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

ILLUSTRATED EXAMPLES

Rand Eppich, *Editor*

Amel Chabbi, *Associate Editor*

The Getty Conservation Institute

Front cover, *top to bottom:*

Inca earthen site of Tambo Colorado,
Peru. Photo: J. Paul Getty Trust.

Detail of the *Last Judgment* mosaic,
St. Vitus Cathedral, Czech Republic.
Photo: Dusan Stulik.

Detail of Mutitjulu Anangu rock art,
Uluru, Australia. Photo: © Cliff Ogleby.

Village of Wadi Do'an, Al Gorha,
Yemen. Photo: © Pamela Jerome.

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Locations of the illustrated examples.

The Getty Conservation Institute, Los Angeles

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

For further information on the RecorDIM Initiative, visit the Getty Web site at www.getty.edu/conservation/field_projects/recordim/index.html

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Foreword

Conservation of cultural heritage requires a critical understanding of the significance, condition, and complexity of a place. Documentation is an essential element in building this understanding. It is a critical component of the conservation planning process and provides a long-term foundation for the monitoring, maintenance, and management of a site. Equally important, good documentation ensures that knowledge of heritage places will be passed on to future generations.

In 2002, the Getty Conservation Institute (GCI) hosted a group of international experts to explore ways of strengthening the documentation component of built heritage conservation. This group—working together as the Recording, Documentation, and Information Management (RecorDIM) Initiative—identified a series of priorities that could benefit the professional community responsible for conserving important heritage places. Among these priorities was the need for a publication that would provide practical hands-on approaches to assist conservation professionals in the design and implementation of documentation strategies. *Recording, Documentation, and Information Management for the Conservation of Heritage Places: Illustrated Examples* is the result.

This volume contains a series of illustrated case studies that demonstrates the successful use of diverse approaches to recording and documentation in a variety of situations. The examples cover a wide range of site typologies from individual buildings to cultural landscapes, and run the gamut of documentation techniques from hand survey to laser scanning. In each case, the approach to documentation is based, first and foremost, on the conservation needs of the site and the context in which the work takes place; technology, tools, and high-tech gadgets are secondary considerations.

For their work on this project, I extend my thanks in particular to Rand Eppich, editor and senior project manager; François LeBlanc, head of field projects (2001–2007); and the entire GCI project team. I am also grateful to all of the contributors, who generously gave of their time and shared their professional experience to help make this publication possible.

It is our hope that this publication and its companion volume, *Guiding Principles,* will serve as valuable tools for those who conserve and safeguard our cultural heritage.

Timothy P. Whalen
Director
The Getty Conservation Institute

Preface

Good conservation of our cultural heritage is based on informed decisions. The information needed to make these decisions is, in part, obtained through the use of documentation and recording tools. Knowledge of these tools and their use is readily available; however, many of the decision makers are unaware, uninformed, or unconvinced of their benefits. Several reasons for this include a misunderstanding of the tools and techniques or intimidation by the technology or language.

This has long been an issue in the field of conservation. To address the knowledge gap, this volume, *Recording, Documentation, and Information Management for the Conservation of Heritage Places: Illustrated Examples,* highlights a wide variety of projects, tools, and techniques through case studies that demonstrate how conservation decisions were reached through the appropriate use of documentation. The publication has been designed and written with the midcareer architect, conservator, or site manager in mind—those who make decisions, work in the field, and need to identify and select documentation tools. It is a nontechnical book, and each concise example can be read by these busy professionals within thirty minutes.

This collection of examples balances technology, geography, and site significance. Our methodology was simple: conduct an extensive and rigorous literature review to select examples that represent best practices for heritage documentation and recording. The layout and numerous graphics were carefully considered to allow professionals to quickly draw parallels to their own projects.

In recognizing that users of this book are interested in solving a pressing problem and are in need of a tool to assist them, each of the eighteen examples addresses the conservation issue first, not the documentation tool. This is followed by a description of the site and project, then a presentation of the tool and its use. Finally, an answer statement, final product, and summary are provided.

A variety of tools ranging in complexity are featured in this publication. After the introduction, the first three sections are organized following the method of the conservation process, whereby information is first gathered, then processed, and finally analyzed. A fourth section covers nontraditional recording tools that have been found useful in addressing a conservation issue.

It is important to note that many of these projects use a number of tools; however, we have chosen to limit our focus to the main tool or technique that assisted in reaching the conservation decision. Although each tool or technique illustrates a specific step of the conservation process, it may be suitable for other stages as well. Appendix A proposes teaching strategies for using these examples to discuss conservation issues and tool selection. A second appendix, appendix B, includes a list of heritage institutions and professional societies, as well as a list of equipment manufacturers.

Our wish is that this collection of examples from around the world will serve as a beginning reference guide to the conservation community. Presenting information as succinctly as possible was our goal throughout the entire process of compiling this publication.

First, we brainstormed conservation issues that recur in the fields of architectural conservation, architectural finishes, structural conservation, conservation planning, archaeological conservation, and landscape preservation. We paired these issues with the tools or methods traditionally used to provide an answer.

We then compiled an extensive and comprehensive bibliography focusing on applied documentation in the field of conservation. We researched and collected more than eight hundred sources from books, conference proceedings, journals, and reports found by searching various conservation-based library catalogues and databases. We considered sources brought to our attention by colleagues in the field, and reviewed recently published periodicals and books. In addition, our team attended various conferences focusing on cultural heritage to learn firsthand of new material and receive references from practicing professionals. A selected bibliography from this work, titled RecorDIM Initiative, is available in the Project Bibliographies section on the Getty Web site at www.gcibibs.getty.edu/asp/.

To guide the selection of contributors for this publication, we created a rigorous evaluation system. The collected source material was then distributed among team members, who systematically reviewed and rated the material against the following criteria:

- Is the conservation issue clearly stated?
- What is the scope of the conservation issue?
- Is there a correlation between the documentation phase and the conservation process?
- Are the documentation tools appropriate to address the issue in terms of cost, detail, precision, time, and availability?
- Are the tools effective?
- Is the writing style clear?

The ratings for each source were compiled into a matrix. Based on the results obtained, our team assessed and discussed the highest-ranking material before making the final contributor selection. In addition to the ranking, we sought to balance the techniques, technology, and geographic distribution of published projects.

From this matrix and our discussions, we obtained a list of potential contributors. We contacted each author and discussed our project, goals, audience, and methodology. The authors wrote about their projects, emphasizing a specific conservation issue, and the team worked with the authors to edit their materials for publication. In devising this systematic methodology to facilitate the collection and methodical review of sources, we believe we created an approach that can be applied to future editions of this publication, if undertaken.

We hope that the *Illustrated Examples* will assist conservators in selecting the appropriate documentation tools for their projects, and that it will serve as an introduction to new tools for the practicing professional, as well as for those studying conservation.

