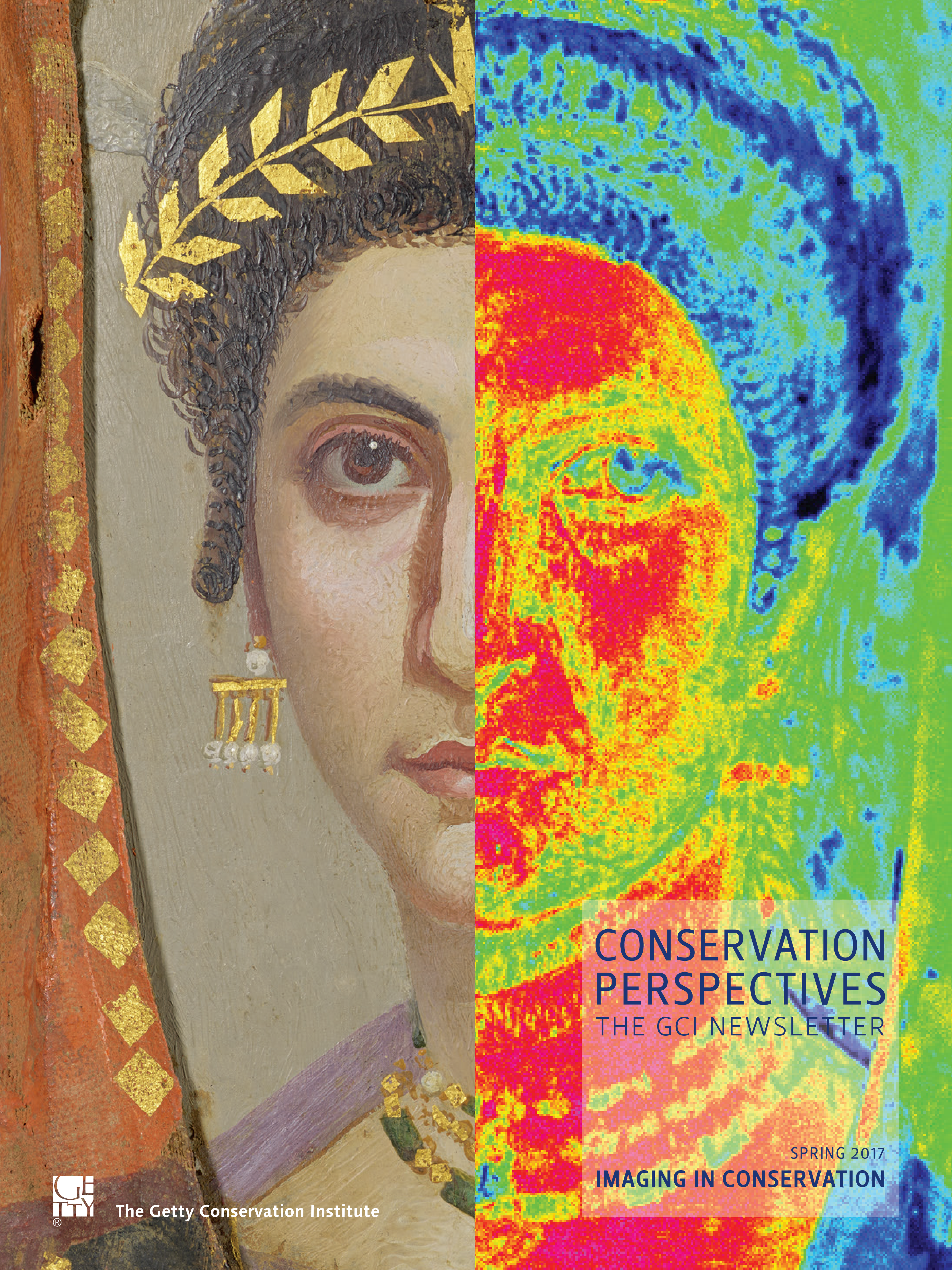


CONSERVATION PERSPECTIVES

THE GCI NEWSLETTER

SPRING 2017

IMAGING IN CONSERVATION

The Getty Conservation Institute

A Note from the Director

Photo: Anna Flavin, GCI

The adaptation by the conservation profession of technologies developed by other fields—sometimes referred to as technology transfer—has for many decades been a critical component of advancing conservation practice. Over the years, conservation professionals have displayed considerable creativity in adapting new and innovative technologies that can improve the efficiency and effectiveness of their work.

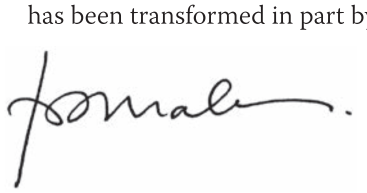
One area where this has been particularly true is the use of imaging technology. Though photography has long been an important documentation tool in the conservator's tool kit, recent decades have seen a marked increase in the number of instruments that offer the profession diverse ways of imaging material heritage. The result has been a significant expansion of the availability of certain kinds of information critical to the profession's work. In the case of objects, for example, current imaging techniques can noninvasively tell us much about the chemical composition and physical properties of materials used in the object, and they can help us differentiate between original materials and those that have been used in restoration. For built heritage, these techniques can disclose the painting techniques and current condition of ancient wall paintings, provide precise measurements of a structure, or reveal the existence of archaeological ruins hidden beneath a jungle overgrowth.

The great variety of benefits that imaging technologies can offer to conservation is the focus of this edition of *Conservation Perspectives*.

In our feature article, Giovanni Verri of the Courtauld Institute of Art in London offers a comprehensive overview of the ways advances in imaging technology have enhanced the conservation both of objects and collections and of built heritage. In the article that follows, GCI staff members Karen Trentelman and Lori Wong detail how imaging technology has been applied in selected GCI projects, both in the laboratory and out in the field. Next, Christian Ouimet, a conservation technologist with Canada's Heritage Conservation Services, describes how a number of different imaging technologies have been utilized in conservation work on Canadian built heritage. In the final article, Fenella G. France, chief of the Preservation Research and Testing Division of the Library of Congress, describes the ways various forms of imaging can not only improve the analysis of an object's materials but also reveal information the object contains—information that might otherwise be irretrievable.

In our roundtable discussion, the ways imaging has altered conservation practice are explored by a diverse group that includes George Ballard, president of GB Geotechnics, an international company focused on the forensic investigation of structures, including historic buildings; John Delaney, senior imaging scientist at the National Gallery of Art in Washington, DC; and David Saunders, formerly keeper of conservation and scientific research with the British Museum and currently the inaugural Getty Rothschild Fellow.

We hope that after taking in the contents of this edition, you'll have a well defined "picture" of the ways conservation has been transformed in part by the development and accessibility of exciting new imaging technologies.



Timothy P. Whalen

CONSERVATION PERSPECTIVES

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IMAGING IN CONSERVATION

THE GCI NEWSLETTER
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ON THE COVER
Left: *Mummy Portrait of a Woman* (detail), about 100–110 CE, from the J. Paul Getty Museum, Villa collection (81.AP.42). **Right: X-ray fluorescence map showing the distribution and relative concentration (red=high, blue=low) of lead-based pigments across the portrait.** This imaging work was done as part of a collaborative GCI–Getty Museum research project. Photo: J. Paul Getty Museum. Image: GCI.

www.getty.edu/conservation



"IT'S ALL IMAGIN

Documentation, Investigation, Visualization,

BY GIOVANNI VERRI

One normally thinks about the imaging of cultural heritage in terms of photography—whether film or digital. But the word *imaging* derives from the Latin term *imago*, which can be translated as *phantom*, *statue*, or *likeness*. In this broad sense, imaging of cultural heritage occurred long before cameras.

G TO ME”

and Communication

Drawings or sculptural replicas, which captured the likeness of their original objects, are precursors of camera imaging. A drawing representing a building and a Roman sculpture duplicating an earlier Greek model are forms of imaging, in 2-D and 3-D, respectively. Other notable examples of imaging through the centuries include the work of the amanuenses who copied earlier texts in the Middle Ages; the seventeenth-century watercolors by Bartoli of the now badly deteriorated Tomb of the Nasonii in Rome; the early nineteenth-century engravings in the *Description de l'Égypte*, which recorded various aspects of contemporary and ancient Egypt; and later, the campaigns to record in easel paintings the murals at Ajanta. The importance of these images from the past can hardly be overestimated, as they are often the only surviving witnesses to lost originals.

In modern terms, imaging may be defined as the recording and representation of the spatial distribution of information over a surface (in 2-D or 3-D) and across time (video or time-lapse). An important difference between historic and modern imaging is that the latter attempts to reduce to a minimum human interpretation—inevitable in a manual reproduction of an object—by employing a reproducible scientific methodology. In the cultural sector, this recording and representation of information about objects, collections, buildings, sites, and intangible heritage, or any combination thereof—all of which we can refer to as *assemblies*—can take multiple forms and different scales and serve numerous functions. Examples of information capture through imaging include the reflection of visible light on a surface (as in conventional photography); the transmission of X-rays through an object (as in X-ray radiography); and the effects of acoustic vibration on detached plaster (as in laser speckle interferometry). The information recorded through imaging may also include material identification (such as pigments, fibers, and metals) and condition (for example, deterioration or damage due to the environment or human activity). All fields of heritage studies benefit from the use of imaging techniques—from archaeology to architecture and from science to conservation.

ASKING THE RIGHT QUESTIONS

The efficacy of the overall methodology used to capture information is as important as the specific methods themselves. Within a sequence of investigations designed to efficiently answer a question about an assembly, where does imaging sit?

Following archival research on the physical, curatorial, and conservation history of an assembly, the next step is visual observation, with and without magnification. Based on this preliminary information, imaging techniques can offer further details. By providing information on a surface, they can permit meaningful comparisons within the assembly itself, for example by providing a distribution map of the presence of a pigment—as well as offer comparison with other assemblies, for instance by determining which objects on a shelf contain uranium glass. Moreover, they may inform more targeted investigations, which could be invasive or noninvasive, and could be image based or employ point analysis. This investigative process, iterative and incremental, maximizes the representative accuracy of the analysis and, in the case of invasive sampling, minimizes damage. In Cambodia, Light Detection and Ranging (LiDAR)—a surveying method measuring the distance to a target with laser imaging—revealed the unexpected extent of archaeological remains and the level of civilization; LiDAR enabled the identification of areas to excavate and strategies to protect

Surviving fragment of a wall painting from the Tomb of the Nasonii in Rome (left), now in the British Museum (1883,0505.4), **and a visible-induced luminescence image of the fragment showing the presence of Egyptian blue as glowing white (middle)**. Photos: ©The Trustees of the British Museum. Shared under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0) license. **A seventeenth-century watercolor (right)** executed by Pietro Santi Bartoli (1615–1700) shortly after the discovery of the tomb. The watercolor—which constitutes a prephotography example of "imaging"—appears to be more faithful to the original painting than the surviving fragment, which has undergone extensive repainting. Photo: Courtesy of the University of Glasgow Library Department of Special Collections.

such sites from deforestation, urbanization, and looting. A proper conservation management plan is difficult to design without an appropriate map of an archaeological area.

Imaging, rather than an end in itself, should be part of a methodology that selects the most suitable imaging techniques to answer initial questions and then combines those techniques with other appropriate investigative technologies.

A STEP CHANGE

Since its development in the nineteenth century, photography has been used in the cultural heritage fields to document and scrutinize. The wide-ranging commercialization of digital cameras in the 1990s prompted a step change in the development and application of imaging techniques. Since technological development, including that of digital cameras, is normally driven by military, medical, scientific, or consumer needs, heritage professionals have had to adapt others' innovations to their specific requirements.

In the past three decades, digital cameras have become easily available to the public. Their popularity has grown exponentially as they have provided increasingly refined digital tools with improved spatial resolution and quality. In addition to visible radiation, digital camera sensors can measure infrared and ultraviolet radiation, making them appropriate tools for the analysis of heritage materials. Moreover, the widespread development of other sensor compounds for infrared radiation (indium gallium arsenide and lead selenide, among others) allows capture of valuable information in other spectral ranges at reasonable cost. In recent years, thermal imaging has become available as a feature for mobile phones, and radar imaging is following soon. This versatility has changed cultural heritage research by providing accessible tools that can address a variety of questions for conservators, curators, and scientists.

IT'S ALL IMAGING TO ME

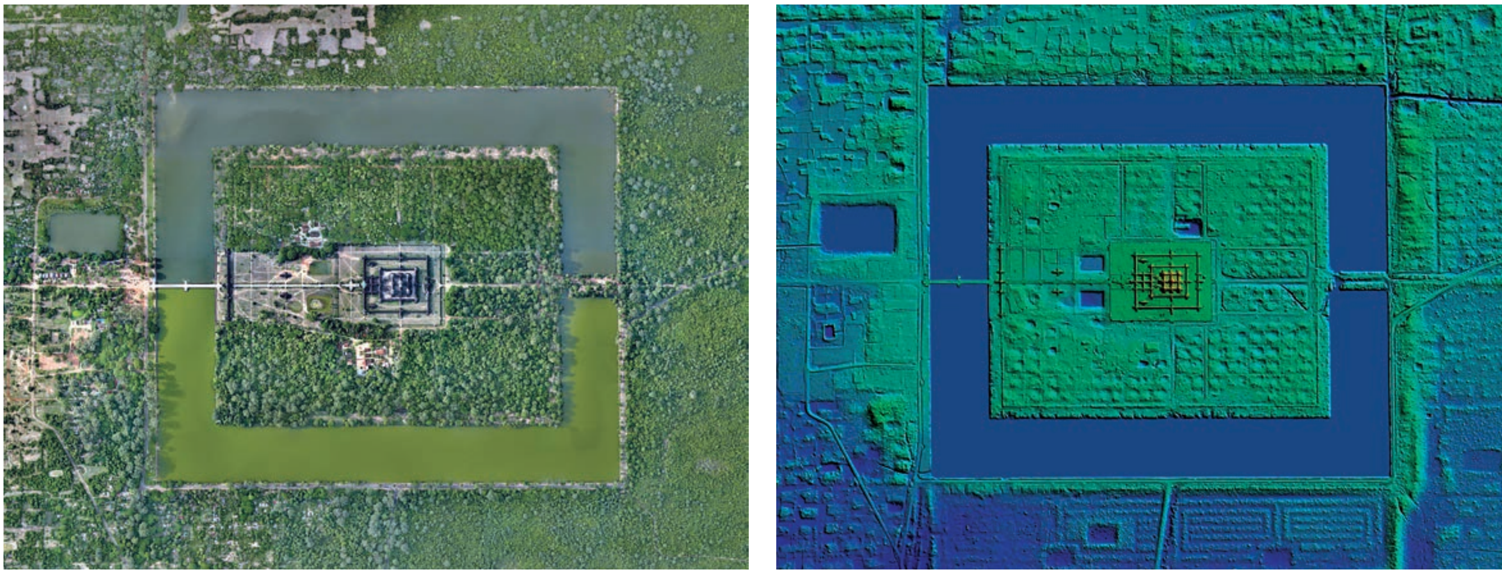
The most intuitive and common imaging techniques capture the interaction between light and the matter of which an assembly is composed. However, virtually any nondestructive investigative technique can be considered imaging if it involves more than point analysis and records spatial distribution in more than one dimension. This expands the definition of imaging to encompass a vast range of methods.

