an honorary research fellow at the British Museum, having been keeper of conservation and scientific research there for ten years, until 2015. He was previously in the Scientific Department at the National Gallery in London. He is a fellow of the Society of Antiquaries of London and vice president of the International Institute of Conservation. In 2016 he was a guest scholar at the GCI, conducting research that underpins much of this book.

On Canvas: Preserving the Structure of Paintings
Stephen Hackney

Throughout its long history in Western art, canvas has played an influential role in the creative process. From the Renaissance development of oil painting on canvas to the present day, the use of canvas has enhanced the scale of painting, freedom of brushwork, and spontaneity in technique. This book recounts some of that rich history in relation to corresponding developments in conservation practice. Rather than concentrating on the familiar concerns of cleaning and varnish removal, this volume considers the preservation of a painting's structure. Focusing on recent studies of the fundamental nature of canvas and its deterioration mechanisms, the book explains new approaches to conservation of both contemporary and historical art—including reversible, passive, and preventive treatments, particularly with respect to lining. *On Canvas* is the first book to look comprehensively at this important subject and is destined to become an invaluable resource.

Stephen Hackney is an independent scholar and author who trained at the Courtauld Institute of Art in London and was formerly the head of conservation science at Tate (for whom he still

acts as a consultant). He has written extensively on the subject of oil painting on canvas.

All of these books are available for purchase at shop.getty.edu.

ONLINE

Handheld XRF in Cultural Heritage: A Practical Workbook for Conservators

Anikó Bezur, Lynn Lee, Maggi Loubser, and Karen Trentelman

In this workbook, conservators and conservation scientists in cultural heritage learn the fundamentals of X-ray fluorescence (XRF) spectroscopy and the application of handheld XRF through hands-on, practical exercises. This noninvasive, in situ technique, which provides information on the elemental composition of an object, is frequently used as one of the first analytical tools, if not the only one, applied in the study of the materials that compose works of art. The book is a training tool for those new to the technique and a refresher for more experienced users. For the most benefit, readers are encouraged to actively engage with this workbook, using it initially as a tool for self-guided learning, and subsequently as an ongoing reference.

ONLINE

The Buildings of Louis Kahn: Conserving Exterior Wood

An Experts Meeting Organized by the Getty Conservation Institute and the Architectural Archives, University of Pennsylvania, May 12–13, 2015

Sara Lardinois and Laura Matarese

In 2015 the GCI convened a meeting with the Architectural Archives at the University of Pennsylvania to discuss conservation of exterior wood elements at buildings designed by Louis I. Kahn. The meeting brought together Kahn experts, conservation and architectural professionals and students, wood scientists, and site managers and owners to share information with the goal that the collective knowledge and expertise might benefit current and future projects at these sites. Meeting participants assessed the heritage significance of the exterior woodwork at buildings designed by Kahn; discussed philosophical and practical conservation challenges, policies, and potential solutions; and identified areas for future research, training, and dissemination. This publication summarizes the outcomes of those discussions.

The meeting was organized as part of the GCI's Salk Institute Conservation Project, under its Conserving Modern Architecture Initiative.

ONLINE

Proyecto de Estabilización Sismorresistente: Recomendaciones para el modelado avanzado de sitios históricos de tierra

Paulo B. Lourenço and João M. Pereira in collaboration with Giorgos Karanikoloudis, Federica Greco, and Claudia Cancino

This is the Spanish translation of *Seismic Retrofitting Project: Recommendations for Advanced Modeling of Historic Earthen Sites* (2018), which summarizes the methodology and presents the conclusions of the modeling phase carried out by TecMinho, University of Minho, Portugal, as part of the Getty Conservation Institute's Seismic Retrofitting Project (SRP). The University of Minho developed advanced numerical models to understand the structural behavior of SRP building typologies, and these models were also employed to validate the retrofitting techniques designed by SRP partners and consultants. This volume provides a review of advanced structural analysis techniques, guidance for finite element modeling users, an overview of constitutive models, and two examples—one of validation and one of application.

This publication is one in a series from the SRP designed to provide professionals and researchers in the field of structural engineering with a methodology for the assessment of historic earthen structures using advanced numerical modeling techniques. Additional reports in the series include *Modeling of Prototype Buildings* (2019) and the forthcoming *Simplified Calculations for the Structural Analysis of Earthen Historic Sites*.

Online publications are available free at getty.edu/conservation.

For more information about the work of the GCI, see getty.edu/conservation and

CONSERVATION PERSPECTIVES
THE GCI NEWSLETTER

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Jeffrey Levin, *Editor*
Nina Devolder, *Production Assistant*
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Conservation Perspectives, The GCI Newsletter is distributed free of charge twice a year to professionals in conservation and related fields and to members of the public concerned about conservation. Back issues of the newsletter, as well as additional information regarding the activities of the GCI, can be found in the Conservation section of the Getty's website, getty.edu/conservation.