Rand Eppich, *Editor*

Amel Chabbi, *Associate Editor*

Acknowledgments

Recording, Documentation, and Information Management for the Conservation of Heritage Places: Illustrated Examples is the result of the efforts and enthusiasm of many individuals and institutions. Foremost, we thank Robin Letellier for his leadership and efforts in forming the RecorDIM Initiative and heralding the cause of bringing together conservation and recording professionals. Sadly, Robin passed away during the editing process, but his legacy will continue through this publication. We also are extremely thankful to the members of the editorial board for their valuable advice and continued guidance during the creation of this publication: Alejandro Alva, Kate Clark, John Fidler, Frank Matero, and Giora Solar.

We also would like to thank Werner Schmid, contributor to the companion publication, *Guiding Principles*. We are deeply grateful to our colleagues from the International Committee for Documentation of Cultural Heritage (CIPA), Bill Blake from English Heritage, Mario Santana Quintero from Katholieke Universiteit Leuven, and Peter Waldhäusl, former CIPA president. John Burns from the U.S. National Park Service offered helpful suggestions that greatly improved this volume. Special thanks go to all of our contributors for their participation and collaboration.

We cannot forget our colleagues here at the Getty Conservation Institute: Tim Whalen, Jeanne Marie Teutonico, and Kathleen Gaines, for their direction and encouragement; Gail Ostergren, Jeffrey Levin, Cynthia Godlewski, and Angela Escobar, for their patient sharing of editorial expertise; and Claudia Cancino and the entire GCI staff, for their insightful comments on both form and content.

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INTRODUCTION

Informing Conservation

Kate Clark

It is easy to see the conservation of monuments, buildings, and sites as a purely technical exercise. All you need to do is diagnose the problem and identify the remedy. Unfortunately, heritage sites are not that simple. What makes something ultimately part of the heritage is not the fact that it is a building or even a ruin; instead, it is the value we place on it. We may value it because it is old, because of its association with a famous person or event, because it is beautiful or familiar, or because it tells a story. If it is value that makes something part of the heritage, then caring for the heritage involves caring for–or at least respecting–what makes it valuable. Values lie at the heart of all heritage management.

It is remarkably easy to damage what is important about a historic site or building. The wrong kind of mortar can accelerate the erosion of masonry; exposure and weathering can erode painted surfaces or soft mud brick; inappropriate cleaning can leave a surface more vulnerable than it was to begin with. Sometimes a site can be damaged by trying to do the right thing: a poorly placed visitor center or poorly designed access ramp can be detrimental to views and setting; overenthusiastic restoration can destroy important fabric; repairing a historic roof may inadvertently affect bat roosts; new services may plow through important buried remains. Although it is important to get the right technical solution for conservation, it is just as important to make sure that your conservation strategy is appropriate in terms of the value of the site.

In order to know why a building or site is valuable, we need to understand it first, and this is neither easy nor straightforward. You can understand what is important by talking to people in the local communities and experts; you can also understand what is important by looking at historical sources, maps and images, and literature. But you also need to look at the site. Historic sites, buildings, and monuments contain within them a story. It is the story of how they were constructed, used, and altered over time. It is a story that may not ever have been put down in writing. Sites will tell you how people lived and what they achieved; they tell of disasters and successes, innovation and conservatism. A building will tell you about the ambitions of the people who lived in it, their successes, and some of their failures; the fabric of a city or town will tell you stories of whole communities. Even a landscape contains a story–in the plants and wildlife that survive today, in the boundaries and the way water is managed, in the aboveground and buried remains.

Understanding the physical fabric of a site is an important first step in finding the right conservation strategy, and documentation is the first step in understanding. Site records can take many forms and may range from high-level aerial photographs down to the most detailed microscopic analysis of paint traces. In between is a wide range of other techniques: photographs, video, sketches, maps, and databases. You can work by hand or with the most sophisticated electronic or remote sensing equipment. In addition to images and representations, a variety of other information can be captured in written form. There are many different ways of documenting a site for conservation–the challenge is to decide which to use!

Kate Clark is founder of Kate Clark Associates, heritage consultants for the historic environment. Kate Clark Associates is involved with issues of heritage training, policy, research, and evaluation, as well as conservation management planning and community engagement in heritage. She is former deputy director of policy and research at the Heritage Lottery Fund. As an archaeologist, she has worked for English Heritage, the Ironbridge Gorge Museum, the University of Birmingham, and the Council for British Archaeology. She is the author of *Informed Conservation: Understanding Historic Buildings and Their Landscapes for Conservation.*

Tools Overview

Ross Dallas

Documentation for cultural heritage has become a much more complex procedure than it used to be. In the past, an architect or architectural draftsperson went to the building that was to be measured. Cloth tapes were slung about and *squareness, assumed horizontals,* and *verticals* were relied on. Perhaps the odd check diagonal was taken. Back at the office, on a sheet of paper, a drawing was drafted in pencil, then ruled in ink.

Times have changed, not only in the methodologies available but also in the perception of what is required and who will provide it. In recent years, a greater appreciation for these procedures seems to have developed, partly in relation to technical developments and partly through raised standards in the conservation field. The definition of *documentation* itself has become much wider: it can encompass everything from the simplest photographic snapshot to the most sophisticated laser scan survey. We should also recognize that the computer has revolutionized the way measured survey methods have developed in the last thirty years, not only in the computer that sits on our desk but also in the embedded microchip–a computer in miniature–that powers, for example, the total station theodolite.

This introductory overview presents tools and techniques, many of which are illustrated in the examples throughout this volume. The following categorization of survey methods was devised by the author some years ago and generally has stood the test of time. As with all categorizations, it is a little simplistic, as tools and techniques are often combined. Nevertheless, it provides a framework to describe each technique in turn.

This article, is taken from the author's "Measured Surveys of Historic Buildings: User Requirements and Technical Progress," which appeared in the Journal of Architectural Conservation, *vol. 9, no. 2.*

Base Recording and Condition Assessment: Manual Survey Techniques

Base recording is a term often used for the gathering of measurements and data to create a document, drawing, or photograph that will be used to make future conservation decisions. This base record will be added to as conservators, engineers, or architects work with the monument or site. The first technique is the oldest and most basic: hand survey.

Hand Survey

Hand survey is defined as the process of measurement of architectural detail where physical contact is made with the feature being measured.

For example, to measure a window, a surveyor most likely will use a tape measure or measuring rod, holding it against each feature and writing down the measurement on a sketch. Right-angle square or diagonal measurements are introduced to ensure accuracy at right angles, and a plumb bob or level is used to check verticality. There are projects where hand survey is the most appropriate technique, and projects where it is a necessary adjunct to other methods of survey. Hand survey remains vital because it is usually a very rapid method requiring few tools and minimal training, and often provides sufficient information with which to carry out conservation. Hand survey also helps architects or conservators become intimately familiar with an object by allowing the discovery of subtle aspects. In discussing hand survey, it should be made clear that high-quality workmanship is necessary to produce accurate drawings. The tools required may seem simple, but a well-done hand survey, efficient and accurate, is highly skilled work.