In recent years, imaging has evolved beyond basic photography and includes scientific methodologies like chemical and physical characterization to detect, for instance, the presence of organic or inorganic compounds. This type of imaging is normally referred to as chemical imaging. For example, X-ray fluorescence spectroscopy (XRF), which provides information on the presence of elements in the periodic table, is normally performed on a single point. However, when attached to an automated arm that scans the surface under investigation, XRF is transformed into an imaging technique and creates a map of the surface's elemental composition. Advanced sensors are composed of pixel arrays, shortening acquisition time. Recent innovations include techniques such as Fourier transform infrared imaging, which allows capture of spatial molecular information, in situ and even remotely. It can measure gaseous pollutants in the environment or the chemical composition of a surface. This level of spatial information obtainable in a single scan was unthinkable a few years ago. Similarly, computed tomography, a 3-D technique developed by the medical and material science industries, creates complex volumetric information by mathematically analyzing a large array of 2-D information. The same quality and clarity of information cannot be easily retrieved through conventional radiography.

The complexity, scope, scale, and variety of imaging techniques is enormous and is constantly redefined as technologies evolve. Imaging techniques can be applied at a macroscopic or microscopic level, from satellite imaging, remote sensing, and unmanned aerial vehicle imaging, which investigates large areas of the surface of the earth, all the way down to scanning and transmission electron microscopy, which scrutinizes matter at a molecular and even atomic level. The depth of penetration is another important parameter. In general terms, imaging techniques using ultraviolet radiation provide information on the surface of an assembly, while infrared, X-ray, gamma-ray, and neutron imaging can be highly penetrative and deliver information on otherwise inaccessible underlying layers.

When imaging techniques are applied directly to an assembly, as in a visible image recording color or a thermograph of a building that captures features not visible to the naked eye, they may be defined broadly as noninvasive and, often, noncontact. However, even if a sample is not removed from an assembly, investigations may cause damage. For example, ultraviolet-induced luminescence exposes an assembly to ultraviolet radiation, which may contribute to the fading of sensitive materials like organic colorants and some inorganic pigments. The same imaging techniques can also be applied to samples and are therefore classified as invasive, as in

A bronze Tibetan Sakyamuni Buddha, dating from the fourteenth to fifteenth century. The X-ray radiograph image (top) does not reveal what the neutron transmission image (bottom) does—the presence of organic materials within the sculpture. Images: ©Paul Scherrer Institut, Switzerland, Neutron Imaging and Activation Group.



Cambodia's Angkor Wat. The image produced by LiDAR scanning (right) reveals the extent and the hidden features of the archaeological site. Images: Courtesy of PT Map Tiga Internasional (PTMI) – Indonesian Geomatics Company; President Director, Francisco Goncalves.

the examination of thin sections of stone, plant and animal fibers, and cross sections of paint samples. It is therefore the nature of the application that qualifies a specific imaging technique as invasive or noninvasive. In general, however, imaging techniques are nondestructive, as the sample can, at least in principle, be reused for other investigations.

PURPOSES OF IMAGING

The specific purposes of imaging for the study and interpretation of the cultural and physical history of assemblies, and for their conservation, vary but can be consolidated into three main categories: documentation, investigation, and visualization/communication. These three categories are closely intertwined, and information from one category can also provide information for the others.

Documentation

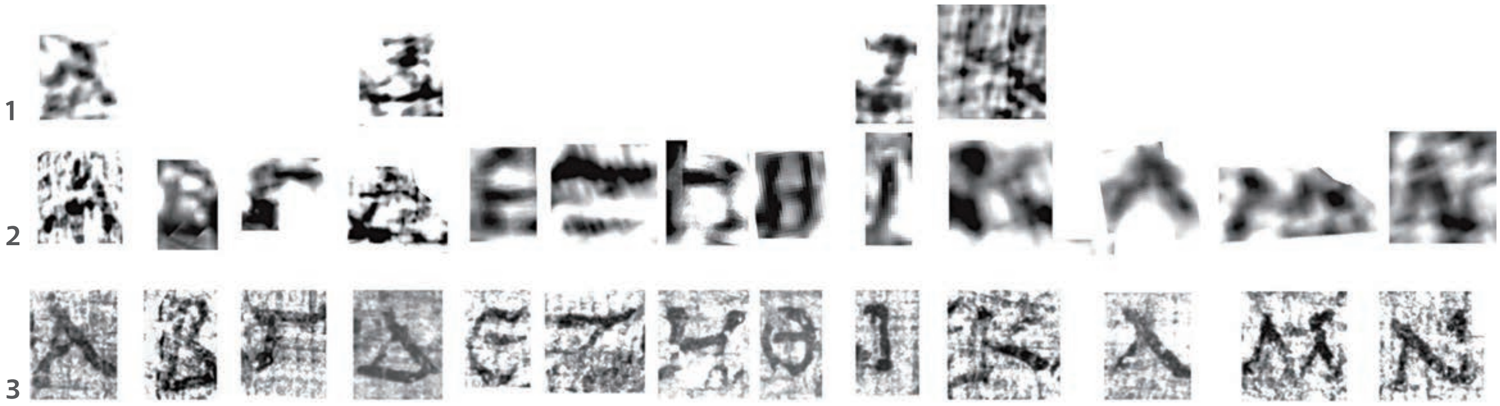
The importance of documentation has long been recognized by heritage communities, and imaging is considered one of the most efficient means of creating a record for the future. Imaging can therefore provide a *terminus post quem* for characterization of change. This type of investigation seeks to understand the making of the object, the materials of which it is composed, and the technologies used in its production, history, and use, as well as interventions it may have experienced. It also attempts to record and understand condition. Generally, the study of assemblies faces different challenges depending on the nature of the heritage.

A perusal of the list of Intangible Cultural Heritage inscribed by UNESCO confirms that video recording and photography are pivotal in the documentation of this heritage, which includes performing arts, knowledge, and skills. The faithful capture of this type of heritage is fraught with difficulties, as all of it evolves through time.

While the museum environment is commonly controlled, making it generally easier to carry out imaging in the museum context, the documentation of museum collections nevertheless presents its own challenges. Collections are often highly heterogeneous and may comprise large numbers of objects. Some objects in museum collections may be extremely susceptible to damage and deterioration, making them difficult to document. For example, the texts and hidden contents of very fragile papyri and religiously sensitive objects remained inaccessible to researchers until the recent application of penetrative techniques like X-ray contrast imaging and neutron transmission facilitated the visualization of their contents. Imaging techniques can provide useful and ingenious solutions to a whole range of problems by analyzing and documenting multiple objects at the same time, in their location, and by offering clues for condition and risk assessments.

The documentation of buildings and sites also has its challenges. Built heritage, by its nature heterogeneous, covers vast surfaces, may be difficult to access, and presents a variety of conservation conditions. Imaging techniques can offer suitable solutions, as many methods have evolved both to become highly portable and to provide quick results. Examples include photogrammetry, ground penetrating radar, 3-D laser scanning, LiDAR, and multispectral imaging in the ultraviolet, visible, and infrared ranges, which, when

A now destroyed arch from Palmyra, Syria, re-created in 2016 in London's Trafalgar Square using 3-D imaging and 3-D printing technologies. Photo: © Amanda Lewis, iStock Editorial, Getty Images.



A papyri scroll discovered at Herculaneum (PHerc.Paris. 4, in the collection of the Institut de France). X-ray phase-contrast tomography (XPCT) revealed Greek alphabet letters inside the papyri without unrolling it. **The letters, as revealed by XPCT**, can be seen above on lines 1 and 2; on line 3 are infrared images of the same letters from an unrolled papyrus (PHerc. 1471 in the National Library in Naples), which was used as a reference for the writing style of scroll PHerc.Paris. 4. Photo/Images: Reprinted by permission from Macmillan Publishers Ltd: *Nature Communications* 6, Article number: 5895 (2015).

coupled with flashtubes, allows capture of spatial information in otherwise adverse conditions.

Investigation

The importance of imaging techniques for comprehending the cultural significance of heritage extends to all relevant disciplines—including conservation. Understanding the making of and the history of assemblies helps establish significance and provides the foundation for conservation interventions.

In some instances, the ability to visualize hidden information has crucial implications. Conservators sometimes face pressure to clean and remove superficial material from paintings to reveal hidden features, as with blackening and fire-related damage. Whereas the superficial material may not be original and therefore could in principle be removed, practical considerations may make its removal unsafe for the stability of the painting. And cleaning is of course labor intensive and costly. The ability to visualize what may lie underneath a darkened layer could facilitate a satisfactory compromise between the needs of documentation and study and those of safe conservation.

A fundamental role of conservation is understanding original and added materials; the latter may be valued, as in the case of historic interventions, or unwanted, as with past conservation treatments. Understanding the spatial distribution of materials informs conservation strategies and minimizes damage. Imaging can also help identify rates of change, diagnose condition, and investigate decay mechanisms. Imaging technologies have also proven essential in monitoring and assessing the efficacy of conservation interventions. The important contribution made by imaging techniques is the ability to extend information from a single point, to another point, to a surface, and through the passage of time, thereby enabling a careful interpretation of phenomena.

Visualization and Communication

An important aspect of imaging is visualizing the results of documentation and investigation. Images are an efficient means of communicating complex ideas to heritage professionals, funders, and the general public. Several institutions have begun systematic digitization campaigns, which, along with their documentary value, enable stakeholders to access information and advance cultural heritage study.

An important difference between digital and analog imaging is that the digital signal converts information into numerical values, which can be processed to improve visualization and, in some cases, make visible what is otherwise invisible to the naked eye. Developments in the computing abilities of modern processors have enabled complex data processing and presentation of results. The information is all contained in the images, but the extraction of the information of interest is the challenge.

Imaging also plays a vital role in the virtual reconstruction of deteriorated or lost assemblies. Efforts have been undertaken over the years to attempt to visualize, in 2-D and 3-D, the appearance of ancient landscapes, cities, buildings, and objects. For example, a physical reproduction of a monument closed to the public makes it available to all, resulting in less pressure to open it to tourism, which benefits preservation. This happened at Lascaux in southwestern France, where prehistoric paintings faced severe biodeterioration, forcing authorities to close the cave to the public and provide visitors instead with replicas of portions of the cave.

CHALLENGES AND FUTURE DEVELOPMENTS

Digital imaging is a subset of digital heritage, which itself was the subject of a 2003 UNESCO charter. Whether born digital or converted into digital format, digital images are not only used for the conservation and study of nondigital objects but are themselves objects of conservation policies. The development of digital data standards is a field of research and development in its own right. Such standards will ensure data interoperability and long-term usability in a world struggling with increasing amounts of data and ever-changing technologies.

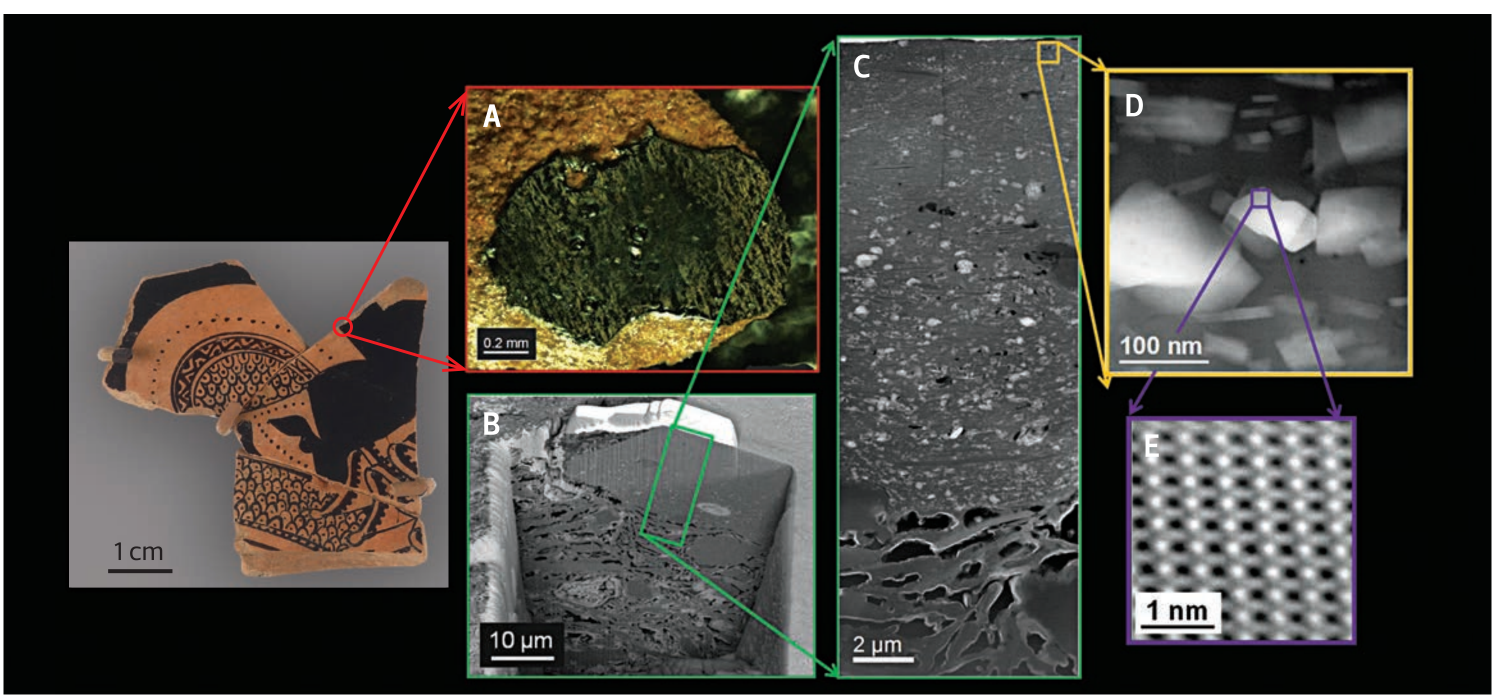
Perhaps more than many other investigative point-analysis techniques, imaging has seen an early democratization of many of its tools (often designed to be used in situ) for the analysis of large and immovable objects, for the identification of representative sampling areas, and for recording actions that cannot be repeated or reversed, such as an archaeological excavation or the act of cleaning a wall painting. Imaging is an invaluable tool for the study and communication of world history. Recent intentional destruction of cultural heritage has emphasized the importance of images, which, captured by professionals and tourists, allow for the virtual and sometimes physical reconstruction of lost heritage. Experienced and shared by millions, the world's heritage lives on in those images. Tragically, the method chosen to advertise destruction of cultural heritage was also imaging, through truculent and disturbing videos.

With the advent of Internet-based media, information is produced, published, and shared as never before. In what some have called our current "post-truth" era, it is important to ensure robust quality control of the data captured and distributed, online or not. This is the case, for example, with the color reconstructions of lost polychromy of sculpture and architecture—a popular online subject—which often do injustice to the artists' skills and trivialize the efforts of those seeking to study the subject seriously. A benefit of visual digital reconstructions over physical reconstructions is that they are more easily updated and improved when more robust scientific evidence is found. Moreover, it is likely that physical replicas will soon need conservation themselves; therefore, a good balance between research and development in the field of replication and research focused on conservation is crucial in a world of scarce resources. Consider that these new replicas could be the *Harmodius and Aristogeiton* of our time—lost now, but replicated in antiquity in different media. The engagement and participation of the public in heritage discourse make heritage more relevant and, when managed conscientiously, will help sustain it. For example, digital information is more easily shared and grouped, which helps to create ad hoc databases of information. In addition, accessible open source or free software allows the creation and sharing of 3-D models of built heritage and of museum objects. With public collaboration and a sensible allocation of limited resources, it will be possible to increase awareness of the importance of documentation and appropriate conservation strategies and to fund research for heritage understanding and preservation.

