Recording, Documentation, and Information Management for the Conservation of Heritage Places

ILLUSTRATED EXAMPLES

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The Getty Conservation Institute

Locations of the illustrated examples.

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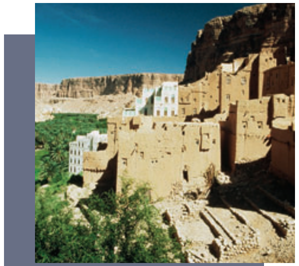

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CONDITION ASSESSMENT: WORKING WITH INFORMATION

Condition Survey

Rand Eppich, Dusan Stulik, and Jaroslav Zastoupil

Over the centuries, the vividly colored images and figures of the *Last Judgment* mosaic, on the southern facade of St. Vitus Cathedral, in Prague, Czech Republic, have been obscured by a gray crust. Before conservators could begin to restore the mosaic, they needed to study the types and locations of damage, previous treatments, and other problems. Graphic documentation enables conservators to record their studies and note conditions. Technology should assist, not interfere, with this process.

How can conservators record these conditions using simple techniques yet still harness the power of technology?

Detail of an angel, shown after cleaning, in the *Last Judgment* mosaic, above the entrance to St. Vitus Cathedral, Prague. Photo: Dusan Stulik.

St. Vitus Cathedral, Prague

Jesus Christ, the central figure in the *Last Judgment* mosaic, is depicted passing judgment on the world, surrounded by triumphant angels above the patron saints of Bohemia. To his right, the dead are resurrected from their graves. To his left, blue devils welcome the damned. These dramatic scenes have become visible only recently. For hundreds of years, they were obscured by a chalky gray crust caused by the corrosion of the small glass cubes, or tesserae, that make up the mosaic. The corrosion was the result of rainwater interacting with the impurities of potassium and calcium within the medieval glass. When exposed to water, these minerals are leached out, creating alkaline salts that react with carbon dioxide and sulfur dioxide and crystallize on the surface.

It is likely that Charles IV, king of Bohemia and the Holy Roman Emperor, noticed the "dimming" of his mosaic. He commissioned the work in 1371 for the southern entrance of the cathedral to symbolize the magnificence of his kingdom. Called the Golden Gate, as much of it was gilded, the mosaic is made of more than a million red, blue, and other brilliantly colored tesserae. It is composed of three panels 4 meters wide by 8 meters high, and is considered to be the most important mosaic north of the Alps. Cleaning and repairs had been attempted several times over the centuries but always with short-term results, and the mosaic soon became obscured again.

In 1992, the Office of the President of the Czech Republic, the Prague Castle Administration, and the Getty Conservation Institute (GCI) began a project to conserve the mosaic and make it permanently visible. An expert conservation team was formed with leading conservators, historians, and scientists from across Europe and the United States. They were presented with three significant challenges: to determine what caused the crust, to safely clean the glass without damaging it, and to protect the work from the elements once cleaned.

The ten-year project was divided into four phases. First, conservators studied and researched the mosaic's history, past treatments, and physical composition to identify and describe the mechanisms of deterioration. Second, they examined and assessed its current condition, documenting in detail the levels of corrosion, cracks, missing tesserae, original traces of gilding, previous interventions, and other significant attributes. This was followed by the third phase, extensive testing of treatments for both cleaning and protection. Conservation was implemented in the final phase once the team was absolutely sure of a safe and effective treatment. After conservation was finished, the mosaic was periodically monitored to ensure that it remained visible.

Constraints on the project were few, as this is a significant work of art and a national treasure. However, there was one significant constraint concerning documentation during the second phase. Project managers wanted to use advanced computer imagery and graphics to record and analyze the information collected on the mosaic, yet expert conservators on the team had never used this technology. The managers insisted that conservators should not have to alter their methods or compromise their condition assessment. An approach had to be developed so that the conservators could collect data on site, yet still use computer technology for analysis, investigation, and publication.

Detail of a figure in the mosaic prior to cleaning, showing levels of corrosion. Photo: Dusan Stulik.

Transparencies

A simple but systematic method was devised using multiple A4-size transparent plastic sheets over printed images of the mosaic. By using this method, conservators were not distracted by technology and did not have to substantially change the way they worked. Several important steps were required, however.

The first step was to begin with a good image of the mosaic to use as a base map. The image had to be of sufficient resolution for the conservators to see each small, 30 × 30-millimeter-square tessera. This step required specific expertise, so the conservation team hired a Czech company to photograph, accurately measure, and process the images to be used for the base map. Each panel of the mosaic was photographed in its entirety with a medium format (13 × 18 centimeter) Carl Zeiss Jena UMK 10/1318 camera with a Lamegon 8/100 lens using Kodak Ektachrome E100s color film, speed 100ASA. The film was then developed and scanned with a photogrammetric Zeiss/Intergraph TD scanner.

High resolution is only one aspect of creating a good base map; the images also have to be distortion free. Distortion is caused by the curvature of the lens, the film, and the position of the camera in relationship to the subject. With accurate measurements of the mosaic and knowledge of the camera and lens geometry, any distortion can be removed through computer processing.

In the second step, the sharp corners of ten individual tesserae on each panel were selected as control points. Then, their three-dimensional coordinates were measured with a Wild T2000/Distomat DI1600 total station. Using the target measurements and the computer program PhoTopoL, the digital images were then rectified, or transformed, and correlated to fit actual dimensions of the mosaic. The removal of distortion and the placement of the images to exact scale were crucial, as each of the three panels was photographed separately during different phases of the work. This allowed images taken before, during, and after conservation of each panel to align exactly.

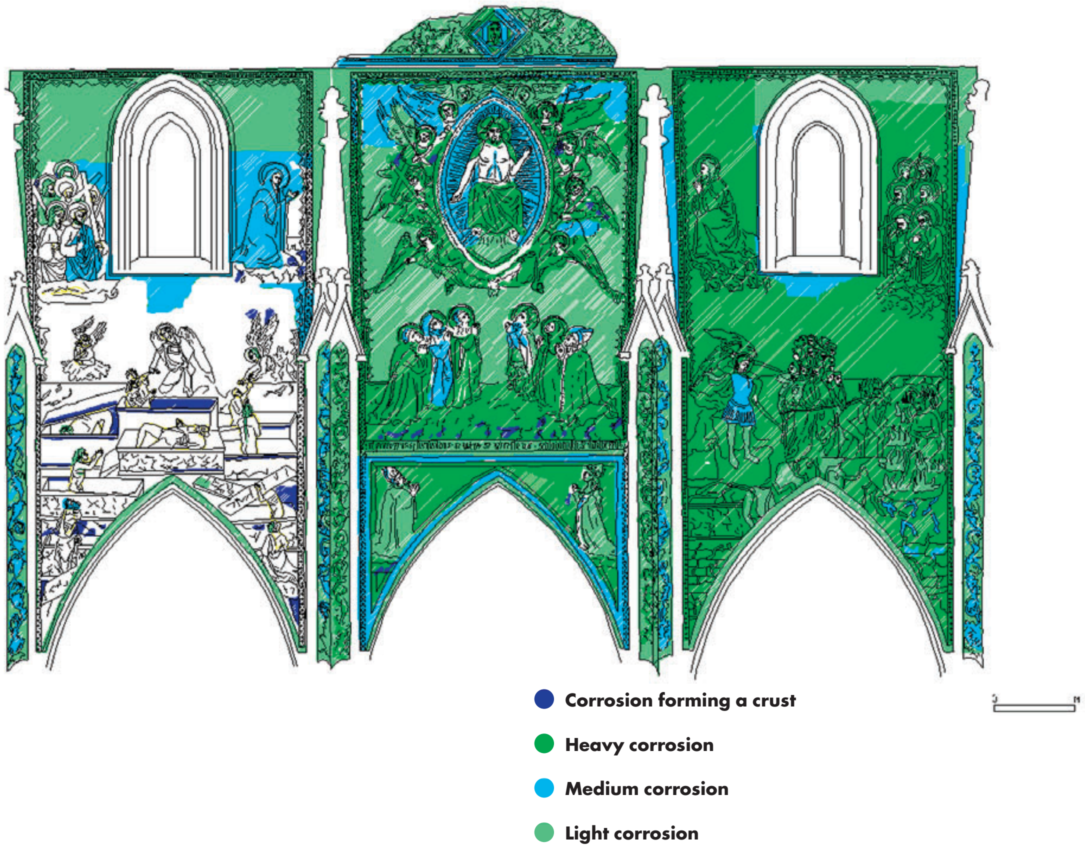
Conservators at St. Vitus Cathedral inspecting the mosaic, recording conditions on transparencies overlaid on rectified photographs of the facade. Photo: Dusan Stulik.

In the third step, the distortion-free images and measurements were imported into AutoCAD, a computer drafting program, and sent to the conservators. Using this program, a grid was then drawn every 20 centimeters over each image, both vertically and horizontally. This, along with a naming standard, created a coordinate system that allowed the team to reference specific sections of the mosaic. For example, Christ passing judgment is located at LJCBC B4. This refers to the *Last Judgment* (LJ), center panel (C), before conservation (BC), column B, row 4. Four rows by four columns were then printed at a scale of 1:4 on A4 heavyweight paper. A4 transparencies were also printed with a corresponding grid in order to align properly with the image of the mosaic. This proved to be a good size, as it was manageable on a clipboard yet still provided an acceptable level of detail. By using the base map image and transparency overlay, conservators could work on the scaffolding to manually record important features.

Information collected by conservators on the transparencies was scanned and imported back into the computer model. Prior to collecting information on the transparencies, it was found that certain colors–green, yellow, and other light colors–were not optimal for scanning. Therefore red, dark blue, black, brown, magenta, and orange were chosen for use. It was also important that only new markers were used. A condition legend was created that corresponded to each color. Red referred to cracks, magenta to traces of original gold, and blue to missing tesserae. In addition, extra transparencies were made available if the conservator made a mistake; no corrections were possible given that the transparency was scanned. All of these issues were carefully explained to the conservators, who were required to change their usual methods.

After the transparencies were scanned as bitmaps, they were converted into a form that could be included in a computer drawing program. Bitmaps (or raster graphics) are how computers and programs such as Adobe Photoshop record and display graphic images. The computer image created from the scan of the transparency is composed of millions of individual points (or pixels) of color. The number of points determines the resolution of an image. In this form, the information is not easy to calculate, combine, or separate into distinct divisions or layers; it is also of limited use at a large size. The individual points in a bitmap image can be seen if printed too large, resulting in uneven lines. The scanned data had to be converted into a different form—a vector graphic image. Vector graphics represent an image through numbers or mathematical models, and in this form it could be combined and manipulated more easily. Cracks could be measured and areas calculated because the graphics are based on numbers, not just on individual points. Vector graphics could also be printed at any size without a loss in resolution. A computer program, Adobe Streamline, was used to perform this conversion. Once complete, the data from each separate transparency were digitally reassembled on top of the image of the mosaic.

Scanned transparency of the mosaic, with graphic recording of corrosion levels. Drawing: Rand Eppich.



Rectified images of the facade, showing its state before conservation (*left*), after treatment (*center*), and after gilding (*right*). Images: Jaroslav Zastoupil.

This simple method allowed a team of five conservators to manually record the condition of each panel in approximately two weeks. It only slightly altered the way they traditionally work, requiring very little training in the use of computer graphics. One junior member of the team was trained in scanning the transparency images, converting them from bitmap to a vector form and then assembling them back into the AutoCAD file. This same member was also responsible for all data management on site and additional work that was accomplished several weeks later. Once the documentation was finished, corrections and additions were made and the data printed at various sizes for further use in the project. The observations of the conservators aided in forming the subsequent treatment plans and also served as a benchmark for future work on the mosaic. At the end of the project, the data were archived in both print and digital form in Prague and Los Angeles.

Alternative tools, such as the direct use of laptop computers, were considered, but this required too much training and may have been a distraction while working on the scaffolding. Computers that allow the operator to draw directly on screen were also considered, but at the time of this project the technology had not progressed sufficiently. This methodology is still viable for projects without sufficient funds to purchase computers. Minimal training was required for the expert conservators but some training in scanning and AutoCAD was needed for the junior member.

An Answer

Conservators recorded the condition of the mosaic in order to understand and note issues that led to a conservation strategy. The techniques used in this example allowed them to conduct their evaluation without significantly changing their methodology.

The information collected, once converted to digital form, allowed conservators to view various conditions in new and different ways. Cracks and areas of loss were easily measured, as were patterns of corrosion relating to the different types of tesserae. The mosaic and the condition record were studied in detail away from the site, in multiple locations, which facilitated communication among the experts. Prints were made at various scales for use on the scaffolding and in presentations to both the public and professionals. Historic photographs were also scanned and included with the condition record. This method provided a tool that was more flexible and useful than if the documentation had not been digital. It also provided a complete visual description of the mosaic and serves as a record of recent interventions.