Generally speaking, hand survey is best suited to small areas. In large areas it becomes very difficult to maintain accuracies and can become too labor intensive. For example, a single bay of a typical church can be measured with good accuracy. If that accuracy is extended across the whole church, using the same methods of diagonal checks and triangulation, the survey most likely will drift out of accuracy. It is also difficult to maintain accuracy when measuring high or vertical elements from ladders or scaffolding. Today, the data collected from hand survey most likely will be transcribed directly to computer as a Computer-Aided Design and Drafting (CAD) file.

Sketch Diagram

This is defined as a drawing, often assuming squareness of horizontals and verticals, of a historic structure or site. Only a few measurements are taken, possibly just two or three of the width or length, with a few diagonal checks. Details such as windows are sketched in without measurement, and wall thickness would be assessed by the most rudimentary measurement through door openings. This method is usually assisted by photography. Sometimes sketch diagrams may be the only realistic way of obtaining any form of measured drawing, but users need to be aware of the limitations and advantages of such surveys. Sketch diagrams, especially in the computer era, have a habit of being drawn or transcribed until they become accepted as accurate. Such drawings will always be needed in times of rapid assessment, but they should be clearly labeled, and the temptation to refer to them as accurate must be firmly resisted.

Instrument Survey Tools

Years ago, instruments were introduced to improve the accuracy of drawings, primarily for mapping or topographic surveys. Instrument survey is a technique whereby the results and accuracy rely on measurement with a mechanical device and without direct contact with the object being surveyed. The principal survey instrument is the theodolite. While modern theodolites look quite similar to the older models, their operation and development have been transformed by electronics.

Total Station Theodolite

A theodolite measures vertical and horizontal angles. Using basic trigonometry, when angles and distances are known, positions or coordinates are calculated. This method was used for generations, but not without some faults. Essentially, the techniques were slow and highly error prone. Every reading had to be written down manually, then calculated in longhand and laboriously hand drafted.

The first great improvement came with the electronic theodolite. Manual recording of horizontal and vertical angles was replaced with electronic reading and recording devices. The theodolite was used just as before, but at the touch of a button the readings and measurements were automatically recorded and stored in digital form.

Concurrent with the invention of the electronic theodolite, methods of electronic distance measurement (EDM) were also developed. In simple terms, an infrared wavelength is transmitted to a prism or target or to the object (prismless), and the time it takes for the light to bounce back is measured (because the speed of light is known) and hence distance is calculated. The benefits are speed and reliability, and measurements can be made over longer distances.

By combining the electronic theodolite with EDM, the total station theodolite was developed. This instrument has become the workhorse of modern surveying. It is valuable in creating building floor plans and site surveys, though it still requires the use of a prism reflector or target and usually two operators. The next development was the reflectorless EDM (REDM) total station theodolite. This improvement has hugely enhanced the usefulness of the theodolite for elevation surveys, as it can take distance measurements straight from a surface without a reflector and requires only one setup, or operator. For surveying a fairly simple facade it is an ideal tool, offering accuracy, speed, economy, and simplicity of operation.

Laser Scanning

At first sight, the latest manifestation of instrumentation survey may seem to have little to do with the examples previously mentioned. In actuality, the "time of flight" laser scanner directly evolved from the total station theodolite and EDM. This type of laser scanner works by sending out thousands of pulses of light per second and, at great speed, calculates the three-dimensional coordinates of points, thereby defining a surface. It is essentially carrying out a task very similar to that of a reflector-less total station theodolite, only automatically at high speed. Horizontal and vertical angles are being measured, REDMs are being made, and the data are converted into coordinates.

Two other types of laser scanners work on entirely different principles: phase comparison and triangulation. In phase comparison laser scanners, the instrument emits light with a known frequency and phase and compares the emitted phases to the returned phases; thus the distance to the object can be determined. With triangulation laser scanners, a light emitter and a receiver are separated by a known distance, and the angle of the reflected laser pulse is used to determine the distance.

The rapidity of data capture and the instant ability to input this to the computer have made laser scanners an accepted tool in the field of survey. At the present time, they are used for everything from buildings and bridges to tunnel designs, objects, and topography, and provide a unique way of recording surface details. The only serious limitations are cost and the overwhelming amount of data collected. Currently, both the hardware and software are expensive, and the sheer amount of data gathered makes this tool not the best for every survey.

Global Positioning System (GPS)

The GPS method of locating positions on the Earth's surface through radio signals emitted from orbiting satellites, and sometimes ground-based transmitters, has been applied in many fields. It has been particularly valuable in the area of land surveying and in surveying large, complex archaeological sites. At first sight, the system seems to have little to do with conventional survey, but in fact GPS follows a traditional method of survey or, more strictly, a principle of trigonometry: If the lengths of the three sides of a triangle are known, the angles in between can be calculated. This means that if two corners of the triangle are fixed or located, the position of the third can be calculated. The satellites provide the known points and intersections for at least three satellites.

There are two general categories of GPS radio receivers: consumer handheld units, which range in accuracy from 5 to 15 meters (and have contributed to the widespread use of GPS), and more professional or survey-grade units. From professional instruments, astonishing accuracies are possible down to ± 10 to 20 millimeters. This means that site surveys and external building profiles can be surveyed directly with GPS instrumentation rather than having to set up theodolites and make conventional measurements. A ground-based system using the same triangulation principles as GPS can also be used for surveying, but with transmitter base stations set up locally—that is, without the use of satellites.

Image-Based Documentation Methods

The value of the photograph in all conservation work is inestimable, whether represented by today's ongoing site-record photographs or early photographs consulted for historic information (it is often forgotten that photographic technology is now more than 150 years old). Image-based documentation can generally be classified into three types: pictorial imagery, rectified photography, and photogrammetry.

Pictorial Imagery

Pictorial imagery constitutes the bulk of standard or ordinary photographs taken in conservation, usually with the camera oblique to the subject and utilizing any of a wide range of everyday cameras, from auto-focus to professional models.

Although it is a primary form of documentation, pictorial imagery is not generally meant to be used for measured survey purposes. Nevertheless, it can be used for measurement with two methods. Every conservation professional will, from time to time, take a photograph containing a scale against the object being photographed to gauge some dimension. This is a very useful method, but it must be treated with caution as accurate scaling on pictorial photographs is difficult to achieve. If at least two photographs of the same scene are available, a second method can be applied to pictorial photographs to provide a source of measurements. Technically, this process needs the services of a professional photogrammetrist, although with some of the computer programs available today, some measurements may be extracted by the photographer.

Video photography can also be considered as part of pictorial photography. An invaluable way of recording a great deal of information quickly, video not only records a building's features but can document its construction, use, and contextual significance as well. Video has the added advantage of simultaneously documenting images and audio commentary.