With increasing public interest in imaging techniques and their capacity to visually communicate to experts and the public alike, it is possible that the demand for more sophisticated and accessible imaging techniques will continue to inspire technological progress, which, in turn, will expand the heritage professional's toolbox (including the currently less accessible chemical and physical imaging). Imaging techniques are uniquely suited to promote dialogue between fields of enquiry, including archaeology, history, art history, science, and conservation. Ultimately, those charged with the responsibility for heritage preservation need to be prepared to adapt existing tools—and design new ones—to address the complexity of heritage protection. Through the use of imaging tools in heritage documentation, investigation, visualization, and communication, it is possible to better assess connections among assemblies, understand and define their significance more effectively, and, eventually, design conservation interventions, assess their efficiency, and monitor their long-term effects.

Like pixels of an image, heritage professionals and the public can diligently and conscientiously contribute to defining a clearer and brighter picture for the future of our past.

Giovanni Verri is a reader at the Courtauld Institute of Art in London.



Images at increasing magnification of a fragment from an Attic red-figure kylix (attributed to the Triptolemos Painter, Greek, 490–470 BCE, JPGM 90.AE.35.42). A sample of black gloss (A) was removed from the edge of the fragment and sectioned using focused ion beam milling (B) to produce a cross section (C), from which transmission electron microscopy can provide images of individual crystal grains (D), and atomic resolution electron microscopy can show the arrangement of individual atoms in the crystal lattice (E). Fragment photo: J. Paul Getty Museum. Microscopy images: GCI and The Aerospace Corporation.

IMAGING AT WORK AT THE GCI

BY KAREN TRENTELMAN AND LORI WONG

AT THE GETTY CONSERVATION INSTITUTE (GCI), THE INCORPORATION OF RECENT IMAGING ADVANCES into our work has allowed us to explore new avenues of research, develop holistic conservation strategies, and more effectively communicate what we do.

Imaging has expanded far beyond its traditional role as a means of documentation. Newly developed imaging methods provide a wide range of information critical to the understanding and conservation of cultural heritage—from surface properties such as color and texture, to the location and shapes of underlying features, to the chemical composition or physical properties of individual components. Imaging not only helps distinguish original from restoration materials; it can also document their precise location across an object. It aids in the visualization of relationships and correlations among different components of an object, revealing, for example, where a pigment might be aging differently in different binding media. Thus, imaging allows us to better understand how objects were made and how they may have changed (or be changing) over time—essential information for conservation planning and for improving conservation interventions. Additionally, because images are a universal language, imaging helps convey complex information to a wide audience, enabling interdisciplinary work and effective communication with a broad range of stakeholders, including scientists, conservators, site managers, architects, engineers, art historians and scholars, and the general public.

The scale of GCI projects can vary from an entire archaeological site or building, to a collection of objects or an individual work of art, to a minute sample removed for in-depth study. The aims of these projects are equally wide-ranging—from developing a conservation and management plan for an archaeological site, to understanding how artistic practice was organized within a workshop, to identifying individual paint layers in a cross section. As such, our imaging needs are diverse, broad ranging, and multiscale. To meet these needs we have acquired specialized equipment, enhanced our in-house expertise, and collaborated with outside partners to explore emerging technologies, all to augment our work to improve conservation practice.

Imaging has long been an integral part of the GCI's workflow, and an example of advances in imaging technology over the years increasing our ability to address research questions is found in the GCI–Getty Museum collaborative study of *An Old Man in Military Costume* by Rembrandt. The existence of a hidden underlying painting—an image of a man—was first discovered in 1968 through X-radiographic imaging. Conservators and curators were eager to "see" this hidden painting, as it could shed light on the artist's working process. In the early 1990s, the painting was studied with neutron activation autoradiography. This imaging technique more clearly revealed certain components of the hidden figure, such as the robe he was wearing, and significantly, it also provided information about the distribution of chemical elements in both the underlying and the surface painting, allowing some of the pigments to be inferred.

Left to right: Detail from Jean Bourdichon's *Louis XII of France Kneeling in Prayer, Accompanied by Saints Michael, Charlemagne, Louis, and Denis* (leaf from the Hours of Louis XII, 1498–99, JPGM Ms. 79a [2004.1]) and X-ray fluorescence maps showing the distribution of gold, silver, and bismuth. The presence of bismuth was discovered using spot analysis, but through imaging the full extent of its use was revealed. Photo: J. Paul Getty Museum. Images: GCI.

Still, questions remained. Nearly twenty years later, a preproduction model of the Bruker M6 macro-X-ray fluorescence (XRF) scanner was brought to the Getty. The painting was scanned in collaboration with Joris Dik of the University of Technology, Delft, and Koen Janssens and Geert van der Snickt of the University of Antwerp. The resulting maps provided the clearest information yet about the distribution of chemical elements across the two paintings. These element maps enabled the creation of a digital color reconstruction of the underlying figure and are now helping conservators and scholars understand how the pigments in the surface painting may have changed over time. However, there are areas of the underlying painting that remain a mystery. Notably, current imaging technologies cannot tell us what, if anything, the underlying figure is wearing on his head. Although we cannot resolve this question today, the advancement of imaging technologies will undoubtedly enable us one day to answer this and other questions.

Until recently, most scientific imaging equipment could not effectively or safely be transported to more challenging environments, such as remote archaeological sites. Today, however, many imaging technologies once available only in a museum laboratory have been adapted with increasing portability for use in the field. A system that fits comfortably into a backpack, utilizing relatively simple and affordable camera equipment and filters, and enabling imaging across the visible, infrared, and ultraviolet regions of the electromagnetic spectrum, has become a regular part of the investigation phase of our projects in remote areas of Egypt, China, and Italy. Such portability proved especially valuable in work in the Tomb of Tutankhamen, in the Valley of the Kings at Luxor. Policy-based restrictions on sampling necessitated greater emphasis by the GCI–Ministry of Antiquities project team on noninvasive examination methods; imaging therefore played a significant role in the investigation of the tomb. Technical imaging of the burial chamber wall paintings provided key information for understanding Egyptian wall painting technique, current condition, and ancient and contemporary interventions undertaken in the tomb. False-color imaging—combining visible- and infrared-reflected images—clearly visualized and mapped areas of modern repainting. These areas had not been recorded previously, and the findings regarding the full extent (i.e., distribution) of this intervention would have been impossible to obtain with point analyses. Experiences like these demonstrate the power of imaging technologies, especially when combined with other forms of invasive and noninvasive investigations, to reduce the number of samples required and, when sampling *is* necessary, to better target areas that provide the desired information.

In multi- and hyperspectral imaging, the capability of the portable imaging system is extended by increasing the number of bands across the electromagnetic spectrum over which images are collected. Besides providing images, these powerful systems allow the extraction of reflectance spectra at individual points (or selected areas) across the image, facilitating the characterization or identification of pigments and dyes. Combined with large-scale XRF mapping, which offers complementary information in the form of elemental analysis, these imaging techniques have revolutionized the examination of painted surfaces, providing unprecedented insight into the original construction and subsequent deterioration of works of art.

An early example of the combined use of these two imaging technologies at the Getty was the study of Jackson Pollock's *Mural*. Imaging helped answer questions about how this large and complex painting was created. With the collaboration of John Delaney of the National Gallery of Art, select areas of the eight-by-twenty-foot painting were imaged using a scanning hyperspectral camera, originally designed for terrestrial remote sensing but modified for examining works of art. Macro-XRF maps of the same areas were collected, which, together with the hyperspectral images, allowed the research team to virtually "unpack" the paint layers, determining the order in which Pollock laid down the numerous overlapping colors and shapes. Without the use of both modes of imaging, this information would have been possible only through the removal of samples for cross-sectional analysis. The inclusion of the hyperspectral images and XRF element maps in the subsequent GCI–Getty Museum exhibition proved to be an extremely engaging means of communicating the results to the public. Many visitors viewed the painting, moved on to study the imaging results displayed in an adjacent gallery, and then returned to view the painting again with the new insight provided by the imaging results.

Imaging is more than static pictures capturing a specific moment in time. Video and time-lapse photography can help us understand dynamic processes such as deterioration, and they can also powerfully communicate complex information. In Dunhuang, China, flaking paint is a recurring problem at the cave temples of the Mogao Grottoes. To test a hypothesis that a previous treatment material, polyvinyl acetate (PVAc), in combination with soluble salts present in the wall paintings might be a factor in the continuing deterioration of the paintings when subjected to uncontrolled environmental conditions, the GCI–Dunhuang Academy project team used time-lapse photography to monitor tiny paint samples subjected to changing humidity levels in an environmental chamber. The resulting video clearly showed the contraction and expansion of the paint samples under fluctuating

Hyperspectral imaging of Édouard Manet's *Jeanne (Spring)* (oil on canvas, France, 1881, JPGM 2014.62). The imaging will provide information about the materials and methods used to create the painting. Imaging conducted by John Delaney of the National Gallery of Art. Photo: Douglas MacLennan, GCI.

Two-dimensional condition maps of the interior decorative surfaces at Kasbah Taourirt, Ouarzazate, Morocco (left) converted into three-dimensional models to correlate interior conditions with structural problems (right). Images: Lori Wong and Samuel Whittaker, GCI.

humidity. Though it is often difficult to translate what happens on test samples at the microscale to full-scale paintings, this video was a persuasive tool in communicating the potential impact of unstable environmental conditions to a range of stakeholders and highlighted the importance of preventive measures to inhibit further loss.

At Kasbah Taourirt in Ouarzazate, Morocco, site of a GCI Earthen Architecture Initiative project undertaken in collaboration with the Centre de Conservation et de Réhabilitation du Patrimoine Architectural des Zones Atlasiques et Subatlasiques, the interior painted decoration was at risk of loss because of the poor condition of the earthen structure. Imaging methods were critical to the development and implementation of integrated solutions that both stabilized the architecture and preserved the interior painting. In conjunction with Carleton Immersive Media Studio, orthographic photo-elevations of the painted surfaces were generated from a photogrammetric model using MeshLab, an open source software, and were used as base images for condition mapping. Tying these two-dimensional condition maps to the overall coordinate system of the surveyed site enabled the creation of a three-dimensional model in which structural conditions, such as cracks and other architectural features, could be correlated directly with the painted decoration. These models were an important tool in the assessment, treatment development, and planning phases of the project, and they helped communicate to the structural team how to design and implement stabilization measures that avoided fragile areas of painting. These advances in three-dimensional imaging and computational modeling, utilizing photogrammetry—and, increasingly, laser scanning—allow for better correlation of conditions between the interior and exterior, improve conservation treatment design and implementation, and enhance our ability to monitor change, such as the widening of a crack or the increase of delamination of an area of painted plaster.

As these select examples demonstrate, imaging technologies have proven a great asset in the GCI's work as we document, study, investigate, plan, treat, and monitor our artistic legacy. Our current suite of imaging technologies has helped us carry out our work more efficiently, with increased specificity and accuracy—and, crucially, less invasively. It is the nature of technology to advance, with each successive development adding new capabilities and functions. Significantly, for the imaging of cultural heritage this progress means that we can look forward to increasingly portable and versatile technologies. It will be exciting to see those developments that lie ahead and the new tools they will provide as the GCI continues to develop a range of resources for conservators, conservation scientists, and other heritage professionals.

Karen Trentelman is a GCI senior scientist. Lori Wong is a GCI project specialist.

DISCO: DATA INTEGRATION FOR CONSERVATION SCIENCE

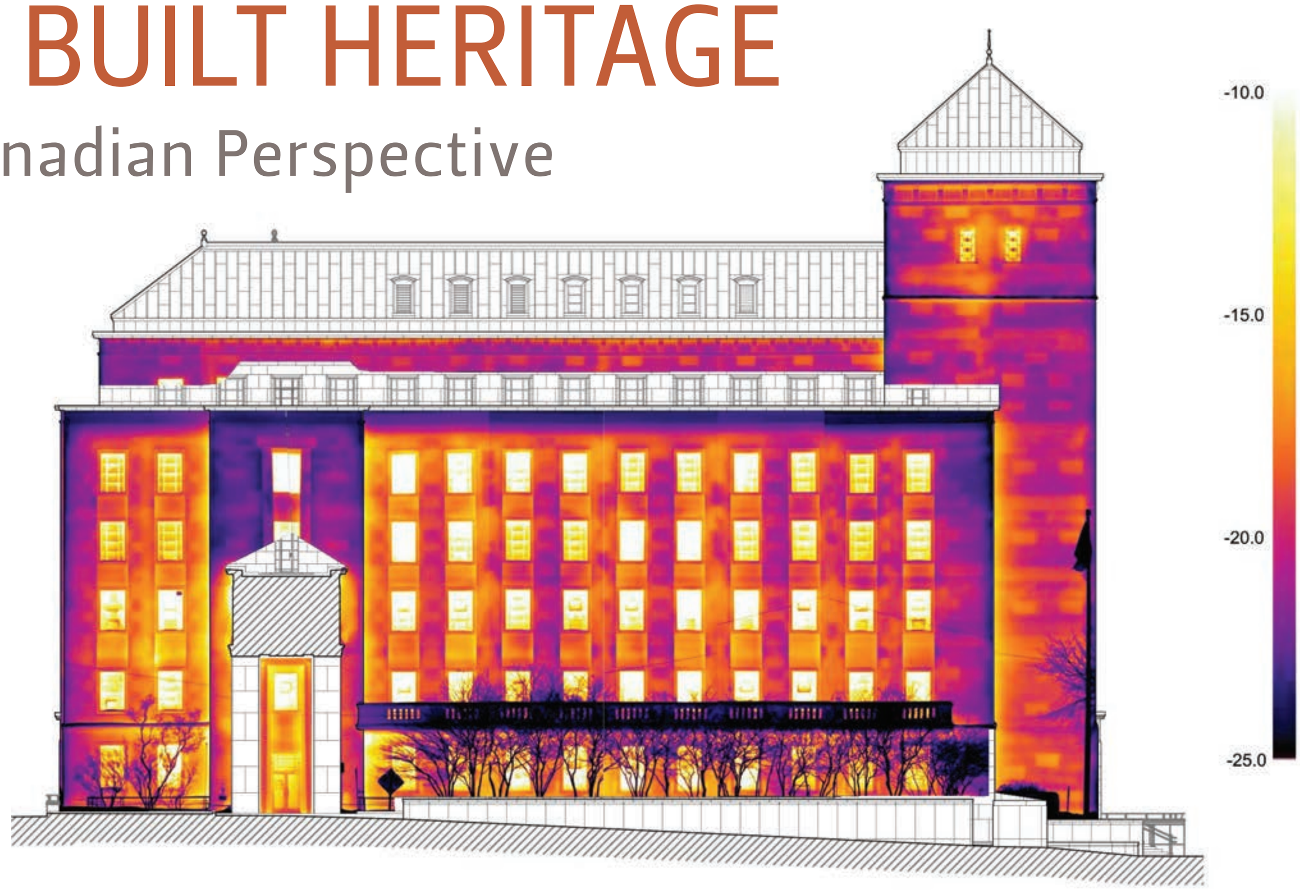
Imaging technologies have the power to provide detailed information across large areas and at multiple scales, but they also generate very large data sets that must be stored, organized, and managed. Importantly, they must also be integrated with other data (including text and non-image-based measurements) to inform conservation treatment and historic, artistic, technological, and cultural interpretations.