After the record was complete, the final phases of the project were carried out. A suitable method for removing the crust was tested and used. The mosaic was cleaned using compressed air and microscopic glass particles that were harder than the crust but softer than the tesserae. After cleaning, the surface was prepared with a solvent to remove any remaining residue. Each tessera was then treated with a complex protective coating that consisted of several layers. The outer layer is sacrificial and needs to be replaced every five years, whereas the inner layer is more durable and expected to last at least twenty-five years. This coating will shield the mosaic from the elements while allowing it to remain visible. The mosaic is inspected annually and photographed systematically in detail to determine if the coating is still functioning. Plans are in place to photograph and measure the entire mosaic every five years.

Rand Eppich is a licensed architect in California who established and is currently managing the Getty Conservation Institute's Digital Recording Lab for architectural documentation and site analysis. He has been elected to membership to CIPA (International Committee for Architectural Photogrammetry) and has taught courses on architectural conservation and documentation at ICCROM and at the University of California, Los Angeles.

Dr. Dusan Stulik is a senior scientist for the Getty Conservation Institute, specializing in photograph conservation. His current research involves development of scientific methodology for identification of different photographic processes and process variants.

Jaroslav Zastoupil, a measured building surveyor and photogrammetrist, was born in Varnsdorf, Czech Republic. He studied at Czech Technical University, Prague, in the Department of Mapping and Cartography. In 1997, he established Zastoupil a Král Land Surveyors and has worked on such projects of significance as the Karlstejn Castle, Chateau Veltrusy, and the Pilgrimage Church of St. John of Nepomuk, on Zelená Hora.

Building Survey

Christian Ouimet

Fort Henry is strategically located in Kingston, Ontario, Canada, at the confluence of the St. Lawrence River and the Rideau Canal, at the eastern end of Lake Ontario. Time and climate have taken their toll on this immense masonry complex, which was built by the British in the 1830s to defend their interests in Upper Canada. In 2000, the decision was made to reevaluate the condition of the fort, and a comprehensive multiyear conservation project was initiated. Extant recording was a critical component of the conservation work.

How can data gathered from a variety of techniques and tools be combined into one shared format to aid in the long-term assessment and conservation of this massive complex?

This illustrated example was completed with the assistance of Bryan Mercer, marketing officer, and Ron Ridley, curator, Fort Henry National Historic Site of Canada, St. Lawrence Parks Commission, Ministry of Tourism. They provided images and details of the ongoing work at Fort Henry, even as the conservation work on the East Branch ditch tower was under way.

The East Branch ditch tower of Fort Henry, overlooking Lake Ontario and the mouth of the St. Lawrence River. Photo: Christian Ouimet © Heritage Conservation Directorate, Public Works and Government Services Canada.

Fort Henry, Canada

Fort Henry is located in Kingston, where the St. Lawrence River leaves Lake Ontario at the start of the Rideau Canal system. It is situated at the easternmost point of the Great Lakes, the major transshipment route for all points west during the eighteenth and nineteenth centuries. The Great Lakes and St. Lawrence River also formed the border between British-controlled Canada and the United States. The fortification consists of the main redoubt and advanced battery, built between 1832 and 1837 to replace an existing fortification from the War of 1812. Fort Henry was designed to protect the Canadian border, its waterways, the Rideau Canal, and the adjacent naval dockyards. Enlarged in the 1840s with the construction of commissariat stores and two outlying towers, it soon became one of the largest, costliest, and most complex fortifications in Canada. The fort represented a significant commitment by the British to protect Canada and was garrisoned until 1870; it was then used by the new Canadian army until 1891.

After 1891, Fort Henry stood abandoned until 1923, when it was declared a National Historic Site. It was first restored between 1936 and 1938. During the First and Second World Wars, it served as an internment and prisoner-of-war camp. The government of Ontario began to operate Fort Henry as a museum and heritage attraction in 1938, under an agreement with the Department of National Defence (DND). In 1999, the federal government transferred administrative responsibility for the site from DND to Parks Canada. The St. Lawrence Parks Commission, an agency of the province, continues to operate Fort Henry. Every summer the site is brought to life by telling the story of the fort through the internationally renowned Fort Henry Guard, guided tours, museum displays, and special events. The complex consists of many individual structures: the main fortification, or redoubt, the commissariat stores, reverse fire chambers, advanced battery, stockade buildings, and the two outlying (branch) ditch towers, so called because they are set above deep trenches.

Canada's cold, wet winters have had their impact on these buildings. The wood rafters of the commissariat stores decayed as a result of a leaky roof. The retaining walls of the fort's entrance ramp deteriorated and required structural stabilization. The limestone blocks that make up the redoubt were fractured and spalling, and the mortar had deteriorated significantly. In the interest of safety, some areas were initially stabilized, but due to the fort's size, complexity, and condition, Parks Canada and the St. Lawrence Parks Commission developed an ambitious long-term conservation plan.

Recording of the fort was initiated to support the conservation efforts and to identify areas requiring immediate attention. Before beginning, it was important to get input from stone conservators, engineers, architects, and building contractors. Stone conservators required surface detail to see the condition of masonry and mortar; architects and engineers needed a comprehensive site plan to coordinate activities; and contractors needed measurements to prepare estimates.

At the outset, questions were raised: Which components of the buildings are to be recorded? What types of drawings are needed: floor plans, sections, or elevation drawings of the walls? What levels of detail and precision are required? Conservation specialists and building contractors recognized the importance of having current and accurate information with which to work.

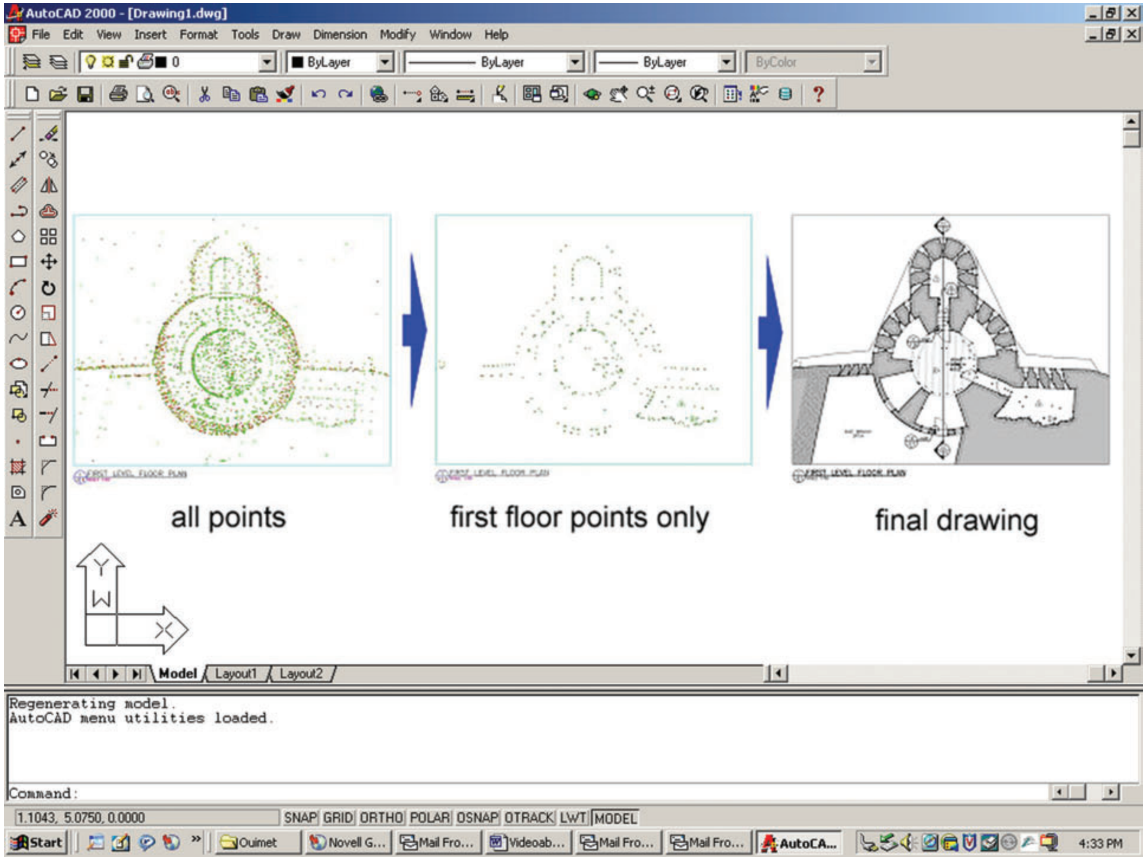
Fort Henry is strategically located on the trading routes between Montreal, Ottawa, and all points west. In the background, the Rideau Canal leads to Ottawa; in the foreground, the St. Lawrence River leads to Montreal. Photo: © Fort Henry National Historic Site of Canada–Archives.

Fractures and spalling of the limestone blocks in an archway of the redoubt. The mortar joints had also deteriorated significantly. Photo: © Fort Henry National Historic Site of Canada–Archives.

Computer-Aided Design and Drafting

Once the aforementioned questions were answered, the next step was to select the appropriate tools and methods to obtain the information needed by the specialists. Although time and cost were important factors, the primary consideration was to fulfill the needs of the conservation specialists. Rectified photography was chosen for the exterior elevations, hand recording with a tape measure for the interior rooms, and survey instruments (including a total station theodolite) to provide overall detailed measurements of the site and exterior curved surfaces. The rectified photography of the walls provided the necessary level of surface detail for the stone conservators to chart cracks and spalling damage and to identify ashlar blocks in need of repair or replacement. For the engineers and architects, the survey plan of the entire site proved indispensable in planning and scheduling the long-term interventions. For budgeting, the building contractors used the measurements to calculate the amount of materials required. Creating the documents that these specialists needed required software that could combine information from multiple sources.

Computer-Aided Design and Drafting (CAD) is software essential to conservation specialists. It enables measurements, data, and images from multiple tools and methods to be combined. CAD is flexible enough to allow the user to produce quick, basic sketches, as well as drawings of great precision and detail. Serving as the common platform for printing and sharing data among specialists at different stages of conservation, images can be imported and data added manually or input directly from survey instruments. Data can be displayed in different ways, including two-dimensional orthographic projections or



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Regenerating model.
AutoCAD menu utilities loaded.

Command:
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Screenshot of the CAD drawing of the West Branch ditch tower, showing the initial data points recorded with the total station (*left*), the later edits (*center*), and the final section drawing (*right*). Drawing: Christian Ouimet © Heritage Conservation Directorate, Public Works and Government Services Canada.

three-dimensional isometric, or perspective, views. Information can be divided using multiple layers, or views, which can then be recombined in various ways. For example, a single site plan can serve both an engineer with a drainage layer and an architect with a visitor path layer.

Autodesk's AutoCAD, a widely used brand of CAD software, was chosen for this project. The first source of data entered into AutoCAD was the total station theodolite survey of the entire Fort Henry complex. This survey established a local coordinate system that provided control, or reference, for all subsequent measurements by other methods. This single coordinate system permitted the combination of information such as building location, wall thickness, wall condition, height, and elevation. It also allowed the combination of data collected over time, an important consideration in a multiyear project.

Once this coordinate system had been established, the strength of CAD became apparent in the assessment of the redoubt's stone wall. The software allowed the team to directly import images of the exterior elevations. The images were placed and scaled (rectified) using measurements obtained from survey targets placed on the stone wall surface. Stones and mortar joints were traced from the images and placed on assigned layers. Stone conservators noted on the drawings where mortar and stones had deteriorated and where replacement or repair was needed.