Rectified Photography

This is the first step up to a method that can provide reasonably accurate measurements from photography. Rectified photography is the process of photographing a facade by aligning the images to be as parallel as possible to the section of facade to be recorded. It includes the use of a relational scale so that dimensions can be measured. The resulting scaled print provides a reasonably true-to-scale image of the facade.

Whereas the photography part of the process is nowadays still quite straightforward, traditionally the printing and scaling were somewhat more complicated. With advances in computers, however, this latter process has become simpler. The photograph is now captured often obliquely to the facade and usually with a digital camera. Through the computer, in a fraction of the time it used to take, the digital image can be manipulated, a scale introduced, and tilts and distortion corrected. Rectification is done using a variety of software and can be a useful, rapid, and inexpensive form of documentation, particularly where the facade is made up of small components such as bricks, earth construction, or rubble walling. Although its main use is in recording flat building facades, it is often used for features such as floor surfaces, ceilings, and painted surfaces. If high accuracy is required—for example, to assess structural conditions—it is not appropriate. Rectified photography is generally provided by specialists, but it can also be done by conservators, depending on the standards required, availability of time, and resources.

Photogrammetry

Here the tools become more complex. As a source of measurement, photogrammetry still seems to be regarded as something of a novelty, yet it was first applied to building surveying as early as the 1870s. The modern use of photogrammetry for survey safely dates to the late 1930s through the 1950s and has since been in continuous use in many countries around the world. Photogrammetry is a much more complicated process than any other type of photography. It is the science of obtaining detailed measurements from photographs, often for the purpose of creating drawings, and encompasses both stereophotogrammetry and orthophotography.

Stereophotogrammetry involves taking stereo-pair photographs with calibrated cameras, then using the resulting images in a photogrammetric plotting device or computer to extract accurate measurements with which to produce drawings. This method is most appropriate in situations where a high level of detail or a great deal of irregularity needs to be recorded.

Orthophotography is a true-to-scale process that combines the benefits of a photograph with its wealth of detailed information and the geometric measurement accuracy of a survey with instruments. This is a complicated process that actually builds on using stereo-pairs of photographs. Very simply, a stereo-pair is captured and an entire series of corrections is made to the positions of identical points in the two photographic images. The result is a true-to-scale photographic image, or orthophotograph. With computerization, this process has become easier, faster, of better quality, and much more inexpensive. It is suitable for the representation of some types of features, such as drums or circular towers, and is also effective in representing irregular or complex facades.

In relation to the quality and quantity of data provided, photogrammetry usually is not expensive; however, a trained professional and special equipment are required. If only simple building outlines are needed, it is unlikely that photogrammetry will be economically justified, but for the highest-quality drawings of major facades, showing all stonework jointing and much architectural detail, photogrammetry remains an important tool.

Data Management

All the methods mentioned above will provide surveys adequate for most conservation work. After being collected, the data must be managed, an increasing role for both conservators and surveyors involved in documentation and conservation. In the following section, related data management techniques are introduced. As with data collection techniques, they may be stand-alone or used in various combinations.

Computer-Aided Design and Drafting (CAD)

CAD for the preparation and subsequent presentation of survey data has become an increasingly important tool in documentation. A CAD program allows the spatial data or drawings–which have been captured from many different sources–to be displayed, edited, and presented on a computer. CAD enables users to view drawings, zoom in and out, add and delete information, prepare specifications, print, and transmit information over the Internet. It is an immensely powerful tool now used in almost all aspects of documentation. Most of the illustrated examples in this book utilize CAD in some way in preparing data.

Computer Modeling

Computer modeling takes CAD a dimension further. Utilizing the capabilities of three-dimensional modeling, the survey and image data for a historic structure can be viewed on screen. The model can be scaled, rotated, and viewed in various ways. This enables a conservation team to assess the effect of likely alterations to a historic building or site.

Databases

A database is a collection of data, usually text, which is separated and systematically stored in tables with key identifiers. Records are often separated into sets, themes, and fields that allow for easy retrieval and "recombination," or queries of data. Databases can be as simple as a few lines of data to keep track of the windows in a small historic building, or as complex as multiple tables for keeping an inventory of all the historic buildings in a region. Other types of data such as images, drawings, measurements, and videos are now stored in multimedia databases. A database can be useful in conservation, not only to keep track of surveys and drawings but also to inform the public or organize and plan a conservation project.

Geographic Information System (GIS)

The concept behind GIS is quite simple, whereas its application can be very complex. GIS is similar to CAD in that it displays graphic information, and similar to databases in that it contains tabular data. The advantage of GIS is that it combines both CAD and databases. Information about a subject can be classified in two ways: first, the position or the spatial location (drawing) of a feature, and second, the descriptive information (text or other form). If these two classes of information are brought together with a computer program, then a GIS has been created.

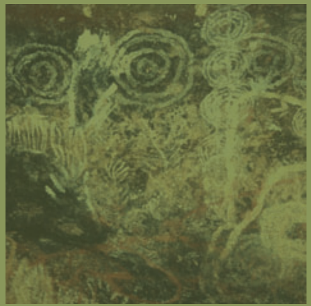
A floor plan of a historic building provides a simple example. To each room in the plan, a set of attributes such as size, function, and features can be ascribed in a text format. This plan can then be combined with the text attributes in a GIS. With one click on the electronic drawing, the attributes can be displayed or the database searched, and the appropriate portion of the drawing displayed. This is useful in managing data for complex or large sites with numerous features or elements; however, its usefulness is questionable for smaller sites or single structures.

A wide range of tools for documentation are available, and all professionals involved with conservation should know their advantages and disadvantages. Architects certainly will be involved, but engineers, archaeologists, and conservators must also be informed and concerned regarding the processes of documentation. As mentioned earlier, others not directly involved with conservation, such as land surveyors or professional photographers, may carry out surveys, and it is important for conservators to understand the tools and processes involved in order to communicate effectively and obtain the best results. In addition, the role of the amateur should not be forgotten—in many countries, and for many years, invaluable work has been done by volunteers and students.

Thus, the documentation of our cultural heritage of historic buildings, structures, and sites is a vital and ongoing process. Though not a new activity in the last half century, the importance and value of documentation has been increasingly recognized within the conservation community. The value of good documentation assists informed decision making and ongoing maintenance for conservation. The wide range of examples in this publication illustrate the many methods and standards that can assist the conservation professional in choosing and applying the most appropriate technique or tool in any given circumstance.

Ross Dallas, BSc, FRICS, is a retired measured survey consultant who spent several years as chief surveyor for English Heritage. With a degree from Glasgow University and a background in land surveying and photogrammetry, he has spent his career in the field of surveying and recording historic structures. He has been elected an honorary lifetime member of CIPA Heritage Documentation (International Committee for Architectural Photogrammetry).