To address the challenge of integrating the many different types of data relating to cultural heritage research, the Getty Conservation Institute in 2013 launched the DISCO project (Data Integration for Conservation Science). DISCO is developing management tools for scientific data—which increasingly is generated by imaging technologies—to enable it to be more easily searched, compared, integrated, and eventually, shared. Using the GCI's Arches system as a data-management platform, DISCO will enable researchers to manage scientific data organized according to uniform standards. Making multiple different data types compatible will facilitate interrogation, visualization, and data interpretation, helping researchers, for example, draw comparisons and correlations among different works of art, different studies, and different points in an object's history.

A picture is worth a thousand words, but digital and scientific images may consist of a million or more data points. As we adopt new technologies, DISCO and Arches are creating new means of managing data to enhance the ways scientific and technical information contribute to the conservation and understanding of works of art.

IMAGING IN SERVICE TO BUILT HERITAGE

A Canadian Perspective



BY CHRISTIAN OUIMET

HERITAGE CONSERVATION SERVICES (HCS), a unit within the Canadian federal government's department of Public Services and Procurement Canada, plays a significant role in assisting all federal government departments in the conservation of historic places. HCS's task includes providing technical expertise for the protection and management of designated heritage buildings, landscapes, and engineering works. Among these are about two hundred national historic sites under the purview of Parks Canada and more than one thousand federally owned heritage buildings across Canada, as well as Canadian war memorials in Europe.

A fundamental aspect of the technical services HCS provides toward the protection and management of these sites is recording and documentation. Of the various recording methods that HCS applies to built heritage, imaging techniques are the ones most commonly used and most accessible: architectural photography or record photography, photogrammetry, and rectified photography. Photographic-based imaging techniques have evolved significantly in recent decades, providing conservation professionals with a range of tools that facilitate documentation, investigation, diagnosis, and monitoring. These tools are critical to HCS's work, which adheres to the pan-Canadian *Standards and Guidelines for the Conservation of Historic Places in Canada*. These standards guide conservation decision-making, with the ultimate aim of protecting heritage values.[1] This conservation decision-making process follows a sequence of actions that includes understanding the historic place, planning for its conservation, and intervening. Imaging is also an important tool for communication and dissemination.

Imaging built heritage can be challenging and very different from working in a studio or museum environment. There are many factors that must be taken into account. In Canada, one is frequently faced with harsh conditions and electricity constraints when working at remote sites. Selecting the most appropriate equipment is important in ensuring successful imaging processes, keeping in mind the required information, level of detail needed, and purpose of the work to be undertaken. Lighting is a major issue, as the photographer must work with lighting conditions present during the allocated time period, with limited options for augmentation. Available lighting must be considered, as well as the possibility and advisability of supplementation with flash photography. Since inclement weather is common, it is imperative to determine the optimal day and time to undertake the work. For challenging high-contrast conditions, images can be bracketed—identically positioning images taken at different exposures to ensure that the details in both shadowed and bright areas are captured. Using software, these images can then be combined into a single photograph by creating a High Dynamic Range (HDR) image to show all details. (HDR images often can have a surreal visual quality, however.) Accessibility is another issue, given the scale and location of some sites. HCS employs long poles, aerial work platforms, cranes, kite aerial photography, and unmanned aerial vehicles to capture the desired point of view.

An elevation of the West Memorial Building in Ottawa captured with approximately thirty individual thermography images that were rectified and mosaicked into a single overall image using existing building elevations. Image: HCS, Technical Services, Public Services and Procurement Canada.

UNDERSTANDING THE HISTORIC PLACE

The first step in the conservation decision-making process as identified in the standards and guidelines is to understand the historic place. This includes—through research and investigation—identifying and describing character-defining elements that contribute to the overall heritage value of the place. Record photography is generally used to capture and graphically convey a sense of the site or space and its character-defining elements and heritage values. Such images help to itemize, explain, and communicate the important elements in heritage values assessment reports and conservation guidelines. The resulting photographs are normally contextual in nature, assisting in the understanding of a site and in planning for future documentation work. A complete posterity record is also typically produced during the first phase of a project to ensure that information is available to future generations in the event of catastrophic loss, demolition, or substantial alteration.

Record photography, which captures a specific moment in time and perspective, is the simplest form and most widely used of technical photography tools for documentation and communication purposes. It requires only basic camera skills—proper focus, exposure, and composition. Advanced photographic techniques can be utilized to augment or enhance record photography. These techniques include perspective control—using shift lenses or digital correction for the removal of perspective through rectification—and image stitching to produce high-resolution panoramic photos.

Another important aspect of the understanding phase is the process of investigating and documenting current conditions and changes over time. Rectified photos of building elevations are often used as a visual basis for recording conditions and then referred to for analyzing potential deterioration mechanisms. Systematically replicating an image from the same viewpoint over time can provide information on a site's evolution and rate of physical change. This is a simple and effective method for detecting change, using a baseline record against which comparisons can be made.

Photogrammetry (see ahead) can be used to produce orthographic scaled images, from which accurate measurements can be obtained, and it can provide the basis for producing scaled architectural drawings, such as elevations and sections. The resulting images can be used for on-site inspections or condition assessments. A popular and effective use of photogrammetry is to periodically capture a building or site to monitor for movement and to determine whether conservation interventions are required.

Thermography is another imaging tool available to investigate the performance and condition of historic places. This technique can help to determine the wall composition or assembly of a building or to detect performance issues or deficiencies, such as air leakage or water damage. These images are usually presented in different colors, representing variances of temperature. For this use of thermography to be effective, there must be sufficient temperature difference between the interior and exterior of the building (winter months usually are best). This technique is normally limited to the building exterior, since temperature differentials are less pronounced for interior floor and wall partitions.

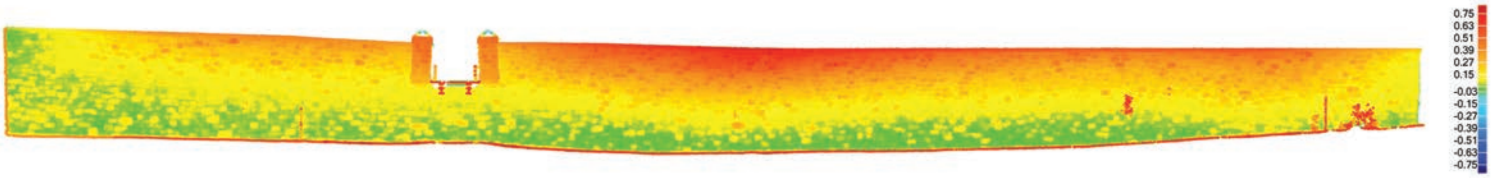
PLANNING

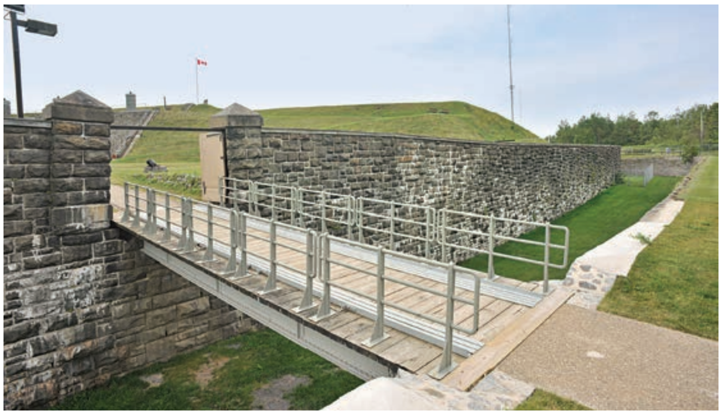
The second phase of the conservation decision-making process is planning for a historic site's conservation. This phase, which includes selecting appropriate and sustainable uses for a heritage place, often entails carrying out impact assessments and determining the primary conservation approach. Having comprehensive record photos as a reference is a tremendous aid to the planning process. For example, HCS produced rectified images of the exterior masonry walls of the Fort Henry National Historic Site of Canada—an 1830s fortification located along the St. Lawrence River—as a basis for stone conservators to identify ashlar blocks in need of repair or replacement.

Conservation professionals also require accurate and detailed metric information, including building elevations, sections, and detailed drawings of character-defining elements, to assist in preparing drawings for architectural interventions and estimates of materials required for conservation work—such as of the stones, windows, rafters, and other architectural elements, as in the case of the rehabilitation of Fort Henry. Photogrammetry, a primary imaging technique to capture metric information, has been used since the invention of photography. Photogrammetry in its various forms relies on the manipulation of photographs using mathematical principles combined with known or calculable variables of the subject and camera to derive metric information. It involves determining the exact location of the camera in relation to the subject when the photo was taken. The process removes distortion, applies known scalar control, and matches common points from one photograph to another through triangulation to orient the images.

In recent years the field of photogrammetry has grown significantly, mainly because of advancements in photogrammetric software that provide automated identification and matching of common points in multiple images, and the refinement of a technique known as Structure from Motion (SfM) photogrammetry. SfM enables the estimation of the dimensions of three-dimensional structures from two-dimensional image sequences combined with metric information captured through a series of camera movements. Photogrammetry offers significant advantages when contrasted with other comparable techniques (such as terrestrial laser scanning) because of the simplicity of the equip-

Various accessibility tools for photography used by Canada's Heritage Conservation Services (HCS), including (1) an elevated platform, (2) kite aerial photography, and (3) a photographic mast. Photos: HCS, Technical Services, Public Services and Procurement Canada.





Above: A fortification wall at Lévis Forts National Historic Site of Canada, Fort No. 1. Top: A single photogrammetric model shows that the wall is out of plane by 0.7 meters (3 feet). Photo/Image: HCS, Technical Services, Public Services and Procurement Canada.

ment required—one needs only a camera and photogrammetric software—and its relatively low cost. Advanced photogrammetric software packages, however, can run into tens of thousands of dollars.

INTERVENING

The third and ultimate phase of the conservation decision-making process is intervening. It includes undertaking project work—either through preservation, rehabilitation, or restoration activities—and carrying out regular maintenance. When physical changes to character-defining elements are undertaken, they must respect and protect the place's heritage value. The documentation work done during the understanding phase helps conservation professionals clearly recognize the elements that contribute to the heritage value, thereby helping to ensure sensitive interventions.

The various outputs of metric records that result from HCS imaging activities—which include architectural plans, sections, and elevations—are essential for carrying out physical interventions. For example, three-dimensional models produced by HCS primarily through photogrammetry have been used with robotic digital fabrication technologies for replacement of deteriorated stone bas-reliefs on the facade of the East Block building of the Parliament Buildings National Historic Site of Canada, in Ottawa. Documentation records produced by HCS (including those produced through imaging) were also essential to implementing conservation interventions in the stabilization of masonry walls at Fort Henry. The physical changes produced through interventions are typically recorded using various imaging techniques before, during, and after their implementation.

DISSEMINATION

In addition to their application within the various phases of the conservation decision-making process, a range of digital imaging techniques also contribute to communicating the heritage value of historic places to a variety of stakeholders, including researchers and the general public. This use is particularly important when access to a historic place is limited or when its location is remote.

Panoramic images are an effective communication tool that can be employed to help overcome some limitations inherent in photographic equipment, namely focal length and resolution. This technique typically consists of stitching together multiple images to facilitate ultrahigh resolution and extremely wide-angle perspectives. Images can also be processed together to produce interactive 360° photo spheres, which the user can zoom into and pan around from the perspective of the camera position. More advanced communication tools, such as animations of photogrammetric models or virtual tours with the use of panoramic images, can also be produced. This information can be supplemented with descriptions or historic information, either in audio or text format. In addition, photogrammetric models can be used to demonstrate how a site is used. The animation of a heritage lock system can show how it assists boats to ascend or descend a river system, for example.

SUPPORTING CONSERVATION

Recording and documentation activities support each phase of the conservation decision-making process. Of those activities carried out by HCS, imaging techniques are the most commonly used and most accessible in their application to built heritage conservation. Outdoor recording of built heritage often requires special tools to provide appropriate vantage points for image capture as well as careful planning, given the often extreme and unpredictable nature of the Canadian climate. Advancements in imaging techniques, including increasingly accurate metric data and improved thermographic imaging techniques, are improving the ability of HCS to document and analyze sites and monuments.

Image-based documentation also greatly assists in providing clarity within conservation projects. Visual and metric information plays a key role in ensuring that various stakeholders gain a clear understanding of the heritage value and character-defining elements of historic places and that they speak the same language when communicating about it. This in turn plays a positive role in scheduling and project budgeting, often resulting in overall cost savings.

While technical innovations in digital imaging are collectively supporting better conservation outcomes, there are issues to address. The increasing ease of digital image capture and the proliferation of an ever-expanding range of digital image data types have brought to the forefront the task of managing an ever increasing volume of digital image data. The benefits of innovation in digital imaging are many, but accompanying those benefits are the challenges of accessing and preserving the data it produces in the future.

Christian Ouimet is a conservation technologist with Public Services and Procurement Canada's Heritage Conservation Services. He was assisted in the preparation of this article by John Gregg and Shawn Kretz, also with Heritage Conservation Services.

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1. *Standards and Guidelines for the Conservation of Historic Places in Canada*, 2nd ed. (2010): www.historicplaces.ca/media/18072/81468-parks-s+g-eng-web2.pdf

VISUALIZING CONSERVATION SCIENCE

Communicating Data through Imaging

BY FENELLA G. FRANCE

FOR COLLECTIONS WITH DIVERSE TYPES OF MATERIALS including paintings, drawings, sculpture, decorative arts, and—of particular importance for libraries and archives—manuscripts, maps, and other historical documents, imaging not only presents a means of studying the objects but also, through digitization, allows greater access and preservation. Along with many other conservation tools, imaging has expanded in scope over the past fifteen years or so, both through advances in technologies used to capture images and with the accompanying development of new and different data types. Traditional photography enabled accurate documentation of an object before and after treatment, and for many years images were considered primarily that—a form of documentation. As the ability to scan and map spectral components developed, it became apparent that imaging could provide a much more complex picture, with layers of information from both the visible and nonvisible regions of the spectrum, greatly enhancing our knowledge of an object's materials.

THE IMAGING PROGRESSION

The progression from an accurate photographic rendition to topographical renditions, spectral maps, and pseudocolor overlays has facilitated a variety of advances in the analysis, interpretation, and treatment of cultural heritage objects. Pseudocolor, or false color imaging (used for many years in medical and satellite imaging), allows a quick visual assessment of the different components within an object. In addition, its ability to reveal aspects of the condition of a heritage material (such as areas of damage, fading, or repair) is critical for effective conservation, documenting an object's status before and after treatment, as well as tracking changes over time.

Newer methods of imaging, which operate in nearly every region of the electromagnetic spectrum, continue to expand the scope of that information by providing data about chemical and physical properties of materials. For instance, hyperspectral imaging captures data in distinct narrow waveband regions of the visible and nonvisible spectrum. Utilizing reference databases, spectral imaging can identify a range of pigments and colorants, and linking this data with other imaging modalities, in particular X-ray fluorescence spectroscopy, enables complete noncontact characterization. Entire objects can be mapped across multiple regions of the electromagnetic spectrum, providing an overview of where materials overlap and where pigments that to the eye appear the same may, in fact, be different—vital information for guiding conservation treatment.

A section of the rough draft of the US Declaration of Independence. Hyperspectral imaging revealed Thomas Jefferson's original use of the word "subjects" before replacing it with the word "citizens." Image: Library of Congress.