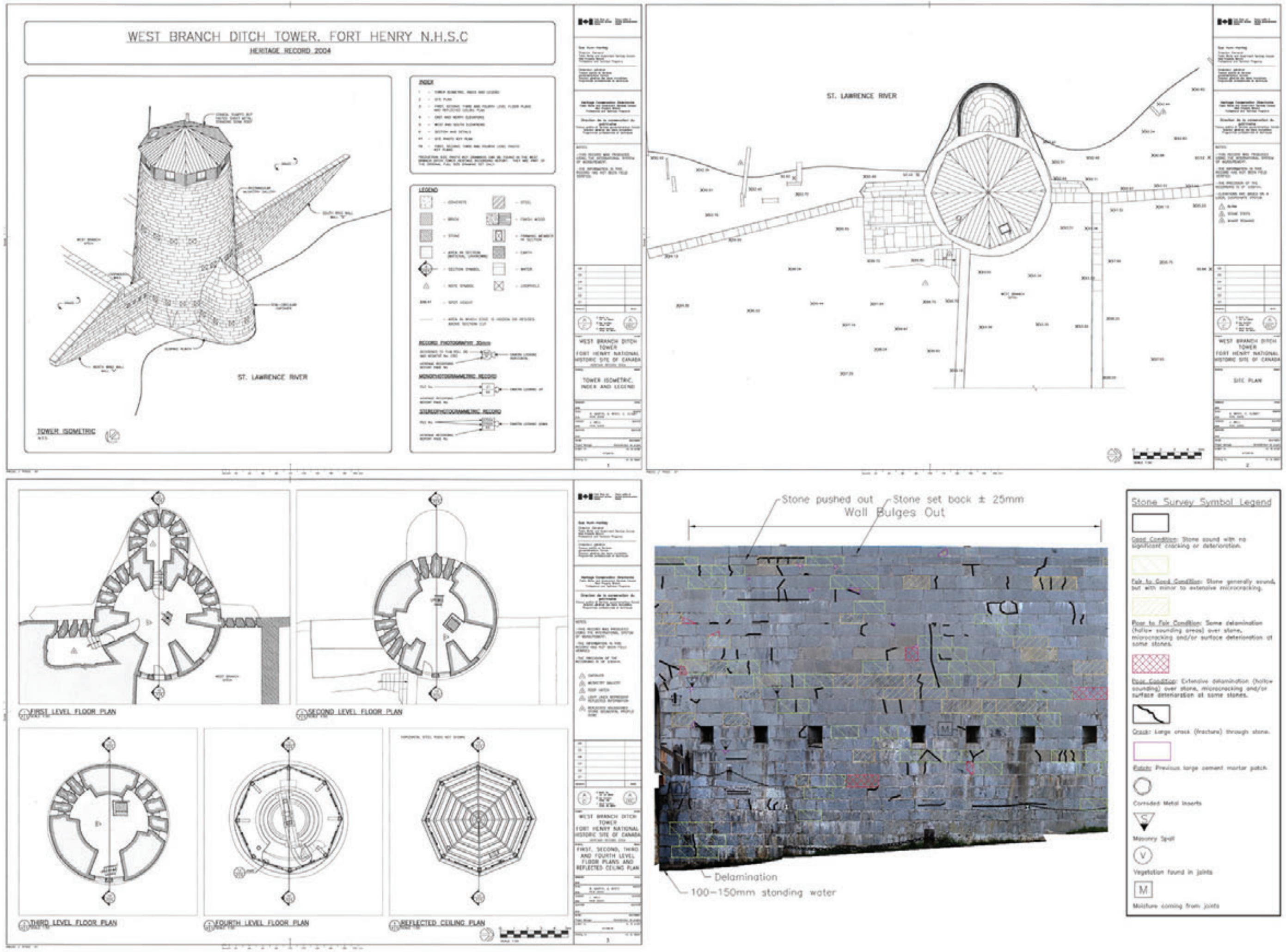
Survey with the total station theodolite was also the primary method for collecting the measurements of the curved exterior surfaces of the branch ditch towers. Measurements from each of the four floors, window openings, roof outlines, and other features were placed onto separate layers. This gave the team greater flexibility in producing the drawings, including a three-dimensional model of the towers' exteriors.

The interior of the towers and the timber-frame roof structures of the commissariat stores were measured by hand due to the small size of the spaces. These interior measurements were related to the overall coordinate system via window openings so that once the measurements were entered, they would align with those taken from the exterior. The CAD software made possible the combination of both sets of measurements obtained from different methods. Cross sections through the tower walls were created using these measurements.

Naming conventions based on existing historical names, locations, and features were applied to the data collected and to the CAD layers, drawings, and directories. Using a naming convention that all specialists could share was essential for multidisciplinary communication. It also allowed the CAD operators to create and draw various CAD files simultaneously.

The final drawings created in AutoCAD included the overall plan of the fort, rectified images of the walls, isometric views, sections, elevations, and plans of the towers; a condition assessment of the stone and mortar was also incorporated. The site work for the overall plan and redoubt involved six heritage recording professionals and took two weeks, followed by two weeks of office work by four CAD operators. Site work for the towers took two weeks during the summer and two days in winter with two recorders. In winter, the areas of the towers that faced the water were recorded from the ice surface, which allowed the recording team to collect data not accessible earlier. Office work in AutoCAD for the towers took approximately two months with two CAD operators.

In subsequent phases of the project, engineers and architects used the CAD drawings for the development of the final conservation plan and the preparation of tender documents for bidding by building contractors. Making the drawings available to the latter increased their understanding of the materials needed for the conservation work and greatly assisted with their cost estimates. The project manager attested to the significant savings in both time and cost for the work done. In fact, the contractor selected to perform the conservation work used the drawings as a primary tool in guiding his workers.



Elevation and section drawings of the West Branch ditch tower. Included is the condition survey of the facade masonry and mortar. Drawings: Christian Ouimet © Heritage Conservation Directorate, Public Works and Government Services Canada.

An Answer

In fall 2002, the rampway leading into the fort, along with the fort's retaining walls, was stabilized and reinforced, and any damaged stone was replaced. Treated steel anchors were inserted through the walls to provide additional structural stability, and the walls were waterproofed from behind. This was followed in 2003–4 with the repair of the timber structures of the commissariat buildings and the reroofing of the buildings with historically appropriate materials. A three-year project commenced in 2004 to waterproof, repair, and stabilize the redoubt, and in fall 2006, conservation work was begun on the East Branch ditch tower to restore the roof and repair the stone walls. This work continues in 2007 on the West Branch ditch tower. Other conservation projects currently in the planning and implementation stages include the repair and repointing of the advanced battery and the north wall of the redoubt. Each intervention reflects a commitment to respecting the established heritage character of the site.

Workers removing deteriorated mortar from the East Branch ditch tower for repointing. Photo: © Fort Henry National Historic Site of Canada–Archives.

The scaffolded East Branch ditch tower during the restoration project. Photo: © Fort Henry National Historic Site of Canada–Archives.

CAD software has dramatically changed the way drawings have been produced over the past twenty years. Drawings can now be easily manipulated, changed, copied, transmitted, and printed in a variety of ways. Along with improved production efficiency, drawings produced with CAD have a more consistent look. Most important, however, CAD provides a means by which drawings from numerous sources can be combined. This combination of sources increases the value of the original data and allows engineers, architects, conservators, and other specialists to gain a better understanding of a structure or site. It also provides greater flexibility for the sharing of information. The CAD work undertaken in support of the conservation efforts at Fort Henry not only provides a record for posterity but also continues to assist during the entire conservation process.

Editor's note: In 2007, the Rideau Canal, Fort Henry, and the Kingston fortifications were inscribed on the UNESCO World Heritage List.

Christian Ouimet is an architectural conservation technologist with the Heritage Recording Unit of the Heritage Conservation Directorate, where he is involved in the documentation and monitoring of monuments, buildings, and sites by means of various documentation tools. He has worked on various projects, from large industrial sites such as the Britannia Mines Concentrator Mill Complex, near Squamish, British Columbia, to topographical battlefield terrain at the Canadian First World War Memorials, in Europe. He has also recorded entire towns, including Old Town Lunenburg, Nova Scotia, a World Heritage Site.

Ancestral Art

Cliff Ogleby

Uluru and the ancestral art sites at its base hold special meaning for the Aboriginal people of central Australia. These sites are threatened by water, insects, animals, and people. A number of these sites have been developed to allow visitor access, while others, considered sacred, are restricted to authorized men or women. If these sites are to survive, conservation and management are necessary.

How can a secure repository for the data be provided yet still allow access for conservation, maintenance, and management of the site?

Mutitjulu Anangu rock art at the base of Uluru. Photo: © Cliff Ogleby.

Uluru, Australia

Jutting upward and rising more than 300 feet from the surrounding arid plain, the rock formation known as Uluru is a dominating presence in the Australian landscape. Made of sandstone, it is a unique formation noted for its changing colors as light is reflected throughout the day. Located almost at the center of the Australian continent, within the country of the Anangu people and Uluru–Kata Tjuta National Park, Uluru is a unique ecosystem, home to a wide variety of plants and animals. It is valued not only for its exceptional natural beauty but also for the special cultural significance it holds for the Aboriginal people.

To the Anangu, Uluru is believed to be the spiritual dwelling place of their ancestral beings, who created the land and all living things. Significant events from the journeys and activities of these ancestral beings are depicted in rock art found along Uluru's base. The most sacred sites, restricted to the Anangu elders, are connected by a network of sacred paths or tracks known as *iwara*. Nearly eighty other sites, petroglyphs, and rock peckings represent the history and traditions of the Anangu people.

Uluru and the surrounding area of Kata Tjuta were first surveyed by Europeans in the 1870s. Named Ayers Rock after Sir Henry Ayers, chief secretary of South Australia, the land was at first considered inappropriate for European settlement and explored only by miners. In the 1920s, the rock and surrounding land were declared the South-Western or Petermann Reserve and set aside as a sanctuary for the Aborigines. However, small groups of settlers, missionaries, hunters, and miners encroached on the sanctuary. When gold was discovered in the area, prospecting soon was given precedence and the sanctuary declaration was revoked. As transportation improved in the mid-twentieth century, public interest in visiting this unique landscape increased.

Tourism had a negative impact on Uluru, its rock art, and the Anangu people, and concerns were raised about the preservation of the land and its resources. This led to the declaration of Uluru (Ayers Rock–Mount Olga) National Park in 1977, later renamed Uluru–Kata Tjuta National Park. Eight years later, the land around Uluru and Kata Tjuta was ceded back to the Anangu and then leased to the Australian government to be jointly managed with the Anangu. A management plan was undertaken in a collaborative effort between Anangu park rangers, the Anangu elders, National Park staff, and the Australian Heritage Commission. This plan required that the park and land be governed by *tjukurpa*. Tjukurpa can be best described as an oral cultural tradition that governs the Anangu way of life and the relationships between people, animals, plants, and the landscape under a moral and religious code. Tjukurpa is the guiding philosophy behind the plan and was integrated into the daily activities of the park.

The monolith Uluru in the glow of sunset.
Photo: © Cliff Ogleby.

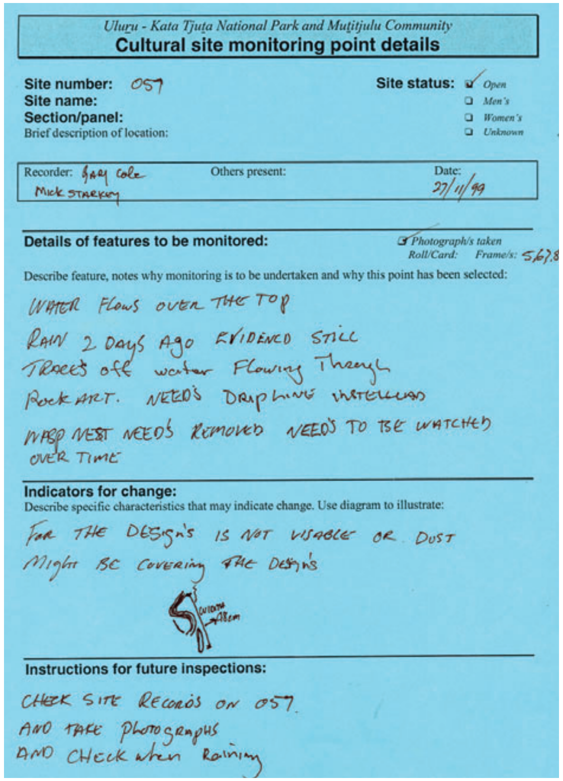
Red graffiti obscuring rock art at Uluru.
Photo: © Mick Starkey.

A fundamental part of the plan was to create the first systematic record of the rock art sites and their anthropological aspects. Anangu elders requested that this documentation include associating "place history" with "people history." They saw it as a permanent record of their intangible traditions and as a way to engage the younger Anangu in their ancestry and traditions. A documentation system was needed as a safekeeping place for the intangible heritage of the Anangu in accordance with tjukurpa, while still allowing daily management, conservation planning, and visitor interpretation of the rock art. One principle of tjukurpa declared that visitors be restricted from viewing certain images or visiting certain sacred places. For example, sites were restricted by gender: Aboriginal women could not view information on or have access to Aboriginal men's sacred sites, and Aboriginal men could not view or visit Aboriginal women's sacred sites.

Databases

The documentation project began by taking multiple stereophotographs of and measuring and mapping every rock art site. Where the rock art was too faint to be captured on film, meticulous sketches were made. It was crucial that the Anangu were actively involved in the process, as they are intimately familiar with the importance and restrictions of the sites and ultimately would be responsible for their management. The process took several years, and during that time the data were organized using an electronic "catalogue." Once photography and mapping were finished, it became clear that if all aspects concerning the rock art were to be recorded, a broader, more inclusive system was required, one that could organize all the data while accommodating new types of information into a central, accessible, and safe repository. It was important that this repository connect the Anangu to their history, excite the younger generation, and keep sensitive data secure, yet still allow park rangers to plan for visitor access, conservation, and maintenance.