BASE RECORDING: GATHERING INFORMATION

Rapid Assessment

Anthony Crosby

Historic earthen adobe buildings from the Spanish Colonial and Mexican Federal periods are the only remains of settlements from the eighteenth and nineteenth centuries in the Los Angeles area. Invaluable reminders of California's past, they are extremely vulnerable to earthquakes. In January 1994, an earthquake of Richter magnitude 6.4 struck an area in which many of these historic earthen structures exist.

How can a team make informed evaluations quickly of these structures and their seismic performance in order to better protect them in the future?

This illustrated example was completed with the assistance of Leroy Tolles and the staff of the Getty Seismic Adobe Project. They provided images and details of the work to complete this example.

Southwest corner of the Rancho Camulos Adobe after the 1994 Northridge earthquake in the Los Angeles area. Photos of historic structures taken immediately after disasters but before cleanup or stabilization can aid engineers in understanding the causes of structural failure. Photo: © Rancho Camulos Museum, 1994.

Los Angeles, California

Historic missions, ranch complexes, and simple houses are scattered throughout Southern California in the Los Angeles basin, the San Fernando Valley, and the San Gabriel and Santa Clara river areas. The semiarid climate, the relative scarcity of timber, and a culture of building with sun-dried mud bricks led to the first immigrants' decision to build their dwellings and religious buildings with adobe. Often these buildings were constructed on soft soils, such as alluvial deposits and unconsolidated sediments. This combination of adobe buildings on soft soils in a seismically active area proved unfortunate.

In the early 1990s, concerned conservation professionals feared that many of California's historic adobes were being seismically strengthened using overly aggressive and damaging methods. In response, these professionals, along with the Getty Conservation Institute, launched the Getty Seismic Adobe Project (GSAP). A project team and advisory committee were formed that consisted of these professionals as well as architects, engineers, university professors, and project managers.

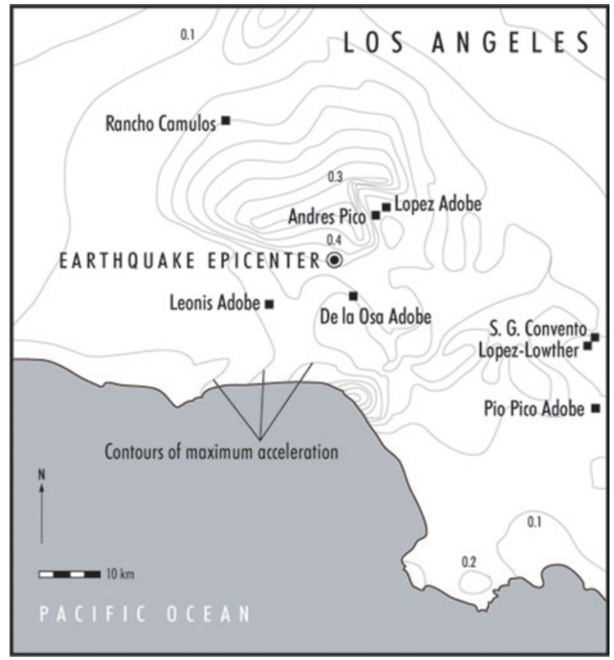
The program's goals were to develop less invasive strengthening methods and produce guidelines for their implementation. The project began by evaluating existing methods and examples of seismic reinforcement with a view toward both life safety and protecting the authenticity of historic buildings. The team took advantage of previous research and specific projects that appeared to address seismic criteria in responsible and sensitive ways. The research also included theoretical and mathematical analysis and extensive shaking-table tests of one-tenth and one-half scale model adobe structures.

The advisory committee met periodically with the program team and project managers to review the progress. One of several recommendations made was to incorporate additional field analysis of historic adobe structures and to study actual failure patterns. This recommendation was incorporated into the program, and in late 1993 field studies were undertaken. The participants in the field analysis were two structural engineers, a material scientist, an architectural historian, and the author, a conservation architect.

On January 17, 1994, the most damaging earthquake to strike the Los Angeles metropolitan area to date occurred. The historic adobes nearest the epicenter, in Northridge in the San Fernando Valley—Andres Pico, De la Osa, Rancho Camulos, and Lopez, as well as the San Fernando Mission Convent—were subject to very strong ground motions of more than 0.4 g. Fifteen other historic earthen structures, including the San Gabriel Mission Convent, were also affected but are located farther away, where the ground motion was significantly less.

Because many of the earthquake-affected adobe buildings had been studied only months earlier, the aftereffects of the Northridge quake provided a unique real-world laboratory. Action was taken immediately, and within a week the original team was back in the field to undertake a rapid assessment and reevaluation of the historic adobes. The effort was supported by the State Historic Preservation Office (SHPO), California State Parks, private and public property owners, and the GSAP. It was critical that assessment of the damage take place as soon as possible after the earthquake, before additional aftershocks, rain, or demolition for life safety erased evidence or unnecessarily removed original sections of the buildings.

The two main objectives of the rapid assessment were (1) to quickly document and evaluate the buildings that were at greatest risk and (2) to record the failure patterns so that an understanding of the relationship between the failures and the earthquake characteristics could be developed and later utilized in the overall GSAP goals of providing guidelines for less invasive seismic retrofits.



Map of Los Angeles, showing locations of historic adobe structures, the quake's epicenter, and contours of maximum acceleration. A map like this was used in planning site visits to the affected area. Drawing: Steven Rampton.

Sketch Diagrams

The rapid assessment began with the identification of buildings that had been damaged or potentially damaged in the earthquake. The SHPO, California State Parks, and building owners were contacted directly for information on the buildings' status. Locations were noted on a map, and site visits were planned to evaluate as many buildings as possible in the shortest amount of time.

All travel was conducted by automobile, and the time spent in transit provided valuable opportunities to discuss each building, preview useful information, and develop a tentative assessment plan. While these conversations were cursory, they nonetheless added to the collective understanding of the structures and proved extremely valuable as an efficient planning method.