Because images are now digital, processing can also enhance or suppress selected aspects of an object to reveal otherwise obscured condition information. At present, the level of information about an object that can be extracted is often restricted only by the ability of the preservation professional to interpret the many layers of data. But as computing capabilities develop to handle the ever-increasing flood of digital information, the ability to extract new insights will correspondingly increase. Significant effort is required to process and analyze the collected digital data, but the effort can lead to a wealth of information.

Along with documenting the current condition of objects, imaging can also help visualize the unknown past of collections, such as revealing obscured or hidden text. Two important historical documents—the Dead Sea Scrolls and the Archimedes Palimpsest—have famously benefited from imaging efforts that made the text of these documents more accessible to scholars. Another interesting example is in Thomas Jefferson's rough draft of the Declaration of Independence. Jefferson changed the word "subjects" to "citizens," obliterating his original word choice. This word choice was clearly critical to Jefferson, who noted this word was "expunged, never to be seen again."[1] However, using hyperspectral imaging, Library of Congress staff could "see" this change, providing scholars with new insight into the creation of this important document. This ability to expose previously hidden information—along with the capacity to characterize materials and production processes through noncontact and noninvasive imaging methods—has encouraged imaging to be embraced not only by conservators and scientists, but also by scholars and curators.

More imaging technologies focus on two dimensions than on three dimensions, yet every object has three dimensions. Many people do not think of documents and textiles as 3-D objects, but they are exactly that. The three dimensions of an object can be easily explored in microscopy and spectral imaging through confocal or z-plane imaging, with software programs that can create composite images. Laser scanning, photogrammetry, reflectance transformation imaging, and raking or side lighting are all aspects of imaging that are integrated with current spectral modalities and, through algorithms, can expand the type of imaging data being captured. As with spectral imaging, utilizing techniques from medical, satellite, and geospatial imaging simply requires customizing the technique to address heritage questions and then modifying the scope. Capturing the 3-D component of materials offers a new way to view them that may increase our understanding of how they were used.

Three-dimensional imaging can also reveal nonvisual aspects of cultural heritage materials, such as resurrecting sound recordings from discs or cylinders that have been broken or damaged. IRENE technology (Image, Reconstruct, Erase Noise, Etc.) uses a laser to create 3-D images of the grooves in the surface of shellac, lacquer, or wax discs and cylinders, which can then be transformed into WAV files to reproduce the sound. Analogous to using Photoshop to remove blemishes from a photograph, this audio file can be processed to remove unwanted noise, such as pops, skips, and distortions, to make the original recording more accessible. No longer are broken or damaged heritage materials considered less useful; the information they contain can be rendered "visible" through an imaging-based approach.

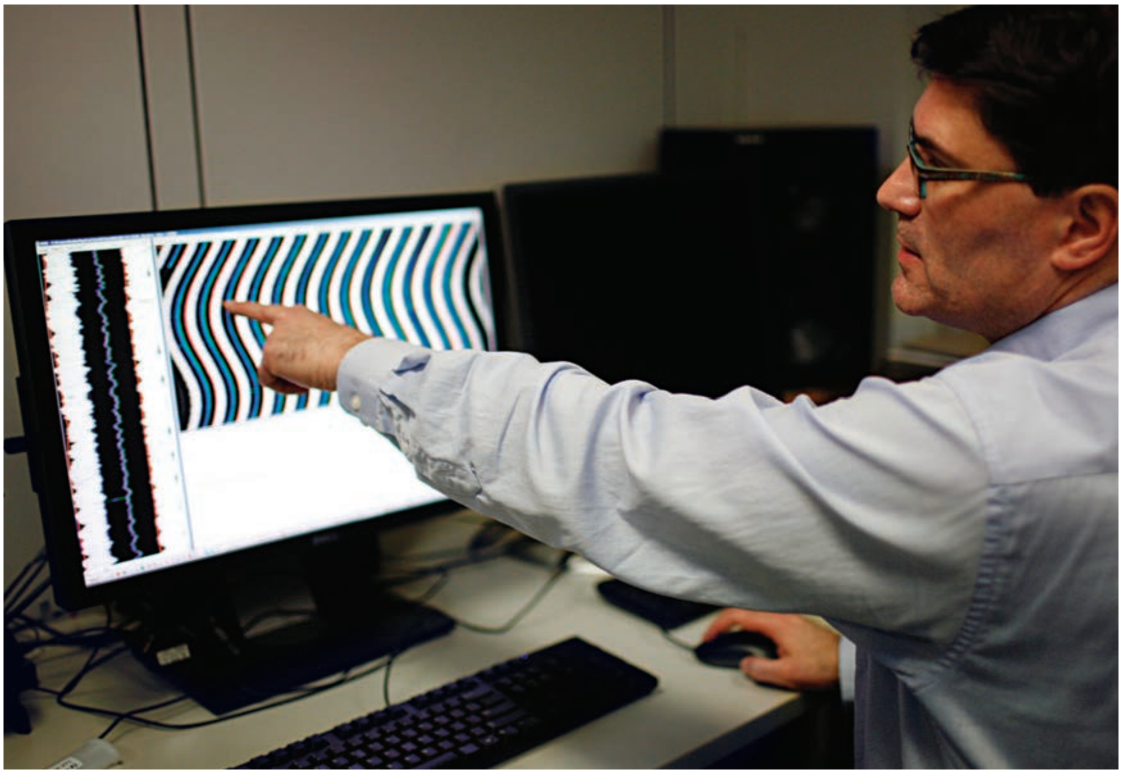
IMAGING AND PRESERVATION

Imaging has also expanded our understanding of previous and new conservation treatments. For example, pseudocolor renderings, created through image processing, can visualize the spread of verdigris or copper corrosion on parchment and paper documents, providing conservators with a precise map of where the corrosion is occurring, even if it is not yet visible to the unaided eye. Along with providing maps showing the distribution of materials, the extraction of spectral curves can be used to monitor and evaluate discrete changes in colorants and the substrate. If collected at various times during a treatment, for example, spectral curves can be used to demonstrate that no unwanted changes have occurred because of the treatment. Even without a spectral component, imaging allows conservation treatments to be monitored. For example, confocal microscopy, which allows different depths within a textile fiber to be imaged, was used to assess the potential efficacy of treatments for the "Star-Spangled Banner," the flag that inspired the US national anthem. This capacity to noninvasively monitor changes before and after an intervention greatly assists in creating a new level of confidence regarding the treatment of heritage materials.

Passive, as well as active, conservation efforts also can be informed by imaging. Of particular interest is the ability of imaging to capture data about exhibition conditions, collection storage environments, and conservation treatments. The ongoing tracking of change in objects through imaging, in relation to their exposure to light, humidity, temperature, or pollutants, can show the effect of these parameters before significant damage has occurred, allowing the specific levels of sensitivity of materials to different environments to be determined. This capacity—which enables a better understanding of the impact of the exhibition environment and more control of display conditions—allows for more proactive integration of preservation into exhibition planning and design. Proactive monitoring to detect change before it is visible is a logical expansion of how we monitor built heritage and the external environment, moving from satellite imaging to object imaging.

Libraries and archive collections often make their holdings available to scholars for study. However, even under controlled conditions, regular handling of objects carries the risk of damage. Imaging further assists in the preservation of such collections by making them more easily accessible while also providing new data for scholars and researchers—data that would not be captured from visual assessments and handling the object. Thus, the need for researchers to handle the materials is reduced, diminishing the necessity for subsequent conservation measures.

A ceramic Maya flask in the Jay I. Kislak Collection of the Library of Congress. The image shows previous mends that are not visible to the unaided eye. Image: Library of Congress.



Peter Alyea, a digital sound preservation specialist at the Library of Congress, displays a digital image of the grooves of an old recording captured by IRENE. Photo: Abby Brack Lewis, Library of Congress.

CHALLENGES AND ADVANCES

One challenge associated with the developments in imaging is the volume of data these advances generate, prompting the need for increased processing capabilities. Many imaging modalities generate a data cube (stacks of 2-D images collected at different points along a third dimension, typically wavelength), and this allows images to be combined in multiple ways. However, with the massive volume of data generated, sufficient time often is not allocated to fully examine all the data. Chemometrics—using mathematics and statistics to observe trends within data—is a tool we need to utilize more effectively to extract data and link imaging with other techniques. Also, too often there is a rush to use large complex systems, when the question should really be how much data is enough to answer the question being asked. One component of the successful use of integrated imaging systems is engagement with conservation and curatorial colleagues. The processing of data should occur in coordination with them.

In our efforts to better preserve our heritage materials, we will continue expanding our ability to extract chemical and physical information noninvasively. The development of new techniques with the capacity to noninvasively image through and within materials offers much promise. For example, magnetic tape is a storage medium containing historic sound recordings, but when damaged it sticks to itself; imaging that could separate the magnetic sound particles from the background without unrolling the tape would assist in the reconstruction of those recordings. With the virtual unwrapping of carbonized papyri through imaging now possible, we can begin to "read" materials once considered lost to us. Fluorescence-lifetime imaging microscopy, a technique that produces an image based on the differences in the exponential decay rate of the fluorescence from a sample, is gaining use in heritage science to identify and map pigments and binders. Utilization of 4-D imaging from ultrasound modalities as a diagnostic tool for heritage materials will expand the use of tomography and reduce the need for invasive core sampling and cross-sectioning.

The types of information that imaging can now provide have enabled scientists to communicate more effectively with diverse audiences. Heritage science is a truly multidisciplinary field, and often scientists and colleagues in different disciplines lack a fully shared language. Images that reveal layers of data in a quick graphic manner reach across disciplines and, of equal import, engage the public, scholars, managers, and administrators, conveying succinct and effective messages. Preservation science remains a mystery to many, so the ability to use visual representations to promote the importance of preserving cultural heritage is critical to its future.

The development of imaging techniques advances our capabilities for seeing how objects have been constructed, created, and used over time, for improving conservation treatments, and for monitoring long-term environmental impacts, among many other benefits. Imaging throws open new portals to what we could not visualize or even imagine before, helping us better understand, appreciate, and preserve our cultural heritage.

Fenella G. France is chief of the Preservation Research and Testing Division of the Library of Congress.

1. Thomas Jefferson, *The Papers of Thomas Jefferson*, vol. 1: 1760–76, edited by Julian P. Boyd (Princeton, NJ: The Princeton University Press, 1950).

LOOKING DEEPER

A Discussion about Imaging and Conservation

GEORGE BALLARD is president of GB Geotechnics, with offices in the United Kingdom, the United States, and Australia.

JOHN DELANEY is senior imaging scientist at the National Gallery of Art in Washington, DC.

DAVID SAUNDERS was formerly keeper of conservation and scientific research with the British Museum and is currently the inaugural Getty Rothschild Fellow.

They spoke with **KAREN TRENTELMAN**, GCI senior scientist, **LORI WONG**, GCI project specialist, and **JEFFREY LEVIN**, editor of *Conservation Perspectives, The GCI Newsletter*.

JEFFREY LEVIN The word *imaging* can mean many different things. What does it mean to each of you?

DAVID SAUNDERS I think of it as *digital imaging*. It's a visual mapping of information. We're dividing up these images into pixels—or voxels if they're three-dimensional—and assigning information to each of those subunits. If it's a color image we're using for documentation or for a presentation, then it's color information we assign to these. If we're using it in an analytical sense, we might assign spectral information to each point. Or we can use each point as a tag for a whole lot of other information about an object.

GEORGE BALLARD For me, imaging constitutes the actions we humans take to transmit information to each other graphically. For example, if I were to describe a hole underneath a large building, I might use a gravity meter to determine the density of the ground and measure it carefully to find its shape and any variation in it. Then I'd present either a 2-D or a 3-D image, which is the information transfer. Imaging involves everything from analytic presentation of abstract information to transferring photographic images. Photography still exists. Even if it's digital, you're still drawing a representation via light.

JOHN DELANEY Imaging is a thing we do—a process. But in a way, it's really the product. The visual mapping of information. The types of data sets we're looking at are multidimensional—there could be a time element, there could be a 3-D element, there could be an energy or spectral element. But it always relates back to spatial information. It includes the multidimensional information and spatial representation of a scene or an object.

BALLARD You're transferring information among people. One difficulty I often have in engineering is expressing graphically some information or idea that I want to transfer to someone. They are all necessarily imaged and presented graphically. We often use photography extensively because we can look at things so much more efficiently. I can stand thirty meters away from a building with a long lens and a fifty-megapixel camera, and back at the office I can put all the images into a complete mosaic, rectified and processed. I can actually pretend at my desk that I'm two inches away from the structure—which is amazing.

LORI WONG You actually may be able to see more. It's providing us with information that wasn't possible to get just a few years ago.

SAUNDERS Yes, on one hand it's a question of resolution, but also the ability of current software to rectify the perspective. In the past, we would have struggled to stitch together all the individual images, even if we used a camera with a really good lens.

DELANEY Having done a fair amount of high-resolution aerial photography work in my prior career, I'd note that a large high-resolution static image of a scene is both a copy of that scene and a temporal snapshot. We've gone beyond just creating a high-quality representation of a scene to capturing it as it evolves, which provides critical information. One thing that interests people in conservation is the deterioration rate of something, if measured with metrics that allow us to follow it so that we can intervene. Change detection is a commonly used process in remote sensing to find changes in the environment, in both urban and natural settings. A lot of those tools are coming into our field, and we can now try to visualize color loss in an art object over a short enough period of time to intervene—hopefully by collecting high-resolution spatial and color information, but in a temporal sense by aligning it in time.

Photo: Tricia Zigmund. National Gallery of Art.

> Imaging is a thing we do—a process. But in a way, it's really the product. The visual mapping of information.
>
> JOHN DELANEY

BALLARD That's comparable to looking at buildings. What we've found is that a stock of old photographs can be digitalized, stitched together, and processed in a way that allows us to use those as comparisons to study rates of deterioration. The old information is not lost.

SAUNDERS This aspect of change detection was how I got involved in imaging. Back in the 1980s and 1990s, we measured color differences in paintings over time to detect change. Before that, we had to select a few points on the painting, and we might miss changes. The idea of making an image of a whole painting, and then redoing it a bit later, drove our research. It's interesting that John mentioned remote sensing, because at that time the people who had the money to invest in such systems were in remote sensing. On one of my first California visits, I went to the Jet Propulsion Laboratory to see how they used remote sensing to study changes in crops over time. We then applied the same technology to paintings.

KAREN TRENTELMAN Since it's rare for instrumentation to be developed specifically for the study of cultural heritage, perhaps we could talk more about how technology has been adapted from other disciplines for conservation imaging, and where we might look in the future for new technologies?

SAUNDERS We're getting a lot of technologies from medical imaging. A big drive in medical imaging that helped us is X-radiography, including both two-dimensional X-radiography where we're collapsing 3-D information into a two-dimensional image, and increasingly three-dimensional imaging using computer-aided tomography. And new multispectral CAT methods have been used to study mummified bodies and sealed objects you don't want to unwrap. Optical coherence tomography, also from medical imaging, looks at subsurface layers and has been adapted for the study of materials in ceramics, documents, and paintings.

WONG The medical industry has also driven innovation in terms of portability and affordability, which has trickled down to our field, yielding things like handheld microscopes that we can put it our pockets and take into the field.

SAUNDERS The big worry a few years ago was that we weren't going to be able to make X-rays in the future because manufacturers were scaling down their film production. This was because the medical industry was moving increasingly to digital imaging, but it did mean that a lot of money was put into developing lower-cost alternatives to film, which made digital technology affordable in museums.