A typical form used for gathering data in the field at Uluru. Photo: © Cliff Ogleby.



Uluru - Kata Tjuta National Park and Mutitjulu Community

Cultural site monitoring point details

Site number: 057

Site name:

Section/panel:

Brief description of location:

Site status: ☑ *Open* ☐ *Men's* ☐ *Women's* ☐ *Unknown*

Recorder: GARY COLE MICK STARKEY

Others present:

Date: 27/11/99

Details of features to be monitored:

☑ *Photograph/s taken*

Roll/Card: *Frame/s:* 5,6,7,8

Describe feature, notes why monitoring is to be undertaken and why this point has been selected:

WATER FLOWS OVER THE TOP
RAIN 2 DAYS AGO EVIDENCD STILL
TRACES OFF water Flowing Through
ROCK ART. NEED'S DRIP LINE INSTALLED
WASP NEST NEED'S REMOVED NEED'S TO BE WATCHED
OVER TIME

Indicators for change:

Describe specific characteristics that may indicate change. Use diagram to illustrate:

FOR THE DESIGN'S IS NOT VISABLE OR DUST
MIGHT BE COVERING THE DESIGN'S

Instructions for future inspections:

CHECK SITE RECORDS ON 057.
AND TAKE PHOTOGRAPHS
AND CHECK when Raining

A team member (*foreground*) instructing an Anangu park ranger on the use and management of the database system. Photo: © Mick Starkey.

A cultural site management system (CSMS) was built upon Microsoft Access, a common database software program. The database used at Uluru is a collection of various types of data, including photographic images, sketches and measurements, condition assessments, and other pieces of information stored in a systematic way for security and easy retrieval. Individual records or data are separated into sets, themes, and fields, with unique identifiers to allow the data to be linked together and queried in various ways. The database can connect the separate pieces of information together. For example, in all photographs the names of the people depicted are included so that data can be searched by name. This may appear unimportant, but under tjukurpa, images of deceased people cannot be seen during mourning; when appropriate, any material related to these individuals can be moved to the "sorry box"–an area of the database where information is unavailable for retrieval–until it is approved for release.

The CSMS was created not only to provide access to the data but also to display interactive maps and short video and audio segments. Often, databases cannot display or play the various types of files required to describe a site, so connections are commonly created to other computer programs. Video and audio segments are played using Microsoft Windows Media Player, and maps are created with ESRI ArcView software. The mapping software used for display is ASPMap, using Internet Information Server (now Internet Information Services), an internal networking component.

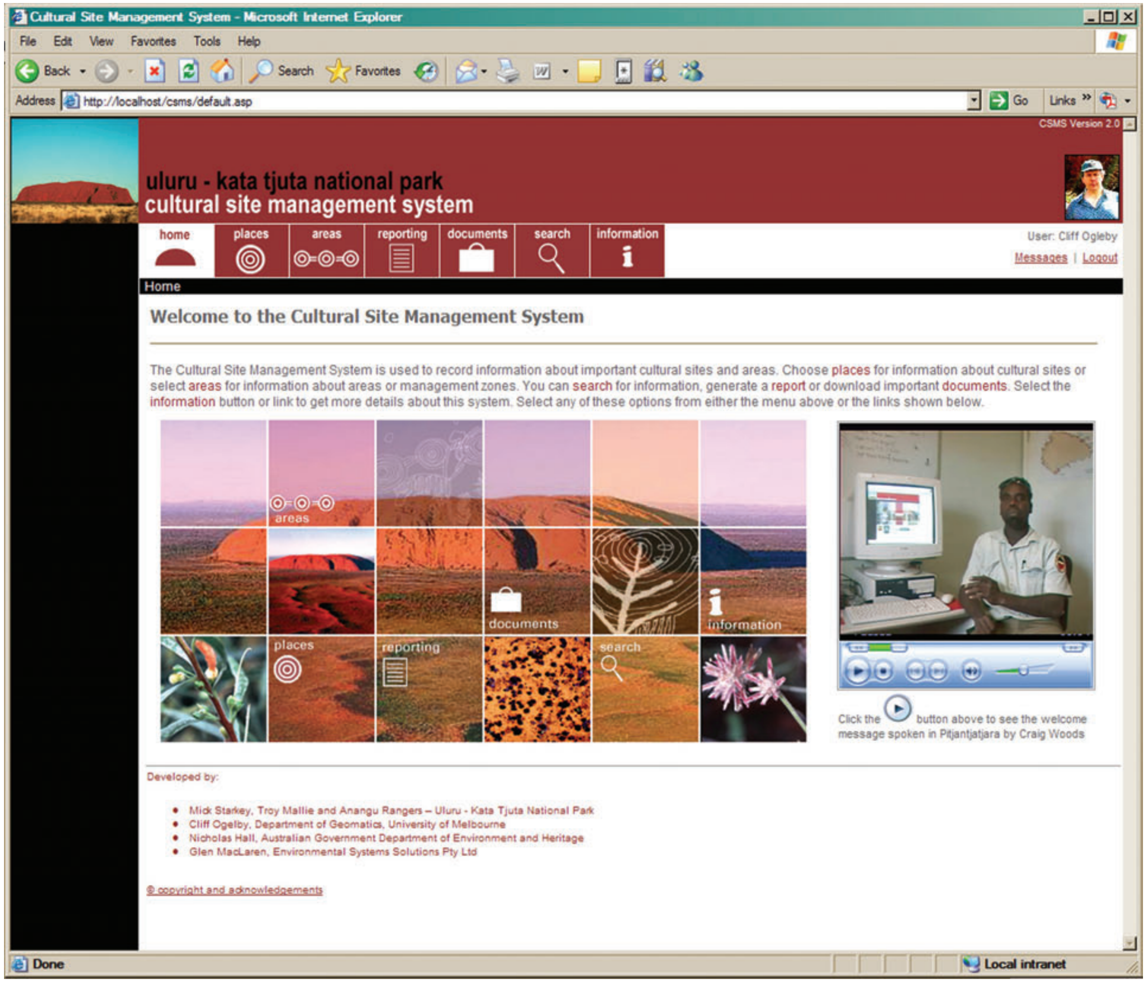
Creation of the database required several phases. First, a team of ten to twelve people, comprised of Anangu elders, park rangers, and surveyors, advised on the design of the database and reviewed all previous information over a two-week period. Second, this information was scanned and other features such as Anangu interpretation, context, significance, and restrictions on access to the sites were also recorded.

Finally, a simple, easy-to-use interface was designed. Options such as Home, Places, Areas, Reports, Search, and Help were included on the main screen, allowing the user to quickly navigate to the area needed. One important aspect of the design was the creation of three levels of data access and storage. The data relating to men's sacred sites must not be accessed or viewed by women or by non-Anangu; the same holds for women's sacred sites. This issue was so sensitive that two different computers were used to store the data separately, yet the database functions were linked by a secure wireless connection. A personal login and password provided an additional level of security.

The design also included a library of standard query boxes and data input modules so that the park's system manager could conduct typical searches and add enhancements. The system incorporates a designer menu accessible by the system administrator, so that new forms and categories can be developed as the need arises.

After the design was finished, park rangers assessed conditions such as graffiti, wasp's nests, and vegetation growth at each rock art site by completing standardized forms. These differently colored paper forms corresponded identically in size, color, and content to the electronic forms in the database. This allowed staff to enter data easily

Screenshot of the database, showing an annotated aerial view of Uluru. Rock art sites are listed by place, with access restricted according to users' real-world rights of access: visitor or Aborigine, male or female. © Cliff Ogleby.



Welcome to the Cultural Site Management System

The Cultural Site Management System is used to record information about important cultural sites and areas. Choose places for information about cultural sites or select areas for information about areas or management zones. You can search for information, generate a report or download important documents. Select the information button or link to get more details about this system. Select any of these options from either the menu above or the links shown below.

Click the ▶ button above to see the welcome message spoken in Pitjantjatjara by Craig Woods

Developed by:

- Mick Starkey, Troy Mallie and Anangu Rangers – Uluru - Kata Tjuta National Park
- Cliff Ogelby, Department of Geomatics, University of Melbourne
- Nicholas Hall, Australian Government Department of Environment and Heritage
- Glen MacLaren, Environmental Systems Solutions Pty Ltd

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into the correct location in the database. Minimal training was then conducted for the park staff responsible for data input and system management. Technical updates and modifications are handled periodically by more experienced database developers. Alternative tools such as a Geographic Information System (GIS) were considered but deemed too expensive and unnecessary. Maps were included in the database but were not of primary importance. However, the CSMS was designed to be interfaced in the future with the larger GIS for park management if needed.

A conservation team member removing graffiti at Uluru. Photo: © Cliff Ogleby.

Rock art at Uluru. Photo: © Cliff Ogleby.

An Answer

The CSMS is currently in use by Anangu rangers of the Cultural Heritage Unit for daily maintenance of the park. Weeds, wasp's nests, and graffiti are tracked for removal, and planning and placement of walkways and interpretive signage are monitored. The federal government is also using the system to develop a master plan for the area of Uluru–Kata Tjuta National Park.

A group of visitors at the base of Uluru. The CSMS helps manage tourist access and impact. Photo: © Cliff Ogleby.

Currently the Anangu elders use the system to create, compile, and add material they feel should be included. They have used it as a teaching tool for the younger generation and consider it a "keeping place" for their cultural information. Because their advice and requests were taken into consideration from the outset of the project and their input integrated into the design, the elders feel a sense of ownership of the system. This has resulted in a more valuable database and ensured its relevance and long-term viability.

Due to the culturally sensitive nature of the content, the public currently does not have access to the database. In the future, however, information on unrestricted rock art sites and other areas may be displayed in a public kiosk at the park's visitors center.

An updated version of the CSMS was launched in October 2005 to mark the twentieth anniversary of the cession of Uluru and Kata Tjuta back to the Anangu people. It is an evolving project, with additions and improvements made as needs become apparent. Layers of information, including vegetation, fire management, and endangered species, will be added in the future. This methodology and technology has since been adapted to several other Australian rock art sites.

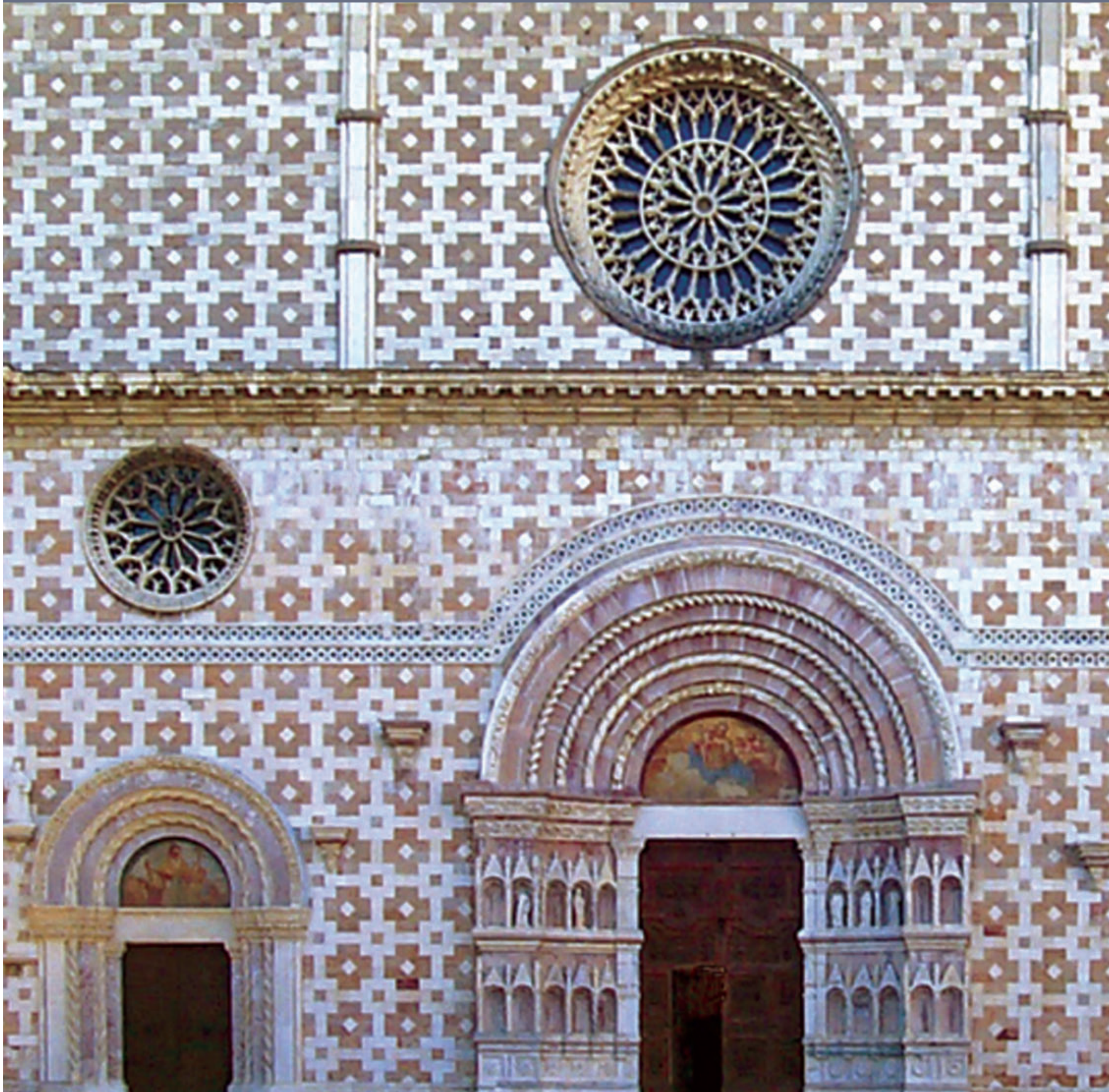
Cliff Ogleby is a senior lecturer in the Department of Geomatics at Melbourne University, Australia, where he teaches surveying, remote sensing, and communications. He has written and lectured extensively on databases, photogrammetry, virtual reality, and new technology. Currently he serves as president of CIPA Heritage Documentation (International Committee for Architectural Photogrammetry).