The Getty Conservation Institute (GCI) works internationally to advance conservation practice in the visual arts—broadly interpreted to include objects, collections, architecture, and sites. The Institute serves the conservation community through scientific research, education and training, field projects, and the dissemination of information. In all its endeavors, the GCI creates and delivers knowledge that contributes to the conservation of the world's cultural heritage.

The GCI is a program of the J. Paul Getty Trust, a cultural and philanthropic institution dedicated to the presentation, conservation, and interpretation of the world's artistic legacy.

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AMERICAN FORESTS

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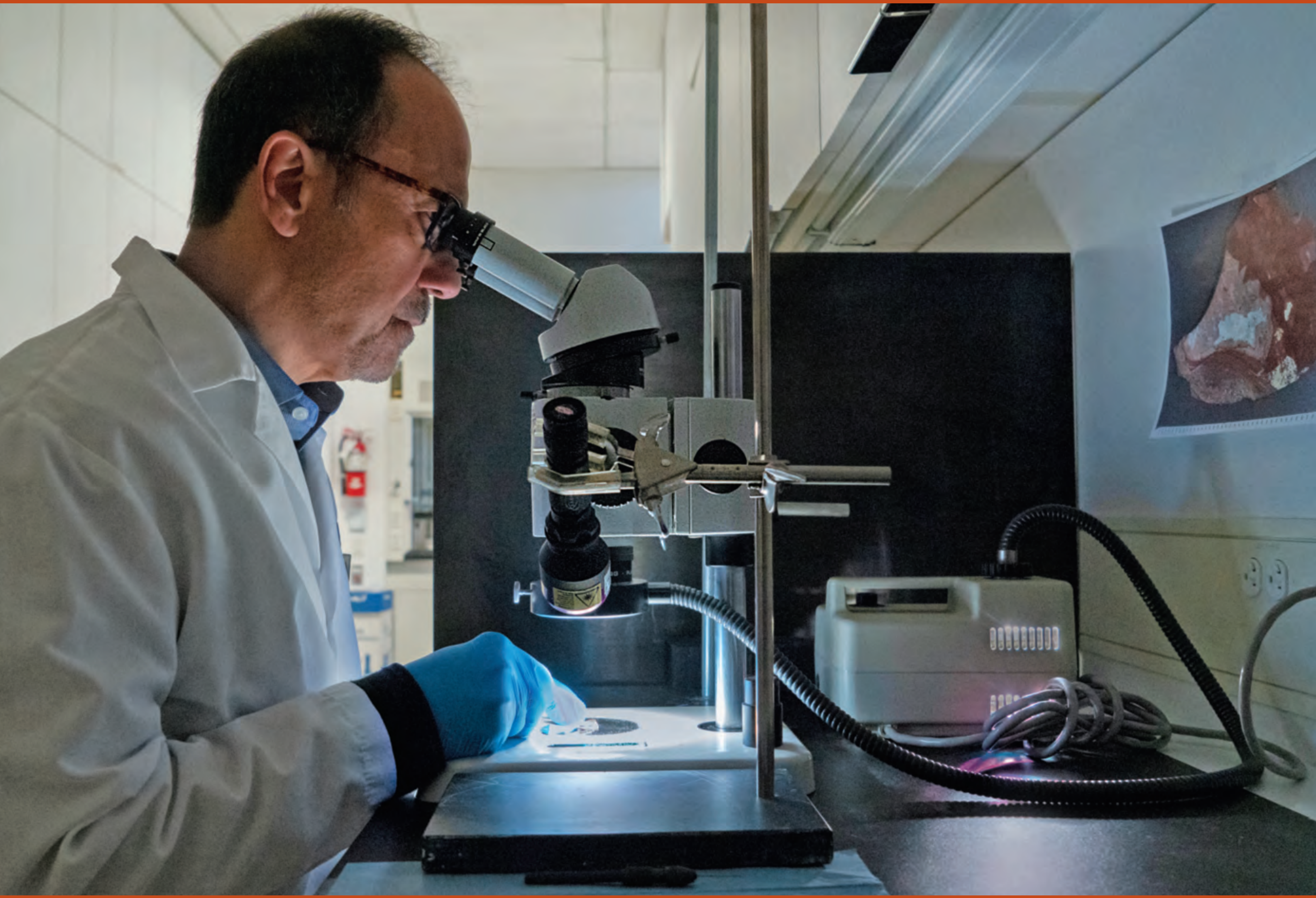
THE GCI NEWSLETTER



Herant Khanjian, a scientist at the GCI, prepares an architectural fragment from Nikko, a World Heritage Site in Japan, as part of the GCI's Asian lacquers project. The procedure—in which micron-sized lacquer layers are mechanically separated and prepared for analysis—has been used in the project to characterize the composition of individual layers and to amplify our understanding of historical material utilized in making lacquered objects. Photo: Andrzej Liguz, for the GCI.

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