DELANEY What I see from doing research on nondestructive analysis with X-rays is that the requirements for nondestructive analysis of pipes and the like drove the requirements for the digital capture more significantly than medical needs had done for our field. The medical industry is quite happy with very low space resolution data. But that's not acceptable in nondestructive testing where you want to achieve film-quality resolution and have a dynamic range the medical industry doesn't require. So I see our greatest benefit coming from the nondestructive field looking at pipes for flaws and things like that.

BALLARD Cross-pollination among disciplines will always be beneficial to a discipline that tends to be underfunded. But each discipline has a different set of resolutions it requires. I came to structural investigations through geophysics, which is all about understanding the center of the earth, where resolution in millimeters is patently not necessary. On the other hand, the techniques we developed for that, which I then brought into structural inspection, use derivations of seismics, derivations of radar, and so on, to look at the minutiae. I currently use a radar system originally developed for finding large objects in the ground with no specific size, for tracking microcracking in the concrete encasements of nuclear reactors. That activity is the result of the extensive work I've done on the conservation of stone, where I've looked for microcracking generated by corroding ironwork within the structures. Things go around and around as you find ways to use technology to good effect.

LEVIN Lori mentioned the increasing portability of instrumentation. Can each of you talk about how that's changed the way we do things?

BALLARD The ability to take a sophisticated scientific laboratory up onto the side of a building, hanging off some scaffold, is quite remarkable. The fact that you don't have to lug a couple of lead-acid batteries up with you, and that it can all be done with a set of AA cells, is fantastic. It's allowed me to continue my chosen profession late into my career!

DELANEY The portability in the analytical chemistry field has been a big driver for a series of stand-alone devices used by nontechnical people in the field to make qualitative decisions. They're very tempting devices and are exciting to see. But there's also risk with some of these devices. The parameters under which they operate might be questionable with respect to the standards we have for examining objects, and they can create some confusion in interpretation. Getting more equipment to more people is beneficial, but the equipment also requires more care.

SAUNDERS We're taking equipment once used only in the laboratory and making it more rugged and easier to use, and also reducing the power requirements so it can be taken out into the field. The desire for portability is driving lab-based research, in that we look at techniques with an eye to how they might be used in fieldwork. We generally begin by testing instrumentation not necessarily on the objects we see in the field but on analogous material, just to see how much information you get, so that when you are in front of the object you have confidence you're going to get sufficient data to make interpretations when you get back. You rarely have the luxury of undertaking data interpretation out in the field.

LEVIN Are you suggesting that these technologies, now that we have access to them, in some ways drive the kinds of research being done?

SAUNDERS I don't think we should say, "Here's the set of tools we have—we'll use these and nothing else." The tools we have now we can use better, while still looking for the next technologies. We all have thoughts on what might be the next big lab-based piece of equipment, and what might be the next existing lab-based equipment that could be adapted for field work.

BALLARD Is the great "intelligence" that's been put into instruments part of that move forward? I'm constantly switching off the automatic processing of my camera, which tells me how to take a better photograph.

SAUNDERS I don't think we should throw away the opportunity to use the intelligence built into equipment, but we ought to be aware what it's doing. There are occasions where you want to turn off those automatic features and have the raw information coming out of the instrument.

DELANEY There is a philosophy that any data you archive for future analysis should be in the raw form—unprocessed and uncorrected, that is. In the remote sensing and scientific fields, they want the raw data. But in your day-to-day work, you may not need it. One thing I worry about is that there are two levels of instrumentation. There are instruments that give qualitative answers rapidly, and then there is instrumentation that is traceable to some level of standards. That difference in quality makes a big difference for complex systems. Because of cost, we're tending toward using those less expensive instruments that may be insufficient. Unlike the scientific community, we don't have groups comparing instruments and rating them for quality.

BALLARD We also don't have ratings of the operators either! Regarding raw data, I think we'd agree that storing raw data is an absolute necessity—so that you preserve the information in its most basic form—but at the same time, making it easier for the operator to interface with that data.

SAUNDERS In storing raw data, having a point of reference is very important. Measurements made on reference materials are critical because when our future colleagues look at that information, they'll need to calibrate the data using the reference points. In fact, they may have better ways of using this information than we have now. That means we have to be careful how we archive and reference data. As for operators, we don't have standards. One of the great fallacies of digital imaging was that suddenly anyone could take an image. What we found within our institution was that the people who took the best digital images were the photographers, even if they weren't necessarily the people who understood the more complex aspects of digital technology.

DELANEY My observation is that many people using digital cameras make the same mistakes. They don't have proper range of the camera to the object to optimize the spatial sampling, they don't quite know how to do frame averaging to reduce noise, and they don't know how to trade off the camera's f-stop with the amount of illumination needed.

TRENTELMAN The first step toward managing large amounts of data is developing, and implementing, standards. Could you each comment on the state of the field regarding standardization in imaging?

SAUNDERS There are a few manuals for specific types of imaging. I was involved in a European project that produced a handbook for imaging in the UV, visible, and infrared regions, which was applicable both to museum objects and for use in the field.

DELANEY There was a recent European project, COSCH [Colour & Space in Cultural Heritage], which looked at 3-D imaging, instrumentation, and procedures and was supposed to give guidance on best practice.

BALLARD The problem with best practice guides is that they tend to be written regarding a specific object and are somewhat inflexible. For example, there's a surveyors' guide to metric surveys, which is the standard form for most conservation. Its definition of representational accuracy is now being applied to ancient buildings. But as you move from general surveying into ancient building surveying, you need to shift your baseline of what representational accuracy actually means, to take full advantage of the digital opportunities given by the building information and modeling.

LEVIN How has imaging affected your ability to communicate your work to colleagues?

DELANEY In the gallery environment, new analytical imaging techniques have made more curators want to revisit art objects that were studied extremely well in the late 1980s and early 1990s with X-rays, infrared reflectography, and cross sections. They want to answer questions about the way in which the art objects were constructed and modified, and to test a lot of hypotheses that were generated from microsampling. And these images are directly accessible.

SAUNDERS We work in a very visual profession, and the use of images plays to those strengths. Our colleagues in museums understand images, and we can use images to present information to them. Digital imaging allows you to produce so many more images very easily. Now that's a double-edged sword, because sometimes you can drown in this information. Nevertheless, it used to be that you might photograph a couple of details from an object when it was in the studio. Now you can image every detail you want, since you're never quite sure whether the detail you're interested in is the detail that will interest your colleagues. Having images to convey all those data to colleagues is very powerful.

BALLARD You take that a stage further with a 3-D object. You can paste all those multiple images together and turn them into a 3-D image on the screen. You can look at every single part and have the opportunity to choose your own point of interest.

DELANEY There are a lot of connections that can be made about how material is distributed or was applied. The mapping ability, especially in the chemical domain, allows you to test that hypothesis. That's new, and it enables scholars to return to unanswered questions they've had. Along the way, you typically stumble across things because the earlier microsampling analysis didn't bring everything to light. It's serving a very powerful purpose of answering outstanding questions about an art object.

SAUNDERS Yes, it's not just about having images—it's about having *quality* images. I recall going to curators in the past with an image and saying, "Look, this shows X and Y," and, quite understandably, they couldn't see it. Today, the images are so much better quality, and now when you say, "Look, there's a drawing underneath here," they get it.

DELANEY I had a case where someone wanted to know if a hand on someone was painted on the ground layer or painted on the other person. The previous data was someone looking through a microscope and saying, "Through this crack I can see some ground, so it's painted on the ground." Well, multi-hyperspectral imagery showed that it was on the other person, and that was clear to the art historian. We can derive new information from the new results.

SAUNDERS Paintings are incredibly heterogeneous systems. Across the surface of even a single area of a painting, there are changes in the paint thickness and underlying materials. Combining techniques has proven very useful—for example, making a multispectral scan and then using something like optical coherence tomography to look at the way that corresponds to the layer structure. The OCT image tells you about the structure without having to take a sample, and piecing the two together produces a better interpretation. Perhaps a smart instrument of the future might use those techniques in tandem.

BALLARD If I am looking at some Roman tesserae, the material underneath, and, potentially, the structure below that, I'll use various techniques to get multiple images of the information on the layering of the structure, to which I'll then apply my knowledge of how to build a Roman floor—which would be very different from how one built a nineteenth-century Victorian tiled floor, even though they're both multilayered structures. Of course, intelligent input from knowledge is potentially vulnerable in the interpretation.

Photo: Courtesy of George Ballard.

With new instruments, we'll always be pushing the boundaries of what we can find in terms of data to look at, analyze, interpret, and hypothesize about.

GEORGE BALLARD

DELANEY There's no doubt about that. Knowing when an art object was produced and knowing where it's from allow you to make a reasonable assessment about the paint layer structures. We can do that for very simple systems. But there is such subtlety in this human craft we call art work that those nuances would be hard to guess at. Sometimes that's where the creativity is—in the unique skill of the person creating the art.

BALLARD The brain is a very good filter, but one should never forget that results are subject to the experience and knowledge of the filtering agent.

DELANEY Well, yes and no. I'll go back to remote sensing, where you have different levels of exploitation of the data. You have people looking at stuff relatively quickly who may be seeking a quick estimate of changes in color. And then you have people trying to squeeze everything out of the data sets. When people do remote sensing of the environment, they typically get only about six or seven principal components from the hyperspectral reflectance image cubes. I've seen paintings where anywhere from twenty to forty principal components come out. There is a huge amount of data, and a lot of the questions asked don't fully mine it. You do need a lot of experience.

BALLARD What you're getting to is how we go through that process.

DELANEY I think it goes to what questions people are trying to answer.

BALLARD And the process you're talking about is developing questions, putting up a hypothesis, testing that hypothesis with data, and sometimes realizing that you have three or four hypotheses that are pretty stupid. Before anybody got a telescope, the hypothesis was that the earth was flat. Then we got telescopes and could see things floating around in space. With new instruments, we'll always be pushing the boundaries of what we can find in terms of data to look at, analyze, interpret, and hypothesize about.

SAUNDERS We shouldn't close our minds to new information that may come from these techniques, but if we're examining an object we must consider those things we already know about it that come from other solid scientific work. One could, theoretically, scan a painting, come out with five principal components, and assign them on the basis of some spectral library, irrespective of the knowledge that those materials would never occur in that object. Sometimes in the scientific literature you see such reports from people with an instrumental background who are unfamiliar with our field and not in day-to-day contact with paintings and painting materials.

TRENTELMAN What are some of the other dangers with respect to reliance on imaging?

DELANEY All these techniques are based on the idea that these materials can be spatially classified as being similar by their signature. That's generally the field of multispectral techniques. Microspectral techniques were brought in with the hope of getting at spectral signatures that are the quality of library

Photo: Rebecca Zamora, The Getty.

What's fascinating for me is that these methods often help us discover things about objects that align with written sources related to their making.

DAVID SAUNDERS

data in order to do assignments. But sometimes you get to a point where you lack sufficient information to make an assignment. People can be too quick to say, "That sort of looks like that, so therefore it could be this." Still, a lot of these techniques work because they're better at classifying than we are with our eyes.

SAUNDERS I always start by looking, and it's on that visual record that we base our subsequent imaging. I'm not saying we stop once we've looked at an object, but we put ourselves in a dangerous position sometimes when we don't start with careful observation.

LEVIN How do the challenges of imaging built heritage differ from imaging objects in collections? Obviously, there are techniques used by both, but there are also some distinctions.

BALLARD The biggest problem for built heritage is that its conservation is active, requiring a major rethink at least every twenty-five years, and some intervention every five years. Most of the information I collect is directed toward what to do next for a structure to stop it from deteriorating. We're fitting that to an imaging system that enables us to transfer information among different professions, because maintaining a structure will be partly its architectural surface and impact, partly its engineering stability, and partly its material robustness and durability, with each requiring different imaging sources. Conservation of buildings is very much controlled by maintenance budgets, and that imposes timing, finance, and understandability of the image that one produces—which is why I stress being able to transfer information from one person to the next as being the essence of imaging.

SAUNDERS Many of the imaging issues faced in museums are similar to those in the built heritage environment, but on a much smaller scale. We sometimes struggle in a museum when dealing with a large object, but how much more you struggle when you've got a cathedral as the subject of your study. And then there is accessibility. Sometimes we curse because we can't take something off the wall. But for built heritage, it may actually be the wall you're interested in—or the floor. So it's not that we don't face similar challenges, but they're at a totally different level.

BALLARD At one point I was charged with looking at a set of fantastic terracotta animals along the outside upper parapet of the Natural History Museum in London. The only access was via the drainage gutter behind the parapet wall, with me balancing one foot on the scaffolding and one foot on the sloping tilework on the roof. Now this was before digital photography, and I was there with my trusty Zenit, a grossly solid Russian SLR of the 1970s and 80s, and the only camera I found that I could drop forty feet from scaffolding, pick it up, and go back to taking photographs! That's the kind of environment we worked with. Now I can use a cherry picker and take a photograph twenty meters away that's far better than anything my Zenit ever managed. And I have a range of techniques that allow me to combine images together, accurately proportioned, derived from those photographic images, digitized, 3-D-ized, and rectified. Life has become a lot easier through that technology.

TRENTELMAN We've talked about imaging technologies that have been developed over the past couple of decades. What sort of advances in imaging might we expect—or want—in the future?

SAUNDERS Well, it's worth looking at the past. A lot of digital imaging started as replacements for photographic techniques we've used in the past, such as X-ray, visible, UV, and infrared photographs. Of course, many new techniques—multispectral techniques, terahertz imaging, X-ray fluorescence imaging, FTIR imaging, and acoustic technologies for buildings—don't have a history in photography. I suspect these will mature in coming years, and instrumentation might become cheaper and more available. And there may be a new generation of instruments using other wavelengths that we're not investigating now. We'll hopefully see a progression of the instruments we use in laboratories making their way into applications within museums and out into the field.

BALLARD That parallels my feeling, coupled with the application of greater intelligence and being able to take computing power out into the field. In the 1960s and early 1970s when I first started doing fast Fourier transform analysis of the frequency content of data, it took me quite some time to make the paper tape punch cards, take them to the computing center, wait a week for results, and then analyze them. Now I'm doing the same process out in the field in real time. The ability to apply not only intelligent programming on-site, but also artificial intelligence, will play a part in the future. Artificial intelligence gives us the opportunity to turn dumb instruments into intelligent instruments, and that aids us in getting to answers faster. Still, it's a dangerous area, because you are handing a lot over to the machine, and you have to be certain that the artificial intelligence you create is the right sort.

DELANEY Something we haven't talked about is the ability to consume large amounts of data quickly. There is a very high capture rate of those systems that add a temporal element to the dataset. When you see a video of an object as opposed to stills, things change in terms of how much you can glean about the object. The same is true if you get multispectral data as a multidimensional object is turning. There will be more video coming with a large number of spectral images—not just color—and the time required to collect all these modalities will lessen.

LEVIN Imaging has vastly improved our material understanding of an object—but ultimately all these things are about creativity. How has imaging enlarged your understanding and appreciation of the creativity behind the things you've studied?