Subsurface Conditions

Marco Tallini

The Basilica of Santa Maria di Collemaggio, in L'Aquila, is the most celebrated medieval church in the region of Abruzzo, in central Italy. The pink and white limestone ashlars that form its stunning facade have cracked and deteriorated, leaving the building vulnerable.

How can the subsurface conditions of the basilica's masonry facade be assessed to indicate where treatments should be carried out?



Facade of the Basilica of Santa Maria di Collemaggio, showing its magnificent arrangement of pink and white limestone. Photo: © Marco Tallini.

Collemaggio, Italy

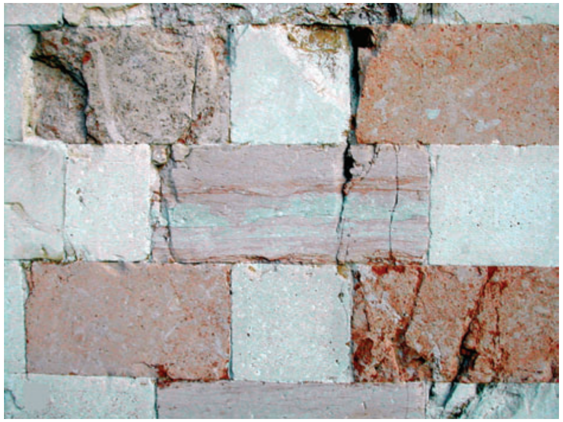
The Basilica of Santa Maria di Collemaggio stands on the site where a traveling hermit named Peter of Morrone, founder of the Celestine order, spent the night after meeting with the pope. The Virgin Mary appeared to the hermit in a dream and asked him to build a church in her honor. Construction of the basilica began in 1287 on land that was purchased by the Celestines. Inside this edifice, Peter of Morrone was crowned Pope Celestino V in 1294 and later buried there. As part of his coronation, he instituted the original Papal Jubilee, designating the basilica a pilgrimage site.

A stunning example of Abruzzese Romanesque and Gothic architecture, the building owes its originality to the magnificent geometric arrangement of ashlars on its facade. The blocks of pink and white local limestone form an intricate woven pattern, giving the church a jewel-box appearance. The facade wall consists of a rubble core faced with dressed stone, and it is these inner and outer ashlars that have cracked and deteriorated.

Over the centuries, the church was the subject of several building campaigns involving aesthetic improvements and structural repairs to damage caused by recurring earthquakes. After the 1915 earthquake, the upper left side of the facade was rebuilt with an accurate replica of the original ashlar coursework. During the 1970–72 restructuring phase, the roof was elevated and the interior baroque decorations removed to restore the building to the style of its medieval period. The raising of the roof increased the seismic vulnerability of the building. Furthermore, the facade presented several deterioration conditions such as surface soiling, cracking, and detachment through exfoliation, splintering, and flaking.

A conservation project was initiated in 2005 to stabilize and clean the facade of Santa Maria di Collemaggio. Detailed knowledge of the church's internal masonry structure was key in this restoration project. Recognizing the detachments and cracks and investigating the extent of subsurface deterioration were crucial in verifying the stability of the facade. The documentation process served to inform conservators about the condition of the masonry so that they could plan the conservation intervention and mitigate any seismic vulnerability caused by detachment zones between the ashlar facing and the internal masonry.

Santa Maria di Collemaggio, following the 1915 earthquake. Photo: © Ministero per i BAP per l'Abruzzo.



Detail showing the masonry deterioration of the facade caused by seismic stress. Photo: © Marco Tallini.

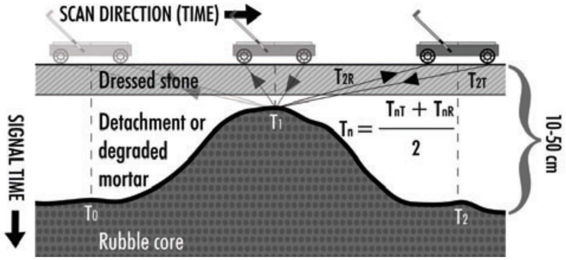
Ground-penetrating Radar

Several techniques exist to investigate subsurface conditions of structures. In the field of cultural heritage, ground-penetrating radar (GPR) uses electromagnetic waves to investigate the underground or internal structures of natural and human-made objects. Although traditionally used in archaeological surveys to initiate or plan excavations, GPR has been successfully employed in investigating the characteristics of and damage to walls and masonry structures, such as voids, detachment, cracks, leaks, and deteriorated mortar joints, to inform conservation projects.

An alternative to GPR is infrared thermography, which detects temperature radiation in the infrared range of the electromagnetic spectrum and produces images of that radiation. Infrared thermography offers fast data acquisition and output, requires no contact with the medium, and can record a large area; however, it has a shallow depth of inspection, is easily affected by thermal perturbations during acquisition of data, and interferes with the emissivity of the object it is measuring. Ultrasonic testing and micro-video-camera inspection can provide useful information but were not considered because they require invasive contact–hammering and micro drilling, respectively–and are time consuming.

GPR was more appropriate for this study because it is a nondestructive technique that requires little contact with the medium. In addition, this tool has a good level of accuracy and is easy to handle and transport. GPR testing was therefore used in order to understand the internal masonry structure of the facade by determining the thickness of the wall, to locate cracks and areas of detachment, and to identify where consolidation treatment was needed.

Technicians using GPR for data acquisition near the basilica's rose window. The GPR system was applied directly to the building's surface. Photo: © Marco Tallini.



During GPR acquisition of data, a point-shaped target generates a hyperbole-shaped radar anomaly. Drawing: Steve Rampton.

The GPR basic system consists of a data acquisition unit and two transmitting and receiving antennae. The transmitting antenna sends pulses of high-frequency radio waves. When a wave hits the boundary of an object that has different electrical properties, the receiving antenna records these variations, known as anomalies, that are reflected in the return signal. The output of the GPR survey is a radar section of the investigated medium showing the direction of the wave trajectory as a function of depth. A surface-shaped target generates a surface anomaly similar in shape to the measured surface, whereas a point-shaped target produces a hyperbolic radar anomaly in which the waves become more spherical as the distance increases between the antenna and the target.

The conductivity of the ground or medium through which the signal travels affects the range of the scan, and the frequency of the signal affects the resolution of the scan. Higher-frequency waves are used for shallower depths and improve spatial resolution of the reflected signal. Two frequencies were chosen for this study. A 600-megahertz (medium frequency) antenna reached about 4–5 meters with a resolution of about 2–5 centimeters. A 1600-megahertz (high frequency) antenna reached about 1 meter with a resolution of about 1 centimeter.

A team of two trained users methodically collected the data. First, the equipment was calibrated by scanning a part of the investigated area where the construction technique and masonry characteristics were already known. Then, based on a grid of radar sections of the facade for both frequencies with a scan spacing of 40 centimeters, the entire facade was scanned. The regular geometric arrangement of the ashlars facilitated scanning of the facade without a complex coordinate system.

The mesh and location of the grid sections corresponded to the vertical and horizontal alignment of the ashlar courses, with a mesh of three-by-three courses. The radar scanning lines were placed in the middle of each course. About three hundred radar sections for each antenna were acquired. The GPR scanned the entire facade below the middle cornice and was extended to two areas located to the right and left of the central rose window, above the middle cornice.

The collected data were visualized and processed by two experienced specialists using GPR software (Ingegneria dei Sistemi, 2000). Two filters were applied to all the radar sections. The first filter (soil sample) removed the effect of distortion due to the air-masonry interface between the GPR antennae and the outer facade. The second filter (pass band) removed background noise in both vertical and horizontal directions. Different types of anomalies visible in the calibration radar section were identified with known voids, cracks, and other building conditions. These conclusions helped interpret the other radar sections, as known voids and cracks could be assigned a specific anomaly type. A team of engineers, archaeologists, and architects participated in interpretation of the data.

Thickness of the facade wall was measured with the 600-megahertz antenna. The right side of the facade wall proved to be 20 centimeters thinner than the left side except in the lower band, which was about 10 centimeters thinner. The radar anomaly marking the boundary between the wall and the air on the opposite side (interior of the basilica) was usually well outlined; however, the radar signals were less clear in areas where the inner face of the wall had architectural or decorative elements.

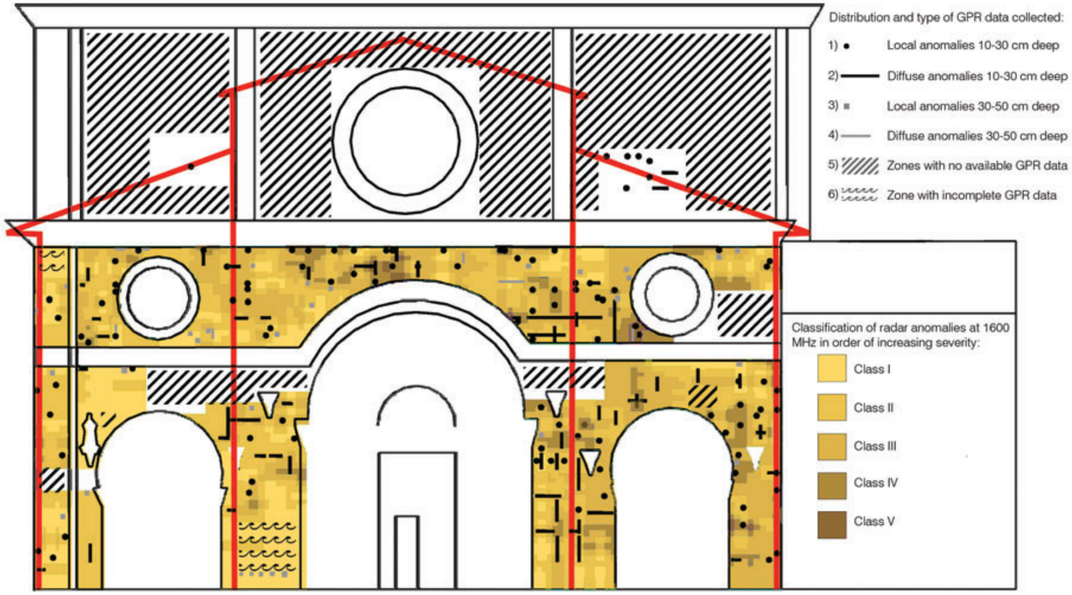
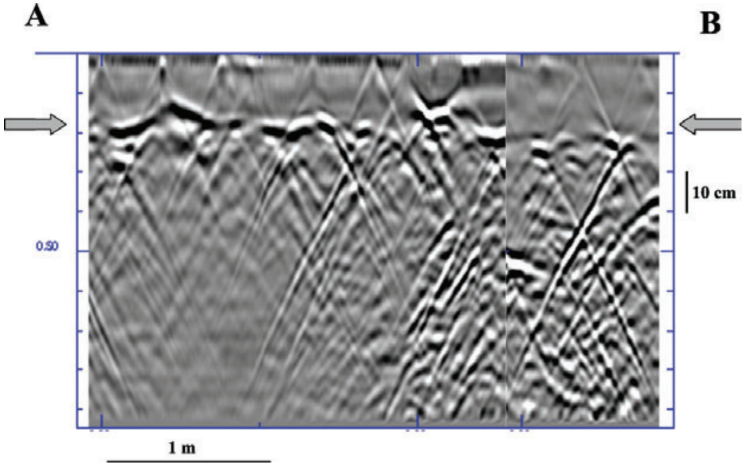


Diagram of the basilica, showing radar anomalies (1600 MHz) after filtering and rasterizing. Colors show anomalies classified according to increasing gravity (classes I–V). Diagram: © Marco Tallini.