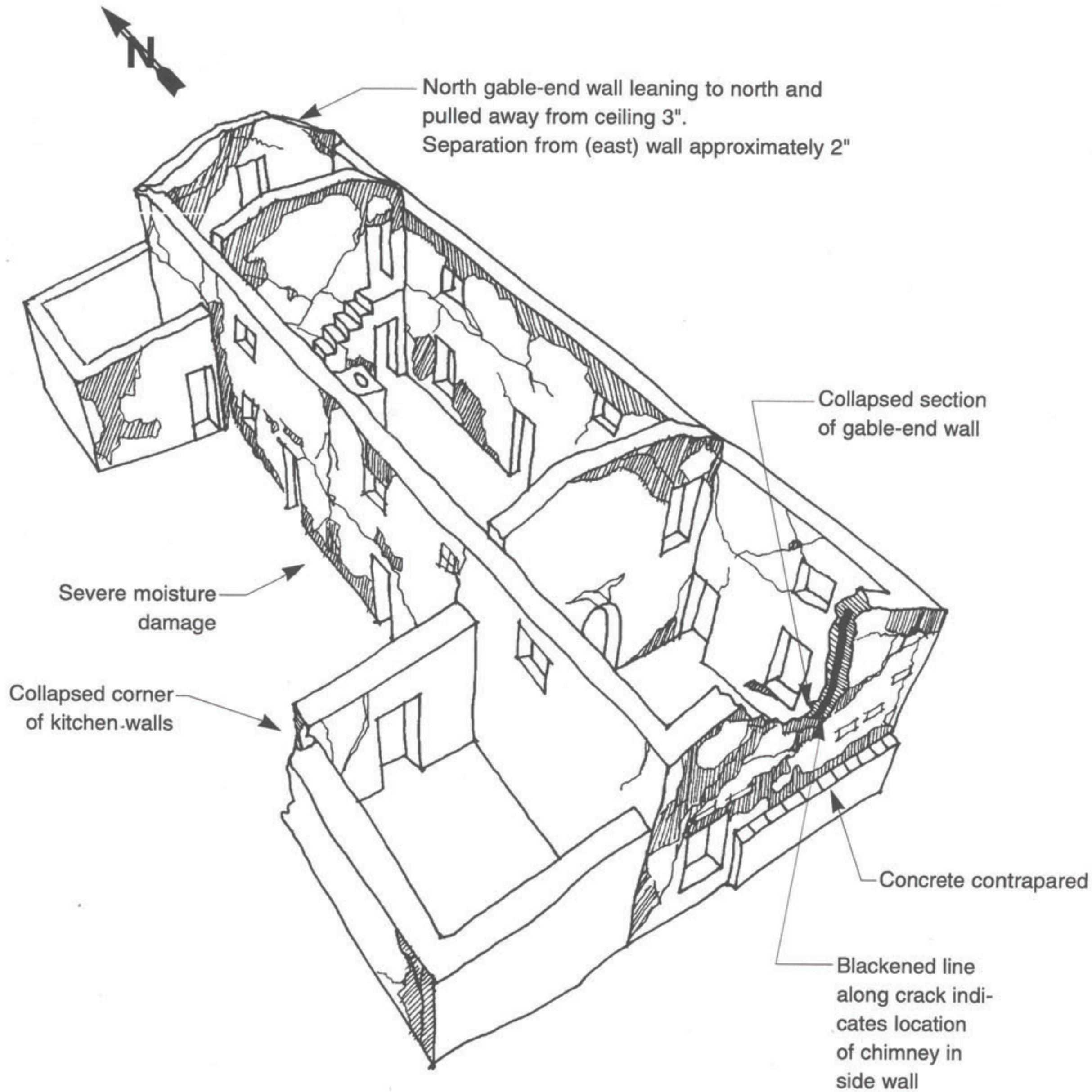
The next step in the assessment was for the five participants to survey the site as a group, then to split up and, individually or in smaller groups, collect as much information as possible. After the individual assessments, there were brief meetings to review findings and discuss building failures and their possible causes. It was important to understand which failures may have been preexisting and whether these preexisting conditions (moisture damage, previous crack damage, or previous repairs and retrofit measures) may have contributed to the failures. One very important aspect of the assessment was to develop a clear understanding of the performance of the entire building system.

Time spent at each building site depended on the overall schedule, size, and significance of the structure, degree of damage, and complexity of the failure patterns. In one case, the assessment of a heavily damaged, simple one-room structure

East exterior elevations of the Andres Pico Adobe, after initial structural assessment. Structural failures such as cracks caused by out-of-plane flexure were sketched on top of 35mm film and Polaroid images that were taken perpendicular to the building. This type of on-site assessment allowed engineers and architects to compile the final synthesis analysis and quickly move on to the next building. Photo: E. Leroy Tolles.

Before and after images of the Andres Pico Adobe. Photo: E. Leroy Tolles.

Final synthesis analysis sketch of the Andres Pico Adobe. This perspective sketch, completed just weeks after the earthquake, allowed engineers and architects to understand all of the failures and interaction of building elements at a glance. Drawing: Anthony Crosby.



required only a few minutes; in other cases, the assessment took several hours. Work began early in the morning and lasted until dark.

When available, existing drawings and photographs were annotated to plot, interpret, and analyze the extent and patterns of damage, and to note construction details. When these were not available, field sketches were used. What proved to be particularly valuable were the notes, photographs, and field sketches of conditions prior to the earthquake from earlier GSAP studies. In several cases, the identification in the earlier study of preexisting structural cracks provided a much clearer understanding of the effects of the earthquake.

Small-format (35mm) photography (color and black and white), Polaroid, and video were also used. Scaled photographs of key wall elevations were assembled and used with field notes to plot crack damage. Video was used to record an overview of the general conditions and capture spoken observations of specific details—this was often faster than writing down the same observations. Elevations, perspective drawings, and sketches were used to record information and plot failures not visible in photographs. Simple hand tools such as a plumb, an optical hand level, and a straight or bubble level were used to quantify some of the field data. Within a period of six days, nineteen structures were evaluated, numerous sketches created, and more than five hundred photographs and four hours of video taken.

Immediately following the fieldwork, the data were reviewed by team members in order to refine their understanding and develop a "failure typology." However, more time was needed to fully comprehend the effects of the earthquake on the adobe structures. Approximately two additional months were spent assimilating the data and relating earthquake characteristics and preexisting building conditions to individual failure patterns.

It soon became clear that a forum was needed to share this information and discuss the findings of the team. A one-day mini-conference was organized within a year of the earthquake, and the results of the rapid assessment and failure typology were presented to other engineers, architects, and building professionals. Case studies of strengthened and nonstrengthened adobe buildings, and the impact of preexisting conditions and building histories on failure patterns, were presented as well.

Though it was never the original intention to produce a formal detailed publication of the results, eventually it became clear that such a report would be valuable to others. Several months were spent further evaluating the data and drawing conclusions, resulting in the publication *Survey of Damage to Historic Adobe Buildings after the January 1994 Northridge Earthquake*. A PDF edition of this book is available at www.getty.edu/conservation/publications/pdf_publications/books.html.

An Answer

The Northridge earthquake revealed on a large scale the vulnerability of historic adobe buildings to seismic forces: vulnerability that can be mitigated through seismic strengthening without being overly aggressive or damaging the buildings. The rapid assessment documentation assisted the project team in understanding the performance of adobe structures during seismic events and led to establishing guidelines on stabilization and strengthening. The conclusions determined that preexisting conditions had a major impact on the structural behavior of the buildings, and that preparations for future earthquakes must be made. Further questions were raised about earthen structures in past earthquakes, and additional studies were suggested. These findings were communicated to building code officials, building owners, and the SHPO.