SAUNDERS These techniques are immensely useful in understanding the artistic process and the choices made. What's fascinating for me is that these methods often help us discover things about objects that align with written sources related to their making. For instance, when you look at the surface of a fifteenth-century painting, it might not be obvious how it relates to written descriptions of painting production in that period. But when imaging lets you see the materials beneath the surface, it keys in nicely. And images can be very helpful in how we communicate this. There were a couple of exhibitions at the British Museum where we presented images showing the preparatory stages of drawings, and by looking beneath the surface you could find careful planning of the composition, at odds with the common view that these were spontaneous representations. That understanding of process and the artist's intent can be very powerful—and communicable to the public through those images.

DELANEY One thing that's amazed me in looking at detailed registered multispectral infrared images of some artworks is the ability of an artist, at particular times, to start with something very well planned and then abandon it on the fly, making minute changes with great confidence—a process that is quite surprising. It's always delightful to see that.

BALLARD That resonates with me, too. I've been particularly excited when I'm working on a Christopher Wren structure to recognize the way he comes up with yet another surprising solution to a problem in physics. It's the imaging that gets you to that, but it's a very personal appreciation of what he's done—for instance, how he solved the problem of the great piers in St. Paul's Cathedral, which was built on clay. He estimated that the cathedral would sink by twenty-two inches over the following hundred years. He was slightly off. It was about twenty-three inches! But he built the structure to accommodate that, with a sufficient margin that his error was inconsequential. And that's stunning.

KEY RESOURCES **IMAGING IN CONSERVATION**

For links to the online resources listed below, please visit http://bit.ly/keyresources_32_1

POLICY DOCUMENTS, STANDARDS & GUIDELINES

Historic England, Digital Image Capture and File Storage: Guidelines for Best Practice (2015).

3 x 3 Rules for Simple Photogrammetric Documentation of Architecture by Peter Waldhäusl, Cliff L. Ogleby, Jose Luis Lerma, and Andreas Georgopoulos (2013), CIPA.

ONLINE RESOURCES, ORGANIZATIONS & NETWORKS

CIPA Heritage Documentation. An ICOMOS scientific committee that promotes the application of technology from the measurement, the visualization, and the computer sciences for the benefit of recording, conserving, and documenting cultural heritage.

ICOM International Committee for Documentation (CIDOC). CIDOC provides the museum community with advice on good practice and developments in museum documentation.

BOOKS, JOURNALS & CONFERENCE PROCEEDINGS

"Advances in Multispectral and Hyperspectral Imaging for Archaeology and Art Conservation" by Haida Liang, in *Applied Physics A* 106, no. 2 (2012), 309–23.

"Analyzing the Heterogeneous Hierarchy of Cultural Heritage Materials: Analytical Imaging" by Karen Trentelman, in *Annual Review of Analytical Chemistry* 10, no. 1 (2017, forthcoming), 247–70.

"Cultural Heritage and Archaeology Materials Studied by Synchrotron Spectroscopy and Imaging" by Loïc Bertrand, Laurianne Robinet, Mathieu Thoury, Koen Janssens, Serge X. Cohen, and Sebastian Schöder, in *Applied Physics A* 106, no. 2 (2012), 377–96.

GCI intern Samuel Whittaker working in Kasbah Taourirt in Ouarzazate, Morocco. Photo: Scott S. Warren, for the GCI.

Digital Imaging for Cultural Heritage Preservation: Analysis, Restoration, and Reconstruction of Ancient Artworks by Filippo Stanco, Sebastiano Battiato, and Giovanni Gallo (2011), Boca Raton, FL: CRC Press.

"Examination of Historical Paintings by State-of-the-Art Hyperspectral Imaging Methods: From Scanning Infra-Red Spectroscopy to Computed X-ray Laminography" by Stijn Legrand, Frederik Vanmeert, Geert van der Snickt, Matthias Alfeld, Wout de Nolf, Joris Dik, and Koen Janssens, in *Heritage Science 2*, no. 13 (2014), 13.

"Multispectral and Hyperspectral Imaging Technologies in Conservation: Current Research and Potential Applications" by Christian Fischer and Ioanna Kakoulli, in *Reviews in Conservation* 7 (2006), 3–16.

Multispectral Imaging in Reflectance and Photo-Induced Luminescence Modes: A User Manual by Joanne Dyer, Giovanni Verri, and John Cupitt (2013), European CHARISMA Project, published online.

"Reflectance Hyperspectral Imaging for Investigation of Works of Art: Old Master Paintings and Illuminated Manuscripts" by Costanza Cucci, John K. Delaney, and Marcello Picollo, in *Accounts of Chemical Research* 49, no. 10 (2016), 2070–79.

Satellite Remote Sensing for Archaeology by Sarah H. Parcak (2009), Abingdon, UK, and New York: Routledge.

Scientific Methods and Cultural Heritage: An Introduction to the Application of Materials Science to Archaeometry and Conservation Science by Gilberto Artioli (2010), Oxford, UK, and New York: Oxford University Press.

3D Recording, Documentation and Management of Cultural Heritage by Efstratios Stylianidis and Fabio Remondino (2016), Dunbeath, Scotland: Whittles Publishing.

"Use of Imaging Spectroscopy, Fiber Optic Reflectance Spectroscopy, and X-ray Fluorescence to Map and Identify Pigments in Illuminated Manuscripts" by John K. Delaney, Paola Ricciardi, Lisha Deming Glinsman, Michelle Facini, Mathieu Thoury, Michael Palmer, and E. René de la Rie, in *Studies in Conservation* 59, no. 2 (2014), 91–101.

"The Use of Synchrotron Radiation for the Characterization of Artists' Pigments and Paintings" by Koen Janssens, Matthias Alfeld, Geert van der Snickt, Wout de Nolf, Frederik Vanmeert, Marie Radepont, Letizia Monico, Joris Dik, Marine Cotte, Gerald Falkenberg, Costanza Miliani, and Brunetto G. Brunetti, in *Annual Review of Analytical Chemistry* 6 (2013), 399–425.

"Visible and Infrared Imaging Spectroscopy of Paintings and Improved Reflectography" by John K. Delaney, Mathieu Thoury, Jason G. Zeibel, Paola Ricciardi, Kathryn M. Morales, and Kathryn A. Dooley, in *Heritage Science* 4, no. 6 (2016).

"Xenon Flash for Reflectance and Luminescence (Multispectral) Imaging in Cultural Heritage Applications" by Giovanni Verri and David Saunders, in *The British Museum Technical Research Bulletin* 8 (2014), 83–92.

For more information on issues related to imaging in conservation, search **AATA Online** at **aata.getty.edu/home/**

GCI News

Photo: Mariusz Talarek/500px.

Project Updates

NEW AGREEMENTS FOR ARCHES

In November 2016 the Getty Conservation Institute entered into agreements with Historic England and the City of Lincoln Council in the United Kingdom to implement the Arches software platform to help manage the rich cultural heritage of Greater London and the City of Lincoln. The Arches platform will also help safeguard the vast accumulated knowledge of the historic environment of Greater London and Lincoln and make it more publicly accessible.

Through the agreements, the GCI will make enhancements to the Arches platform based on the common needs of local heritage authorities in England. These two projects will help create an open source software platform that will be freely available and can be readily applied by other English cultural heritage organizations to configure and use as they see fit. Implementation of the projects is expected to begin in 2017 in Lincoln and 2018 in London.

Arches is an open source, web- and geospatially based information platform built to inventory and ultimately help protect cultural heritage places, including buildings, archaeology, and historic landscapes. Arches Version 4.0, which includes new features (among them an installation wizard and a number of configuration tools), was completed in March 2017. An online-offline mobile data collection app that will sync with Arches is planned for completion before the end of 2017.

The Arches platform was jointly initiated by the GCI and World Monuments Fund in 2013. For further information on Arches, please visit archesproject.org.

MOSAIKON PARTNERS MEETING

Representatives from the four partners of the MOSAIKON initiative—the Getty Conservation Institute, the Getty Foundation, ICCROM (International Centre for the Study of the Preservation and Restoration of Cultural Property), and ICCM (International Committee for the Conservation of Mosaics)—convened at the Getty Center in January 2017 for a three-day meeting to discuss the initiative's achievements to date and the progress made toward its goal of improving the conservation and management of archaeological mosaics in the southeastern Mediterranean region. The MOSAIKON partners also engaged in strategic planning, identifying follow-up activities to solidify gains made in the last eight years.

Since 2008 MOSAIKON has directly engaged and impacted over two hundred practitioners and cultural heritage professionals from the region. Activities have included multiple training programs for conservation technicians of both in situ and lifted mosaics, archaeological site managers, and museum professionals, at both national and regional levels. These courses offered practical approaches to the conservation and management of archaeological sites with mosaics and helped create a robust and dynamic community of practitioners.

Additionally, a model field project and research into improved backing techniques for lifted mosaics have provided sustainable methodologies and an approach to practice focused on the use of locally available and affordable materials and resources. Further research, centered on protective sheltering for archaeological sites, will result in publication of a technical handbook to guide practitioners through the sheltering process.

Grants from the Getty Foundation have allowed ICCM to broaden its geographical reach and deepen its impact in the region, thus reinforcing the regional professional network and creating stronger links to the international community of mosaic heritage and conservation practitioners. MOSAIKON has also expanded access to conservation resources by making ICCM conference proceedings available online for free and undertaking Arabic translations of seminal conservation literature. Forthcoming online didactic course materials will further increase dissemination of MOSAIKON's work and encourage information sharing.

As the MOSAIKON initiative draws to a close in 2018, its partners are focused on measures to ensure the sustainability of these achievements into the future.

FIELD CAMPAIGN AT TOMB OF TUTANKHAMEN

The Getty Conservation Institute's multiyear project with Egypt's Ministry of Antiquities for the conservation and management of the tomb of Tutankhamen is nearing completion following the field campaign conducted in February and March.

King Tut, as he is called, achieved fame not because of the longevity of his reign (which was less than ten years) or for his prowess in battle; he was perhaps younger than twenty when he died of unknown causes. But he was pharaoh of the world's mightiest empire at the time of his reign more than three thousand years ago. The treasure discovered in 1922 by Howard Carter in Tutankhamen's final resting place in the Valley of the Kings draws crowds to the Egyptian Museum in Cairo and to the tomb on the West Bank at Luxor where Tutankhamen's sarcophagus, outermost gilded coffin, mummy, and clay seals from the entryway to the tomb remain.

Key aspects of the collaborative project included conservation of the wall paintings in the burial chamber, the only decorated room in the small tomb; refurbishment of the infrastructure, which includes a new viewing platform, stairs and ramp, lighting, and a filtered air supply to reduce dust, humidity, and carbon dioxide from heavy visitation; and Arabic translation of the existing interpretive panels. Scientific investigation of the materials and techniques of execution of the wall paintings, detailed documentation of the

Project team undertaking wall painting conservation in the tomb of Tutankhamen burial chamber. Photo: Lori Wong, GCI.

condition, and study of the causes of deterioration all preceded the wall painting conservation, which emphasized stabilization and cleaning.

Working with experts from the Ministry of Antiquities and the private sector in Egypt, the project utilized expertise from many disciplines, including architectural design, environmental science, and documentary filmmaking. It also included the training of local conservators and inspectors for the future management and maintenance of the tomb.

Recent Events

XRF WORKSHOP HELD

In November 2016 the Getty Conservation Institute and the Yale Institute for the Preservation of Cultural Heritage, together with the Stichting Restauratie Atelier Limburg (SRAL), presented the third jointly organized XRF (X-ray fluorescence) Boot Camp for Conservators at SRAL and the Bonnefantenmuseum in Maastricht, the Netherlands.

During the four-day workshop, eighteen participants representing ten countries gained in-depth training in the principles of XRF spectroscopy and practical instruction on the collection and interpretation of data, focusing primarily on qualitative analysis and the use of handheld instrumentation. Interactive lectures were paired with laboratory activities involving hands-on instrument use, data processing, and interpretation. In addition, for this year's workshop instrument representatives from Bruker, Niton, and XGLab were on hand to assist participants with questions specific to the different models of portable XRF units used.

The application of XRF to the study of core material groups in cultural heritage collections was emphasized throughout the workshop and illustrated with examples from ongoing projects at SRAL and the Bonnefantenmuseum collections. The analysis of painted surfaces was highlighted, focusing on the common challenges faced by conservators of paintings, objects, and works on paper when dealing with multilayer coatings on a variety of substrates. In addition, recent advances in XRF instrumentation and techniques applied to the study of cultural heritage, including scanning macro-XRF, were discussed. On the last day, the participants, who had worked in pairs from the beginning of the workshop, presented the results of their analysis, and a group discussion with the instructors followed.

Participants in November 2016 Maastricht workshop engage in a hands-on exercise using a portable XRF unit. Photo: Stéphanie Auffret, GCI.

The XRF Boot Camp is part of the GCI's Research into Practice Initiative, which develops educational activities and resources to facilitate the practical application of new scientific research to conservation problems.

SYMPOSIUM ON VALUES IN HERITAGE MANAGEMENT

In February 2017 the GCI convened a group of international heritage conservation professionals at the Getty Center for a two-day symposium to review emerging trends in dealing with values in heritage conservation practice. The symposium was developed in collaboration with Erica Avrami of Columbia University and Randall Mason of the University of Pennsylvania.

The symposium, built on GCI research into values in heritage management dating back to the late 1990s, was aimed at reviewing how values-based approaches have influenced practice, taking stock of emerging approaches to values in heritage practice and policy, identifying related knowledge and tool gaps (as well as prevalent challenges related to values-based approaches), and proposing specific areas where development of new approaches and future research may help advance the field.

Participants explored themes such as heritage values within non-Western cultures, the integration of tangible and intangible as well as natural and cultural values in conservation practice, current approaches to values assessment, including economic ones, and understanding identity-based conflicts that relate to heritage places.

A publication from the symposium is expected to be issued by Getty Publications in spring 2019.

ARCHAEOLOGY AND CONSERVATION EDUCATION ROUNDTABLE

In February 2017 the GCI convened a meeting of educators in archaeology and conservation from leading universities where both fields are taught. These included the University of California, Los Angeles; the Institute of Fine Arts at New York University; the University of Pennsylvania; University College London; and Durham University in the United Kingdom.

The meeting's objectives were to assess the state of graduate education in both fields and to

Participants in the February 2017 GCI–organized Symposium on Values in Heritage Management. Photo: GCI.

strategize on how to address educational needs through curriculum change and increased joint training both in the classroom and in the field.

Also participating and providing perspectives on education of future professionals were representatives of several US professional organizations, including the Archaeological Institute of America (AIA), the American Institute for Conservation, the Society for American Archaeology, and the American Schools of Oriental Research.

Building on discussions at recent AIA annual meeting workshops, participants proposed actions to strengthen interdisciplinary education. The proposals included a seminar on theory and practice taught jointly by archaeology and conservation faculty and the delivery of a field school module for students of both archaeology and conservation. Proposals for activities outside the university setting included developing a one-day seminar with an orientation to competencies in both fields, to be offered in conjunction with annual meetings of professional organizations, and creating a website portal.

A summary document of the roundtable is being drafted and will be available on the GCI website in early fall 2017 so that proposed activities can be disseminated widely to both fields.

AWARDS

Los Angeles Conservancy Chairman's Award

The Los Angeles Conservancy is awarding its 2017 Chairman's Award—given for exceptional contributions in the field of historic preservation—to SurveyLA, The Los Angeles Historic Resources Survey, which was carried out by the City of Los Angeles with the advice and assistance of the GCI. The survey grew out of an assessment conducted by the GCI of the potential for a comprehensive historic resource survey in Los Angeles, and the Institute went on to work closely with the city on the survey's development, methodology, and implementation. (In 2015 Los Angeles launched HistoricPlacesLA: Los Angeles Historic Resources Inventory, which contains information gathered through SurveyLA, as well as information on thousands of Los Angeles's designated historic resources; it was created through the GCI's customization of its Arches open source platform, which was jointly developed by the GCI and World Monuments Fund.)