A 1600-MHz radar section. The arrows highlight strong anomalies probably related to the widespread detachment of the ashlar facing from the rubble core or to zones of degraded mortar. Image: © Marco Tallini.



Treatment plan for the facade, implemented in spring 2005 based on conditions mapped in previous diagrams. Colored areas are related to the increasing density of the grout.
In some cases, injections were combined with the insertion of 12-mm-thick stainless steel. Diagram: © Marco Tallini.

The 1600-megahertz GPR survey identified structural features of the masonry and the middle cornice that supported elements of the facade, and also identified areas of deterioration. The varying densities of materials were reflected in the radar anomalies, but the heterogeneous composition of the wall made the radar sections difficult to read. Many radar echoes interfered or hid the anomaly signals corresponding to detachments, voids, and degraded mortar joints. Nevertheless, detachments of the ashlar facing from its rubble core were generally visible as surface anomalies at the interface, while detachments at the middle cornice were shown as strong hyperbolic anomalies located at regular steps. In some cases, anomalies were observed inside the ashlar facing, probably corresponding to cracks or voids. Furthermore, the radar sections exhibited evenly shaped anomalies every 2 meters. These matched the through-stones placed between the inner and outer ashlar facings to support the middle cornice.

An Answer

GPR was effective in investigating the internal structure of the basilica's facade in depth and at high resolution. This technique requires little contact with the inspected medium; however, data analysis can be a lengthy process depending on the area of investigation. At the basilica, data were acquired in a week and processed and interpreted over a one-month period. The results were quite accurate, enhanced by the signal calibration. The participation of specialists from various disciplines was helpful in comparing different possible interpretations of the deterioration phenomena reflected in the radar sections.

Using the high-frequency radar results, voids and cracks in the degraded ashlars and mortar joints were located and areas requiring injection grouting, as well as density of the grout, were determined. The medium-frequency testing allowed characterization of the internal structure of the facade and measurement of the thickness of the wall. A mathematical model was generated and used in calculating the depths of the voids as well as in planning the retrofitting work to mitigate the seismic vulnerability of the basilica.

The objectives of the 2005 restoration campaign were to improve and reestablish internal cohesion of the facade wall against seismic stress and to reduce water infiltration. The activities included injection grouting with a hydraulic lime-based grout and insertion of 12- millimeter-by 100-centimeter-thick stainless-steel bars. To help prevent leaks of the injection mixture, voids and surface cracks on the outer facade were first plastered. Grouting was then carried out on the back inner-face facade, starting at the bottom and moving perpendicularly toward the top. The mortar mixture was injected, and the stainless-steel bars were placed so as to reach the rubble core and the inner zone of the ashlars. Grouting was combined with steel reinforcement predominantly around the rose window and in the upper right corner of the facade.

Marco Tallini is associate professor of applied hydrogeology at L'Aquila University, Italy. His fields of interest focus on GPR application in environmental geology, civil engineering, and geoarchaeology. He has authored numerous papers on GPR application, hydrogeology, and regional geology.

Monitoring Movement

Giorgio Croci

The Tower of Pisa, in Italy, has been moving and tilting since its construction began. The heavy masonry load on the unstable clay subsoil and previous unsuccessful attempts to save the tower have contributed to its tilt. In the late 1980s, its lean approached a critical point and the tower was near collapse.

If the famous tower is to be saved for future generations, how can its stability be monitored before, during, and after necessary interventions?

The studies and designs in this illustrated example were carried out by a committee composed of Professors M. Jamiolikowski (chairman), John B. Burland, R. Calzona, M. Cordaro, G. Creazza, Giorgio Croci, M. D'Elia, R. Di Stefano, J. de Barthelemy, S. Settis, L. Sanpaolesi, F. Veniale, and C. Viggiani. Soil engineering was devised by John Burland, professor of soil mechanics at Imperial College, London, and monitoring was carried out by BRE, Watford, England.

View from the fourth balcony of the Tower of Pisa, following the structural stabilization campaign. Photo: © Gary Feuerstein, 2002.

Pisa, Italy

The Tower of Pisa, the construction of which began under the direction of Bonanno Pisano in 1173, started leaning shortly after the tower's foundations were laid. This, combined with Pisa's war against Florence, halted construction. Work resumed a hundred years later, only to stop again in 1278 for the same reasons. A final effort to complete the tower began in 1360, but the uneven settlement continued and the lean increased as more weight was added. In each period of construction, attempts were made to remedy the problems but were always unsuccessful. The upper portion was built vertically even as the tower leaned, resulting in a slight bend to the north.

Finished in 1370, the cylindrical tower consists of two faces of limestone ashlar blocks assembled without mortar around a conglomerate core of lime mortar and stone rubble. An interior staircase spirals upward toward the belfry and allows access to colonnaded balconies on each of six floors. At less than 20 meters in diameter and 60 meters high, the tower serves as the campanile to the adjoining duomo, or cathedral. The tower is an interesting example of Byzantine influence between the medieval and Renaissance periods and is famed for its extreme lean.

The stratigraphy of the subsoil is at fault. It is composed of sand and clay silts for the first 8 meters, followed by medium-gray sand for 2 meters on top of 11 meters of Pancone clay. The settling of up to 2.5 meters vertically is concentrated in this layer of Pancone clay. A seasonal fluctuation in the water table and an increased pumping of groundwater has exacerbated the problem. As the water table rises, the inclination of the tower increases, mainly between the months of September and December.

In the early twentieth century, the first detailed measurements of the displacement were scientifically recorded using survey equipment. Then, in 1934, a pendulum was hung inside the tower to measure the displacement of the top with respect to the base and therefore any change in inclination. The pendulum consists of a cable suspended from the sixth floor that descends to the first floor with the help of a small weight. This plumb line traces the horizontal displacement as the tower continues to move. Various interventions were attempted throughout the centuries, including diverting groundwater, injecting concrete into the subsoil, and prohibiting automobile traffic near the tower. Even the bells were silenced, yet the tower continued to move. By 1987, when the tower and its surrounding buildings were inscribed on the UNESCO World Heritage List, the lean had increased to more than 5 degrees, or more than 5 meters from vertical. An intervention was urgently needed.

In 1989, after the collapse of a masonry tower in nearby Pavia, the prime minister of Italy and the city of Pisa formed an international research committee of engineers, architects, conservators, and scientists to study the tower's situation and propose a solution. Because of the tower's significance and economic contribution to the city, there were few constraints except time and politics. The structure's current rate of movement and severe lean made the committee determined to act before the end of the millennium. World-famous experts in structural and soil engineering were invited to propose solutions to the committee, while the most modern and sophisticated equipment was made available. The first step, though, was to study any movement and accurately monitor the tower.

The Tower of Pisa in 1993, with its belfry under conservation during the preliminary stabilization phase. Photo: © Gary Feuerstein, 1993.

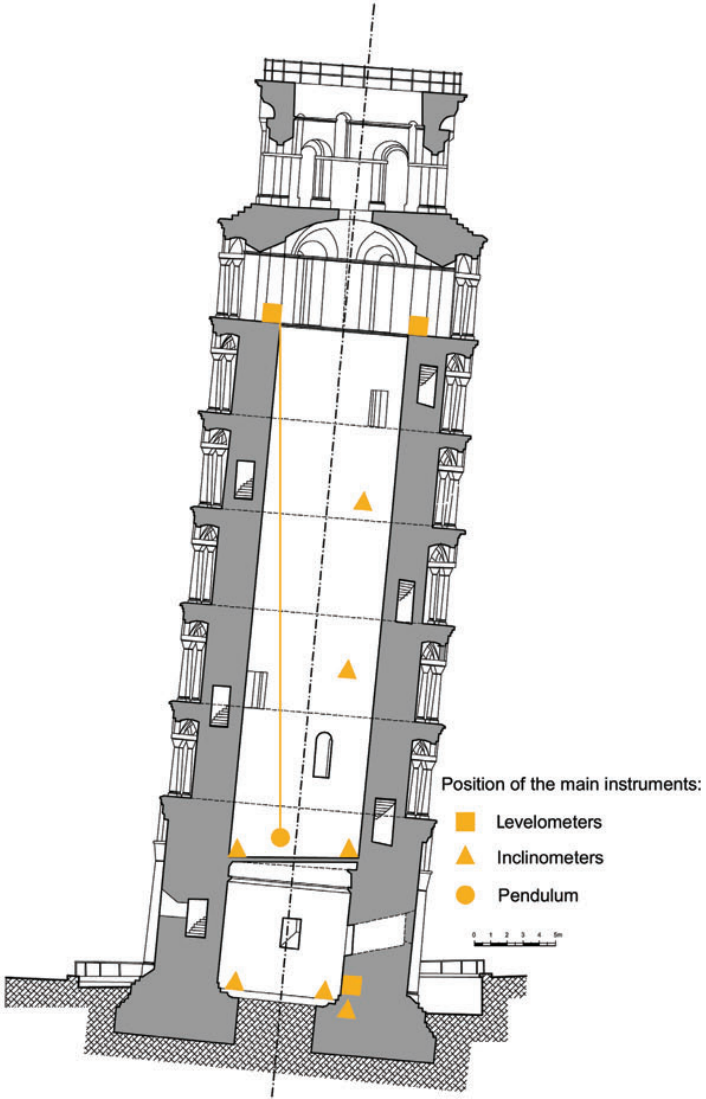
Automated Monitoring System

A variety of tools were required. The committee installed modern computerized measuring and monitoring systems to examine the tower and its surrounding soil. The system included special devices to measure the amount of lean, vertical settlement, cracks, and any other movement.

The first obvious measurement needed was degree of inclination. This was accomplished with the use of several inclinometers, which are sensitive, extremely accurate electronic levels that measure degree of tilt or angle using a sensor set against an artificially generated horizon. These instruments were mounted in various configurations throughout the tower along different axes to capture degree of tilt and rotation. The inclinometers and their placement informed the engineers of the present degree of tilt and, more important, informed them in real time of any changes in the tower as they carried out their interventions.

The tower is not only leaning but also sinking vertically; therefore, another device–a levelometer system–was needed to measure the amount of differential settlement. This system is a series of small containers filled with a special liquid and interconnected by a hydraulic network. As the liquid reaches the same horizontal level in each of the containers, the change in distance between this common level and the bottom of each container provides a measure of the vertical relative settlements.

The tower also moves daily by small amounts. Movement due to temperature differences and wind forces in masonry buildings is typical, but in situations when the structure is at risk, it is important to establish a base measurement. This measurement informs engineers whether any



The placement of devices throughout the tower provides a picture of the structure's overall condition. Drawing: © Giorgio Croci.

Clockwise from top left: weather station; biaxial inclinometer, which measures tilt in both north–south and east–west directions; accelerometers, which measure three-axis seismic acceleration; transductors, which measure strain on cracks. Photos: © Giorgio Croci.