The conclusions also showed the value and effectiveness of conducting such a survey soon after the earthquake using only basic tools and equipment. More sophisticated equipment simply was not needed, as the study and analysis were conducted by an experienced multidisciplinary team. While it may have been beneficial to include additional team members, there was not enough time to organize and train a larger team who would have had only a minimal understanding of the buildings and their failures. With less experienced team members, the collection of data would have taken longer and would have had to be more comprehensive and accurate if it was to be interpreted by others.

In 2000, the GSAP was completed, resulting in the publication of *Seismic Stabilization of Historic Adobe Structures* and *Planning and Engineering Guidelines for the Seismic Retrofitting of Historic Adobe Structures* (PDF editions of these books are available at www.getty.edu/conservation/publications/pdf_publications/books.html). The rapid assessment of historic adobe buildings after the Northridge quake greatly contributed to these publications and to the overall project. Another benefit of the project was the publication of a detailed report that resulted in the subsequent conservation and seismic strengthening of the heavily damaged Rancho Camulos Adobe, in Ventura County. Many other damaged adobe buildings in and around Los Angeles have since been conserved using the guidelines produced by the GSAP.

Anthony Crosby is an architect specializing in the conservation of earthen construction. He has many years of experience working for the U.S. National Park Service and internationally in the Middle East. He was a member of the GSAP advisory committee and is based in Denver, Colorado.

Southwest corner of the Rancho Camulos Adobe, after rehabilitation. Data collected during the rapid assessment were used to design earthquake mitigation techniques and devices that can be used on other historic earthen structures. Photo: Gail Ostergren.

Wall Deformation

Sandeep Sikka

The Buddhist temples and monasteries in the western Himalayan regions of Spiti and Kinnaur, India, have survived for nearly a thousand years. Today, they are susceptible to innumerable natural and man-made threats. Seismic vibrations, changing climate, and improper interventions have caused serious damage to these historic earthen structures.

How can a simple and effective tool record impending wall failures and assist in designing treatments for these buildings?

The earthen structures of Dhangkar Gompa, a Buddhist monastery in the western Himalayas, have survived for nearly a thousand years but are under threat from inappropriate interventions, seismic vibrations, and a changing climate. Photo: © Marek Kalmus, 2005.

Spiti and Kinnaur, India

Perched high in the mountains of Himachal Pradesh, numerous Buddhist monasteries dot the landscape. Buddhist architecture evolved as builders struggled with the region's harsh climate, hostile invaders, and meager resources. Built of rammed earth or sun-dried adobe blocks on rubble foundations, the structures are simple and symmetrical in plan. The walls of most temples are devoid of any openings, and the only source of light and ventilation is provided by small openings in the ceiling or at the entrance. The flat roofs are made of compressed mud layered on a mesh of willow twigs supported by wooden beams set on columns and load-bearing mud walls. The interiors are intricately decorated with paintings applied on the smooth mud-plastered walls and ceiling panels, while beautiful earthen sculptures are attached to the walls with wooden plugs or mounted on stone slabs. Local inhabitants revere these religious complexes, which have remained active places of worship since their construction nearly a thousand years ago. The sites are used for local ceremonies and festivals as well as major religious gatherings, such as the festival of Kalachakra, hosted by His Holiness, the Dalai Lama.

Deterioration of the structures has rapidly increased within the last fifty years. Inappropriate repairs, insufficient maintenance, increased rainfall, and frequent earthquakes threaten their very existence. A project to save these important treasures was launched in 1999 and supported in part by UK–ICOMOS (United Kingdom–International Council on Monuments and Sites) and the Museum of Archaeology and Anthropology, University of Cambridge. The project was designed in five phases: preliminary investigation, risk assessment and measured survey, evaluation, conservation implementation, and maintenance. The first two phases were crucial, as they guided the overall course of the project and determined which structures were at greatest risk.

The first phase, preliminary investigation, was conducted by a large team of architects, historians, wood and painting conservators, material scientists, and engineers–twenty in all. This was a rapid inventory that mapped locations and assessed the significance of and immediate threats to more than twenty individual structures and their components. Photographs were taken, notes and sketches made, and plans laid for the second phase later that summer. Planning was critical, as access to this remote region is difficult due to narrow mountain passes, rough roads, and deep snow. Only two field visits per year could be carried out during the summer: after the snow thaw, and before the first snowfall. Just two months were available for the preliminary investigation, and three months for the next phase; therefore, work had to be organized and accomplished quickly.

The second phase, detailed risk assessment and measured survey, was more difficult. There were no previous archival drawings or records of these buildings, and the team's budget was extremely limited. Complicating matters was the small size of the survey team, composed of only one trained architect, two conservators, and four local workers. The goal of this second visit was to examine four of the structures at greatest risk (Dhangkar Gompa, Chango, Nako Temple complex, and Mantra Chakara, also known as Dhungur Lhakhang), determine the causes of deterioration, identify and map major structural issues, and create architectural drawings. Accomplishing these goals was crucial to the success of the overall project, because the results were intended to help other members of the team and serve as the basis for understanding and planning the conservation strategy. Given these parameters, the project needed low-tech tools and a simple documentation technique.

Interior of the Lotsawa Lhakhang Temple. Sculptures, decorations, and painted surfaces inside the temples and monasteries are threatened. Photo: © Sandeep Sikka.

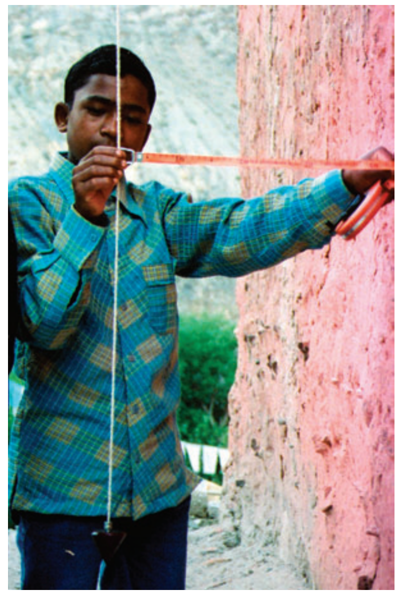
Hand Survey

The buildings and wall profiles were measured manually with 50-meter steel measuring tape, string, pencil and graph paper, architectural scale, right angle, and plumb bob. Manual recording techniques, although often labor intensive, are readily available and allow conservators to study buildings in great detail. Usually this method of recording provides detailed information and sufficient accuracy to begin conservation of earthen structures. Other survey tools, such as a total station theodolite, were considered; however, this equipment was unavailable and did not fit the budget, and no one on the team had the expertise.