CAA Award for Distinction

Tom Learner, head of GCI Science, was awarded the College Art Association/American Institute for Conservation Award for Distinction in Scholarship and Conservation at CAA's 105th Annual Conference in February. The Awards for Distinction honor the outstanding achievements of individual artists, art historians, authors, conservators, curators, and critics whose efforts transcend their individual disciplines and contribute to the profession and to the world at large.

AAP PROSE Award

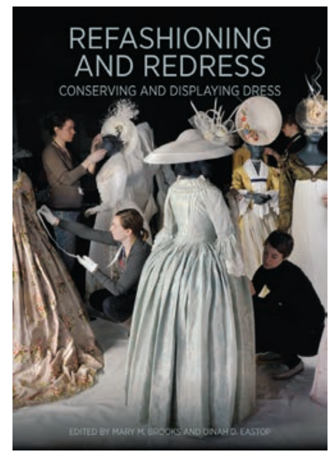
In February the Professional and Scholarly Publishing division of the Association of American Publishers announced the 41st PROSE Awards winners. The catalogue for the Getty Conservation Institute–Getty Research Institute exhibition, *Cave Temples of Dunhuang: Buddhist Art on China's Silk Road*, was awarded the top prize in the art exhibitions category. The PROSE Awards annually recognize the very best in professional and scholarly publishing by bringing attention to distinguished books, journals, and electronic content in over fifty categories.

GETTY HUB

In March 2017 the Getty launched @GettyHub, a Twitter stream dedicated to interdisciplinary resources for research, practice, and teaching across the Getty's programs, including the GCI. Read more about how the Getty came to develop this audience-centered approach on the Getty Iris: http://bit.ly/NewGettyHub

Follow @GettyHub on Twitter at: https://twitter.com/GettyHub

New Publications



Refashioning and Redress: Conserving and Displaying Dress
Edited by Mary M. Brooks and Dinah D. Eastop

This volume explores the conservation and presentation of dress in museums and beyond as a complex, collaborative process. Recognizing this process as a dynamic interaction of investigation, interpretation, intervention, re-creation, and display, *Refashioning and Redress: Conserving and Displaying Dress* examines the ways these seemingly static exhibitions of "costume" or "fashion" are actively engaged in cultural production.

The seventeen case studies included in the volume reflect a broad range of practice and are presented by conservators, curators, makers, and researchers from around the world, exposing changing approaches and actions at different times and in different places. Ranging from the practical to the conceptual, these contributions demonstrate the material, social, and philosophical interactions inherent in the conservation and display of dress and draw upon diverse disciplines ranging from dress history to social history, material cultural studies to fashion studies, and conservation to museology. Case studies include fashion as spectacle in the museum, dress as political and personal memorialization, and theatrical dress, as well as dress from living indigenous cultures, dress in fragments, and dress online.

Mary M. Brooks is a conservator, curator, and consultant. She currently teaches conservation, museology, and cultural heritage studies at Durham University, United Kingdom. Dinah D. Eastop is a conservator, researcher, and educator. She works as a consultant in conservation and material culture studies for universities and heritage organizations worldwide, notably for ICCROM. They are the editors of *Changing Views of Textile Conservation* (GCI Publications, 2011).

The Restoration of Paintings in Paris, 1750–1815: Practice, Discourse, Materiality

By Noémie Étienne

The decades following the 1973 publication of Alessandro Conti's *Storia del Restauro* have seen considerable scholarly interest in the development of restoration in France in the second half of the eighteenth century. A number of technical treatises and biographies of restorers have offered insight into restoration practice. *The Restoration of Paintings in Paris, 1750–1815*, however, is the first book to situate this work within the broader historical and philosophical contexts of the time.

Drawing on previously unpublished primary material from archives in Paris, Berlin, Rome, and Venice, Noémie Étienne combines art history with anthropology and sociology to survey the waning decades of the Ancien Régime and early post-Revolution France. Initial chapters present the diversity of restoration practice, encompassing royal institutions and the Louvre museum as well as private art dealers, artists, and craftsmen, and they examine questions of trade secrecy and the changing role of the restorer. Following chapters address the influence of restoration and exhibition on the aesthetic understanding of paintings as material objects. The book closes with a discussion of the institutional and political uses of restoration, along with an art historical consideration of such key concepts as authenticity, originality, and stability of artworks, emphasizing the multilayered dimension of paintings by important artists including Titian and Raphael. There is also a useful dictionary of the main restorers active in France between 1750 and 1815.

Noémie Étienne is Swiss National Science Foundation Professor of Art History at the University of Bern. She is a former Getty Research Institute fellow.

These publications can be ordered at shop.getty.edu.

Final Report Published

Conservation and Rehabilitation Plan for Tighermt (Kasbah) Taourirt, Southern Morocco

By the Getty Conservation Institute and Centre de Conservation et de Réhabilitation du Patrimoine Architectural des Zones Atlasiques et Subatlasiques

The oasis valleys of southern Morocco are home to thousands of earthen *kasbahs* and *ksour*, or fortified earthen settlements. From 2011 to 2016, the Getty Conservation Institute partnered with the Centre de Conservation et de Réhabilitation du Patrimoine Architectural des Zones Atlasiques et Subatlasiques in Morocco to develop a conservation and rehabilitation plan for one of the region's most significant settlements, Kasbah Taourirt in Ouarzazate.

Conservation and Rehabilitation Plan for Tighermt (Kasbah) Taourirt, Southern Morocco is the final report from this project. It presents the work in ten chapters, including documentation of the site; archival and historical research; conditions assessment of architectural fabric and wall paintings; significance and values of the Kasbah; policies adopted to guide the site's reuse; conservation interventions; and recommendations for future conservation and management.

An extensive bibliography provides references related to the history and cultures of southern Morocco; Amazigh architecture and decorative arts; rehabilitation planning and intervention case studies; and practical references related to conservation of rammed earth. The appendix presents all documentation produced during the project.

This report is available free online at http://bit.ly/Taourirt

Tributes

FRANK PREUSSER (1944–2017)

Frank Preusser, the first staff member of the Getty Conservation Institute and the individual most responsible for shaping the GCI's scientific program in its early years, passed away suddenly in January 2017.

Frank began his career in conservation after earning his PhD in 1973 in physical chemistry and chemical technology from the Technical University of Munich. Shortly after receiving his degree, he was hired to serve as the head of the research laboratory for the Doerner Institute, the research center of the Bavarian State Painting Collections. He held that position for ten years.

In February 1983 Frank was recruited from the Doerner Institute by the Getty Trust to create a scientific research program that would form the core of scientific activities of an envisioned conservation institute, as well as supply analytical services to the Getty Museum. Formally appointed director of the GCI Scientific Program in 1985, he had already begun developing a wide range of GCI research activities that expanded in short order. Essentially starting from scratch, Frank began building a scientific department by recruiting a team of young scientists interested in undertaking the challenge of applying science to the conservation of cultural heritage. He also brought on board as consultants or staff several senior scientists who had previously worked with Getty Museum conservators. He initiated a series of collaborative research projects with established and accomplished research institutions around the world and sought to use industry as a resource for existing materials that could be applied to conservation problems for the first time.

Photo: Anna Flavin, GCI.

By 1987 the Scientific Program's research activities under Frank's leadership encompassed strategies for preventing damage to collections, such as that caused by air pollution and light, fluctuations of temperature and humidity, and insect pests; methods for identifying materials and developing procedures for testing them; research and analysis of artists' materials, including pigments, binding media, and varnishes; evaluation of new analytical, diagnostic, and treatment techniques that could be applied to works of art; and the conservation of building materials such as stone and adobe. In 1990 Frank was appointed associate director of Programs for the GCI, a position he held for three years. During his tenure at the GCI, he also served on a number of international advisory committees focused on the preservation of significant heritage around the world.

Following his 1993 departure from the Institute, Frank founded Frank Preusser & Associates, consulting for a number of cultural institutions and undertaking scientific investigations of specific works of art. In 2005 he was appointed Andrew W. Mellon Senior Conservation Scientist in the Conservation Center of the Los Angeles County Museum of Art (LACMA), a position he held until his death. Among the projects he led while at LACMA was the museum's project to conserve Watts Towers, a Los Angeles landmark.

Frank's legacy includes laying a solid foundation for the work of GCI Science today. In the Institute's embryonic phase, he established the GCI's credentials by quickly carrying out important work that made substantive contributions to the field. For that work, and for his lifelong leadership in conservation science, he will be remembered.

The Institute offers its condolences to his wife, his children, and his grandchildren.

ERIC F. HANSEN (1949–2016)

Eric F. Hansen, a former member of the Getty Conservation Institute's Science department staff, died in September after a long illness.

Eric joined the GCI in its very early days, hired as a research assistant in 1985 after earning degrees in chemistry and chemical engineering. Two years later he was made an assistant scientist, in 1989 he became an associate scientist, and in 2000 he was promoted to scientist. Eric's early Institute research focused on accelerated-aging testing of certain polymers for use in conservation and on investigating the optimal relative humidity conditions for long-


Photo: Dennis Keeley, for the GCI.

term storage of materials that contain collagen and skin. He subsequently studied the problems of consolidating matte paint, particularly on ethnographic objects, and he codeveloped and edited a special supplement to *Art and Archaeology Technical Abstracts* on that subject. Later he headed a GCI scientific research project, Lime Mortars and Plasters, which focused on the study of the fundamental characteristics of lime. His work in this area grew out of his long interest in the Maya and the dissertation research he conducted at the site of Nakbe in Guatemala. His study of the technology used for plaster and stucco production in late preclassic Maya sites was at the core of his PhD in archaeology, which he received from UCLA in 1992.

Eric served on the board of the American Institute for Conservation (AIC) and the Western Association for Art Conservation and was one of the founders of the Research and Technical Studies Group of the AIC. In 2006 he received the President's Award for his contributions to the conservation profession at the AIC annual meeting in Providence, Rhode Island.

After over twenty years at the GCI, Eric retired in 2006 and moved to Washington, DC, to become the chief of the Preservation Research and Testing Division of the Library of Congress; there he oversaw the increase in scientific staff and the remodeling of the division's laboratories. When his tenure at the Library of Congress was over he returned to Los Angeles, where he served as a consultant to the conservation department of the Museums of New Mexico and joined the advisory committee for the Los Angeles County Arboretum and Botanic Garden's historic section.

Eric was a highly valued colleague and friend of many at the GCI and throughout the conservation field. His persistence in serving the field even while confronting illness is a testament to the dedication and enthusiasm for his work that he displayed throughout his career. We celebrate that work as we mourn his loss.

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

CONSERVATION PERSPECTIVES
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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, www.getty.edu/conservation.

The Getty Conservation Institute works to advance conservation practice in the visual arts, broadly interpreted to include objects, collections, architecture, and sites. It serves the conservation community through scientific research, education and training, model field projects, and the broad dissemination of the results of both its own work and the work of others in the field. In all its endeavors, the Getty Conservation Institute focuses on the creation and dissemination of knowledge that will benefit the professionals and organizations responsible for 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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CONSERVATION PERSPECTIVES
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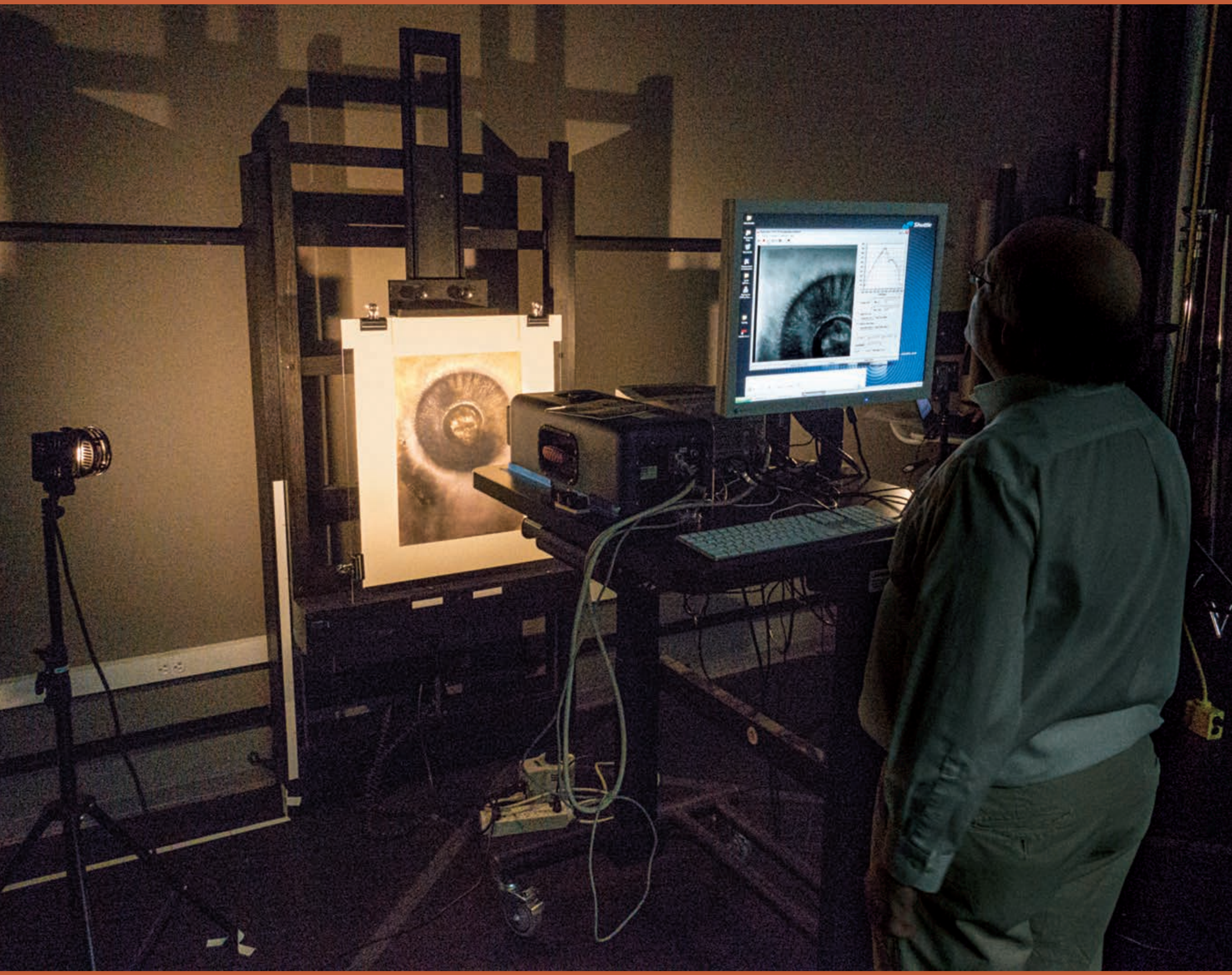

John Delaney of the National Gallery of Art performing hyperspectral imaging on the mixed media drawing *Head within an Aureole* by Odilon Redon (1894–95, J. Paul Getty Museum, 2016.10) as part of a GCI-Museum research project into the characterization of nineteenth-century black drawing media. Photo: Jeffrey Levin, GCI.

The Getty Conservation Institute

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