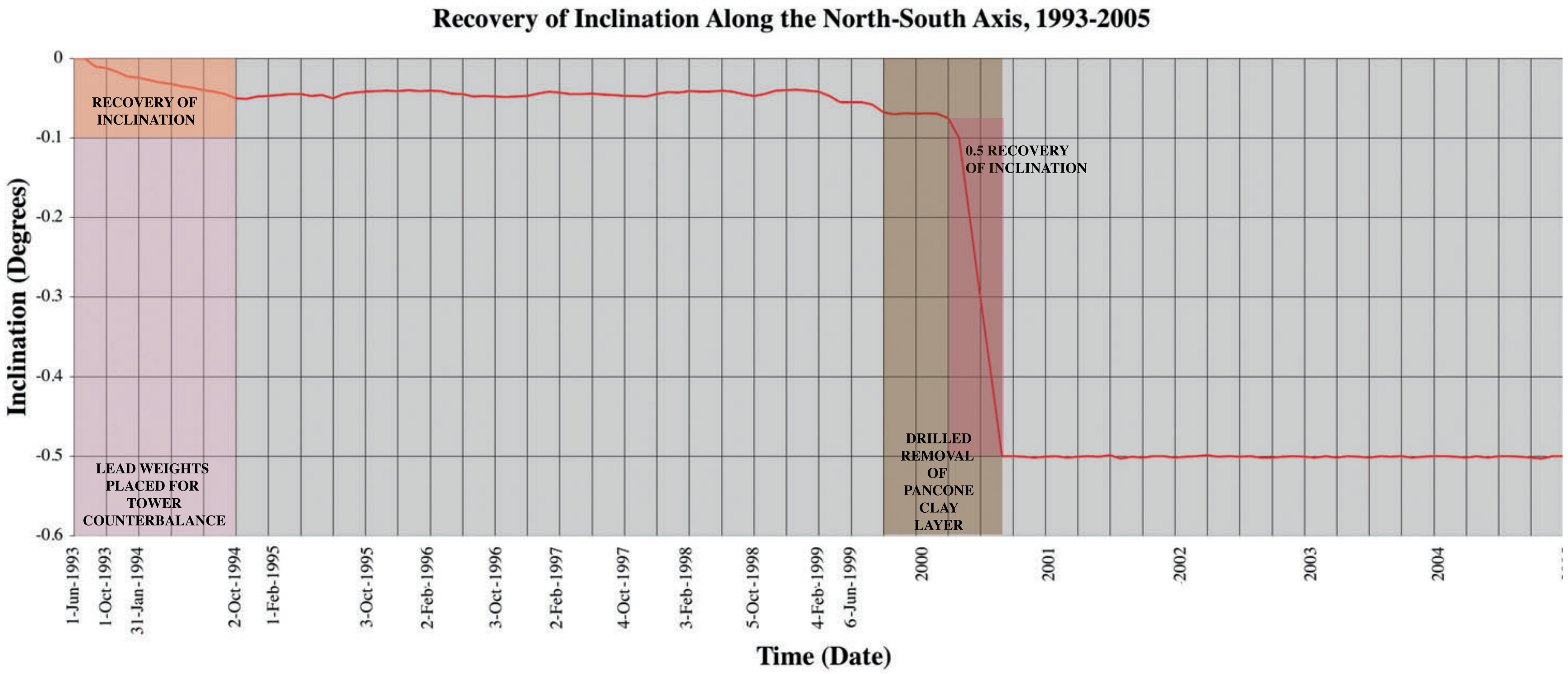
movement is due to a strong wind, a sunny day, or, more important, their intervention or an impending failure. A weather station was positioned on top of the tower to record wind direction and speed, ambient temperature, and radiation from the sun. Thermometers were placed inside the masonry on different floors to correlate deformations of the structure with temperature. These measurements record how the structure reacts to environmental forces and were useful before and during work on the tower.

Cracks are also typical in masonry buildings, especially in towers eight hundred years old. They can be beneficial by relieving stress but also can be a warning sign of more serious issues. Strain gauges were installed to measure crack propagation or reduction in twenty-five different locations. These highly sensitive instruments were affixed to the cracks and essentially converted mechanical motion into an electronic signal. The gauges were calibrated to take into account temperature changes and other material properties. As with environmental measurements, the crack monitors served to inform the engineers as they conducted their studies and made changes to the tower.

Less complicated, nonelectronic, and inexpensive inclinometers, soil sample techniques, and simple crack-measuring devices are available. However, in the case of such an important tower in risk of collapse, the engineers required the most sensitive monitoring and measuring tools. These devices were connected to data loggers, or small computers that recorded all the measurements continuously, providing the engineers with time-sensitive information. From the data, changes were plotted to give an accurate picture of deformations, vertical settlement, movement, and temperature. The results were therefore immediately available for use by the committee to formulate theories and propose appropriate action. As action was taken, the same devices recorded the intervention.

The measurements and studies showed that the inclination of the tower progressively increased to a critical point. The force corresponding to the weight of the tower had compressed the soil twice as much on the southern side than on the northern side. The tower was in imminent risk of collapse due to a sudden subsidence of the soil.

Chart showing recovery of inclination. Lead weights reduced tower lean by 52 seconds. With the removal of the clay layer, the lean was further reduced by a half degree (nearly 10%) and stabilized. Chart: © Giorgio Croci.

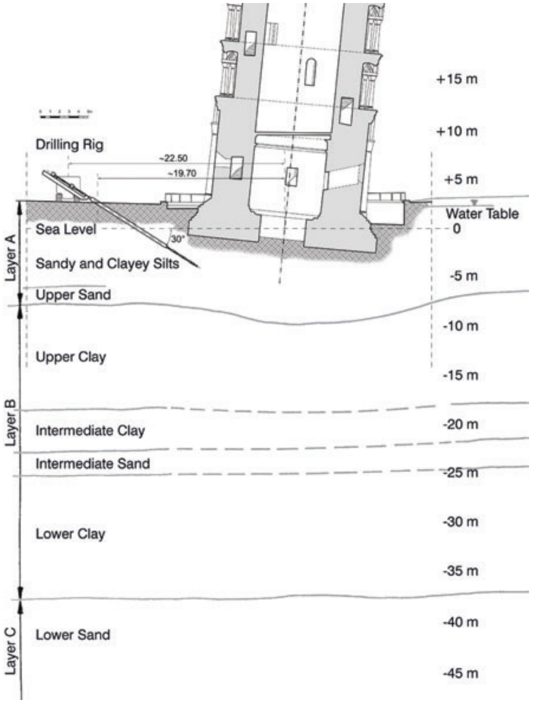


An Answer

In 1993, the committee set urgent provisional measures to prevent further movement by applying 600-ton blocks to the north side of the tower's foundation. This was later increased to 900 tons. The sophisticated monitoring system already in place reflected a reduction in the inclination of around 52 arc/seconds, or about 0.014 degrees. More important, the tilt of the tower was halted. In 1998, cables were provisionally applied around the tower and anchored to massive weights hidden behind other buildings. This was done as a precautionary measure before starting further interventions.

The definitive stabilization of the tower began in 1999. Thirty-five cubic meters of soil were removed from the subsoil under the north border of the foundation through a series of twelve casings drilled diagonally into the ground. The result of this excavation was the formation of small cavities that were progressively closed, producing small artificial differential settlements to counteract the south tilt of the tower. This operation progressed slowly and carefully. Soil continued to be removed in small quantities. Data were collected from the monitoring system and analyzed to evaluate the impact of each extraction on the movement and tilt of the tower.

When the operation was completed in 2001, nearly 10 percent of the tilt had been recovered. The committee and the Italian Ministry of Culture agreed that this value retained the important lean while guaranteeing stability. At present, the monitoring system continues to operate, showing that the tower is stable and its inclination is the same as it was in the middle of the eighteenth century.



Drilling allowed the strategic removal of clay from the subsoil under the tower's foundation. Drawing: © Giorgio Croci.

Giorgio Croci is a professor of structural engineering at the University of Rome "La Sapienza." He has participated in many studies and projects dealing with structural design and restoration, investigating structural damage and material decay on sites in Italy and worldwide. He received a gold medal from the mayor of Pisa for his work as a member of the research committee in charge of the restoration of the tower.

Lead weights were used to reduce the tower's lean.
Photo: © Giorgio Croci.

Reading Interventions

Soon-Kwan Kim

The conservation of historic Buddhist temples in Korea derives from a long tradition of dismantlement and reconstruction. As these temples were rebuilt, hidden inscriptions describing details of the reconstructions were left on their structural timbers by generations of craftspersons. Many original decorations were painted over, obscuring important historic evidence. Over time, both these writings and decorative paintings have faded.

How can such faded or obscured clues to the history of these temple buildings be viewed and documented?

Detail of the multibracket system used in the construction of the Hall of Paradise (Geukrakjeon), in Bongjeong Temple, South Korea. Photo: Jong Hyun Lim.

Bongjeong Temple, South Korea

At the foot of Mount Cheondeung, in northern Gyeongsang Province, stand two of the oldest wooden Buddhist structures in South Korea. The Hall of Paradise (Geukrakjeon) and the Main Sanctuary (Daeungjeon) house images of the Buddha of Boundless Light and statues of his disciples. They are part of the Bongjeongsa temple complex begun in 672 by King Munmu's preceptor, Uisang.

Built primarily of interlocking wood beams and columns on stone foundations, the two temples represent the pinnacle of architectural and decorative painting styles from the Goryeo period (918–1392). During this period, most roof structures were built using simple, single wood-bracket systems (*jusimpo*). However, the Hall of Paradise is one of only three examples in Korea of a multi-bracket system (*dapo*). The brackets, interior beams, columns, and walls of the Hall of Paradise are decorated with paintings of colorful figures, geometric patterns, and floral designs. These decorations and paintings, which depict the Buddha teaching, are regarded as unique historical references that reflect the strong Buddhist artistic and religious influences at the time of construction.

Over time, these paintings and wood members deteriorated, damaged by humidity, insect infestation, and discoloration from oxidation and carbon deposits. Consequently, the temples underwent many restorations throughout the centuries. Conservation of temples in Korea follows a long tradition of completely dismantling the structure and rebuilding it. Each individual member is evaluated, deteriorated members are replaced if needed, and old pieces are reused in different ways and in new locations.

In the restorations of 1972 and 1996, workers noticed Chinese "graffiti" hidden among the older wooden members. These writings provided valuable clues about previous restorations and building processes. Unfortunately, the markings were extremely faded. The inscriptions were examined with a magnifying glass and an optical microscope, then recorded using sketches and conventional photography. In some cases, the characters were visible and simply documented, whereas in others they had been repainted by restorers based on their best judgment and past experience.

Despite these recent dismantlings and restorations, the Hall of Paradise and the Main Sanctuary still suffered from active structural problems. In 2002, the management of Bongjeongsa requested that the National Research Institute of Cultural Heritage (NRICH) in South Korea carry out a new dismantlement and rebuilding campaign that would include a detailed study of the writings on the wood elements and the faded decorative drawings. It was hoped that information gathered from the writings would inform and guide the restoration project.

The objectives of the study were to locate, identify, and interpret previously unknown writings and reinterpret the writings that had been overpainted. Other painted designs and finishes were also to be analyzed to provide a record for posterity and a chronology of previous interventions. After a preliminary meeting of the architects, conservators, and surveyors, it was determined that an advanced imaging method was required to find and examine these hidden works.

The Hall of Paradise, during restoration. Dismantlement of the temple allowed each building component to be documented individually. Photo: © Soon-Kwan Kim.

A Buddhist wall painting on the back side of the Main Sanctuary (Daeungjeon), during restoration. Photo: © Soon-Kwan Kim.

Infrared Reflectography

Paintings that have faded or been overpainted often contain traces of original pigment. This remnant material still reflects and absorbs light, but outside the visible spectrum. The surveyors decided to record the writings by capturing this invisible light through infrared reflectography (IRR).

IRR is a nondestructive digital or photographic imaging technique that uses a specialized digital detector or heat-sensitive film to capture absorption and emission characteristics of reflected infrared radiation between 750 and 2000 nanometers. The technique is simple, quick, and effective in investigating surface conditions by detecting original faded or hidden drawings, and in penetrating through upper layers of overpainted surfaces.

A Hamamatsu Super Eye C2847 IRR instrument was used in the study at Bongjeongsa. The instrument consists of three main components: an infrared emitter or lamp, a detector, and a computer. The lamp is positioned at an angle approximately 2 meters from the object being studied and emits a precise frequency of infrared light. The detector is aimed at a 90-degree angle 2 meters from the object and captures the reflected light. The computer displays and stores the resulting images. The team for this study included a professional operator who controlled the exposure of the detector, a specialized assistant who monitored and operated the computer, and a trained assistant who assembled the system.

IRR was carefully carried out on every dismantled wooden column, eave, and purlin from the Hall of Paradise and Main Sanctuary to locate and record any Chinese inscriptions. It was also used to examine faded decorative drawings and successive restoration paint layers. In order to compare the IRR image with the visible spectrum, each wooden member was also photographed with a conventional digital camera.

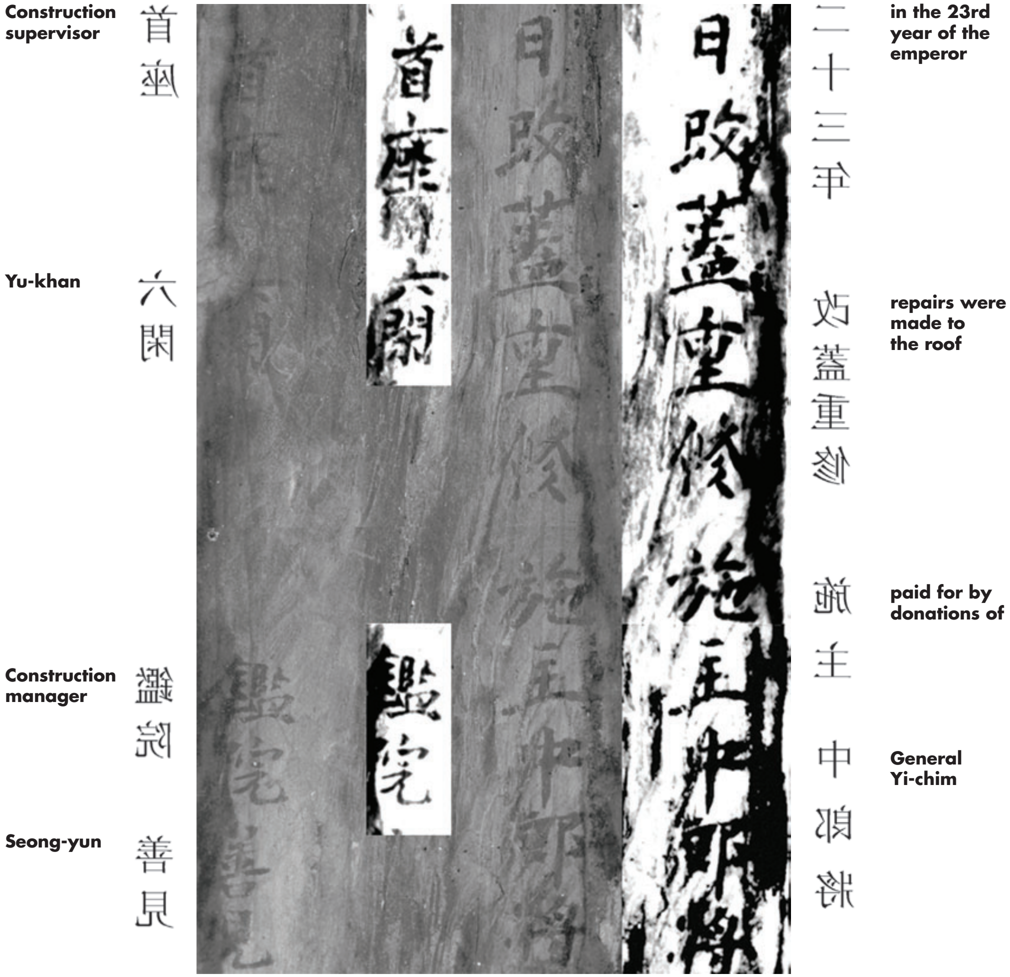
IRR instrumentation is affected by environmental conditions such as ambient temperature and humidity and is very sensitive to light and motion. Therefore, members of the study team carefully controlled their surroundings by positioning the instrument on a flat, stable work surface and maintaining uniform lighting. They also bracketed exposures, taking multiple images of the same subject using slightly different settings. This method produced more images than needed but greatly improved consistency and quality. In addition, the team had to be aware of the limitations of IRR. Infrared wavelengths can easily detect black, white, brown, and red pigments but are limited in detecting pigments that do not transmit or block infrared, such as azurite and malachite. Fortunately, the ancient pigments used at Bongjeongsa did not include these minerals, so this was not an issue.

IRR acquisition of the images was conducted both on the individual components and in situ for the composite building. Photo: © Soon-Kwan Kim.

Over the course of five days, more than six hundred IRR and conventional images were captured and processed. Processing consisted of quality control with the Zeiss KS 300 Image Analyzer program and editing for contrast and brightness using Adobe Photoshop. Photoshop was also used to assemble multiple images of large objects, as the IRR instrument used for this survey had a low-resolution (4800 dpi) detector, which limited the size of each image.

Once the data were processed, experts in ancient Chinese calligraphy were consulted to interpret the characters. The images and interpretations were discussed among art historians, painting conservators, architects, and project managers. The data were saved on CDs, and copies, along with a project report, were distributed to the Bongjeongsa management team and the Korean NRICH Digital Information Center.

The application of IRR at Bongjeongsa was successful in uncovering many important clues regarding the history of these buildings. Except for a few entirely missing or heavily soiled characters, most of the writings on the wooden members were successfully interpreted. Chronology of the numerous restorations, significant structural changes, original positions of the wooden members, and names of those involved in the ancient restorations were identified and documented. Archival records were corrected based on this study, making it possible to piece together entire periods in the history of the buildings. This information supported the 2002 reconstruction by assisting team members in dating and identifying important pieces that should receive special attention. Pieces that could be reused were also identified and carefully "reinserted" during reconstruction. Pieces that had deteriorated were conserved and eventually may be placed on display.



IRR was used to reevaluate visible-light photography of the top purlin in the Hall of Paradise. During restoration work in 1972, surveyors studying the Chinese characters by eye had misinterpreted the writing, resulting in inaccuracies in the archival record. Through the use of IRR in the 2002 survey, a character misidentified as "owner" was corrected to mean "caution." Photo: © Soon-Kwan Kim.

An Answer

At the Hall of Paradise, the IRR team was able to correct previously misinterpreted Chinese characters from prior studies and interventions. In the Main Sanctuary, IRR was helpful in detecting original decorative patterns and overlapping paint layers on the Buddhist wall murals. The study of these original patterns was crucial in identifying the changing themes and stylistic characteristics of Goryeo Buddhist painting. As a result, the principal mural in the Main Sanctuary was identified as the oldest known of its type in Korea.

Due to their advanced state of paint deterioration, the murals of the Main Sanctuary had been traditionally repainted based on their original color scheme, as identified by the IRR study. However, no repainting had been done in the Hall of Paradise. Instead, conservation was carried out, and NRICH is researching ways to display a virtual restoration of the writings and decorative drawings.

Following the study, an image database was compiled, which included the raw and edited IRR images as well as postrestoration photographs. This central database system is managed by NRICH and is accessible to conservators and researchers interested in ancient Goryeo art history, architecture, and conservation science.

Soon-Kwan Kim is a project manager specializing in wall-painting research at the National Research Institute of Cultural Heritage, South Korea, and has investigated ten significant Buddhist temples using IRR. He received a master's degree in cultural heritage management at Myongji University, Korea, and has carried out several wall-painting conservation treatments, including the ancient tomb of Gobyep-ri and the Hall of Paradise of Moowui Temple. He has researched synthetic resins, the influence of acid rain on masonry, and traditional color paints of Korea. Currently he is involved in a project in North Korea on conservation of wall paintings in ancient tombs.

A monk (*right*) officiating at a ceremony to replace the construction records in the ridge beam. These records, transcribed with additional information after each period of construction, maintain the Korean tradition of passing documentation on to future generations. Photo: © Soon-Kwan Kim.

The Hall of Paradise, after completion of the 2002 conservation. Photo: © Soon-Kwan Kim.

APPENDIXES

APPENDIX

A

Teaching Approaches

Mario Santana Quintero

The illustrated examples of documentation for conservation presented in this volume clearly explain the role of good information in the conservation of cultural heritage. They also show the effective use of particular documentation tools and techniques for sustainable conservation. This appendix proposes teaching strategies, based on the illustrated examples, that can foster collaboration and enhance the knowledge of conservators around the world.

Prior to presenting the illustrated examples, an introductory lecture based on the contents of this book is suggested. The lecture should include information from "Informing Conservation" and "Tools Overview." The information found in these essays places an emphasis on understanding why documentation is needed, selecting the appropriate tool or technique, and obtaining and presenting the results. Ideally, the lecture will prepare those involved in cultural heritage by explaining that conservators should understand certain basics, such as the advantages, disadvantages, and final product of the tools and how to ensure cost effectiveness and safety during the recording process. It will also stress the usefulness of preparing a work brief and specification. The examples themselves can then be presented using four different approaches:

1. Introducing the conservation issue
2. Deducing the conservation issue
3. Preparing an illustrated example
4. Demonstrating tools and techniques

Approach 1: Introducing the Conservation Issue

This approach is recommended as an introduction for managers or conservators and is intended to deliver a basic understanding of available documentation tools and techniques and how they are applied. Such an understanding is essential for managers in mid- to high-level positions in order to allocate resources required for documentation. It is also a good starting point for professionals and students in conservation.

The exercise could begin by focusing on the conservation issues, available resources, and site limitations presented in the illustrated examples. Managers and students should be asked to read and reflect individually on only the first two sections of a particular example in the book. They would then prepare their own strategies to document and provide an answer to the conservation issue.

After the managers and students present their strategies how they would resolve the conservation issue–possibly in a group with a facilitator–the answer from the illustrated example would then be revealed. A discussion ideally would follow, centering on identifying the similarities betweeen the answer provided by the manager or student to that given in the actual example. Constraints and available resources should be discussed, as well as the appropriateness of the various solutions. Parallels could be drawn between the group's actual projects and the examples from this book.

Approach 2: Deducing the Conservation Issue

This approach is recommended for conservators responsible for documentation and for graduate students in conservation. Advanced knowledge of documentation techniques is a prerequisite. When studying the illustrated example, conservators or graduate students should read only the sections on the tool, final deliverables, and answer–the reverse of the first approach. Conservators would then be asked, in a group discussion, to deduce the conservation issue and available resources.

Conservators would present the results of their group discussion to a panel of experts with a facilitator. Following the presentation, the facilitator would read the issue statement provided in the book, including the resources outlined, and moderate a discussion that compares the issues and strategies deduced by the conservators to those of the actual conservation. This exercise should provide a comprehensive understanding of documentation tools and their benefits and constraints, as well as how to prepare a concise conservation issue statement.

Approach 3: Preparing an Illustrated Example

This approach is suited to conservators who are directly responsible for documentation and already have a solid understanding of and easy access to the variety of tools presented in the examples. Requiring more training resources, time, and equipment than the previous two approaches, the objective of this exercise is to provide additional training to experienced conservators and practical application of the tools for conservation purposes.

Ideally, a facilitator should set a time frame for a number of deliverables to be prepared by the conservators. These deliverables should closely follow the illustrated examples and consist of a conservation issue statement, description of site and resources available, description of the tool and phases of work, and overall documentation strategy, followed by an answer statement or summary. Conservators could use their own projects as a basis. A discussion comparing the conservators' projects to the illustrated examples in the book could follow, bearing in mind the possibility of including their work in future publications.

It is important that conservators be able to do the following:

- Understand the need for preparing a concise conservation issue statement
- Prepare a work brief and specification for the documentation that fulfills the needs of the conservation issue
- Describe the tools, techniques, and final product required to meet the work brief and assure cost effectiveness and safety in the recording process
- Know the advantages, disadvantages, and final product of all the tools and techniques

Approach 4: Demonstrating Tools and Techniques

The final approach, adequate for short introductions, is based on presenting the tools and techniques illustrated in the book. This exercise can be extended if more time is available. If the allocated teaching time is short, then this approach will be more of a demonstration.

The ideal situation allows the instructor to present the illustrated examples with the assistance of hands-on demonstrations, wherein conservators would observe the respective tools in actual use. This approach is applicable to all levels, from managers to beginning professionals and students; an institution such as a local university or government agency could request additional support from local companies or other institutions to prepare the demonstrations.

The aim of this approach is to allow managers to directly assess not only the complexity of tools that require sophisticated technology but also the time required for manual direct-contact measurement techniques. In addition, beginning conservation professionals and students could learn exactly how certain tools function in order to identify the best tools for their own projects. This approach can be easily combined with approaches 1, 2, and 3 as the second phase in learning about documentation.

In conclusion, an introductory lecture based on "Informing Conservation" and "Tools Overview," followed by one or more of the four training approaches suggested here, provides a variety of opportunities to take full advantage of the information in this volume. It is recommended that addressing conservation needs remain the primary objective, not just focusing on tools or technology. In order for documentation to be effective and sustainable, it must be suitable and address particular conservation needs. An institution should not invest in or request resources for documentation techniques that do not satisfy this need or their staff resources, equipment, or institutional framework. Conservators can gain an appreciation, through these examples and teaching approaches, of what tools and techniques can achieve for the conservation of cultural heritage.

Mario Santana Quintero completed his architectural studies in 1994 at the Universidad Central de Venezuela, and in 2003 obtained a PhD from the Raymond Lemaire International Centre for Conservation (RLICC) at Katholieke Universiteit Leuven, in Belgium. He is an assistant professor at RLICC in the master's program in conservation of monuments and sites. He is currently vice president of the ICOMOS International Committee for Documentation of Cultural Heritage (CIPA) and executive officer of the Virtual Systems and Multimedia Society. Since 1997, Dr. Santana Quintero has worked on various projects around the world as a cultural heritage documentation consultant for UNESCO's World Heritage Centre, the World Monuments Fund, the Getty Conservation Institute, the United Nations Development Programme, ICCROM, the University of Pennsylvania, the Abu Dhabi Authority for Culture and Heritage, Petra National Trust, the University of Applied Sciences of St Lieven, and RWTH Aachen University.