Measuring began by establishing two datum, or station, points. These are semipermanent markers created in the earth with large nails on the interior and exterior of each structure. Both of these points had to be seen in a straight line through the only door. These points formed a baseline that allowed the measurements taken on the interior to align with the measurements taken on the exterior. Supplemental reference lines were created along the interior and exterior walls parallel and perpendicular to this baseline using the right-angle tool. The right-angle tool is two 30-centimeter-long rectangular pieces of metal connected at exactly 90 degrees. These supplemental reference lines were made with a tightly stretched string held against the right angle and baseline. The string had been dipped in blue indigo dye, which, when dry, created a powder that transferred to the ground. The station points, baseline, and reference lines were then measured with the steel tape, and a plan was drawn to scale on graph paper.

Using a plumb bob and string, the intersections of these lines were transferred vertically. A plumb bob is a pointed weight of between 100 and 500 grams that, when hung from a string, creates a vertical reference line and allows the user to transfer points or lines. Horizontal strings were stretched taut and reference lines made on the ceiling and parapets. The plumb bob was suspended with a string knotted every 50 centimeters, and the wall deformations were measured with the steel tape from every knot to the wall. The plumb bob and string were then moved 50 centimeters horizontally for another set of measurements. This, in effect, created a grid of measurements that mapped the wall deformations. A modular grid of 50 centimeters was chosen in order to obtain an appreciable curve of the bulges and closely corresponded to three courses of adobe masonry. This grid was helpful in generating plans and sectional profiles of the walls, clearly showing bulges and other deformations. It allowed the architects to get a comprehensive picture of the buildings and any potential failures.

All sheets containing the sketches and measurements were labeled with building identification numbers and marked with directions and detailed notes. When the team returned to New Delhi, all drawings were photocopied and the originals retained by the lead architect. The points and measurements were entered into AutoCAD, a computer drafting program, which provided a final check on the measurements. If discrepancies existed between interior and exterior measurements, the building was scheduled for remeasurement the following spring. Following this process, plans, sections, elevations, and wall profiles were created and distributed to the architects and engineers to devise a strategy for structural conservation.



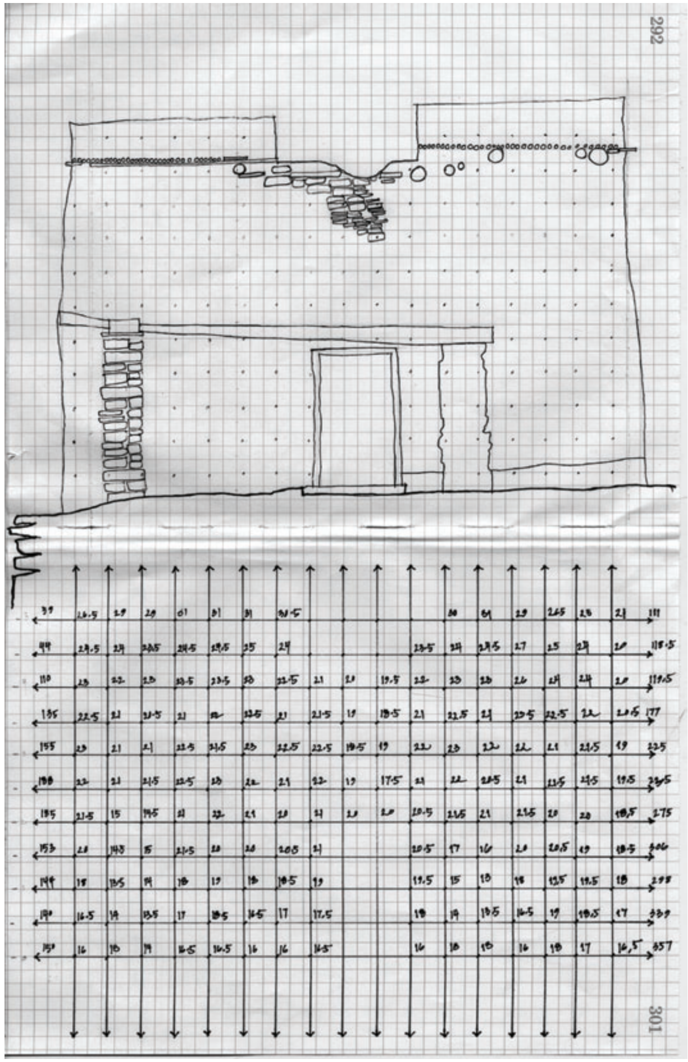
A worker measuring exterior deformation in reference to a vertical plumb line at Chango Temple. Photo: © Sandeep Sikka.

A local worker recording the front elevation of Chango Temple. Manual recording techniques, although labor intensive, are readily available and allow conservators to study buildings in great detail. Photo: © Sandeep Sikka.

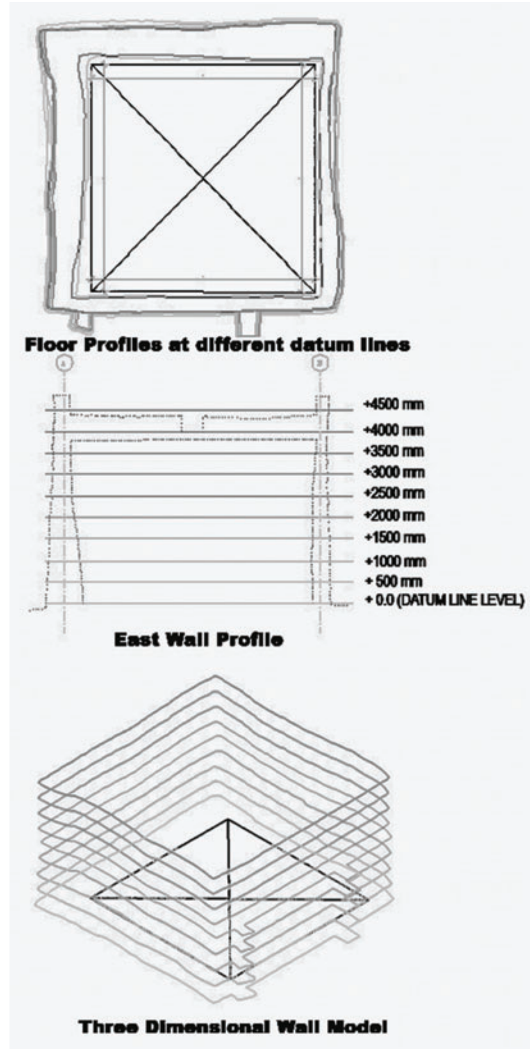
Some problems arose using this process. When the interior and exterior drawings did not align, the measurements had to be completely repeated for the entire building. The indigo-dye reference lines were not permanent and faded after a short time. Also, the 50-centimeter measuring grid could have been adapted to allow for the recording of smaller deformations. The reverse was also true: if a wall was relatively straight, fewer measurements could have been taken, speeding up the process. A heavier plumb bob, greater than 200 grams, should also have been used, as high winds disturbed the exterior vertical reference line. Another tool that could have improved accuracy was a bubble line level to ensure that the reference lines were exactly horizontal.

The hand-measuring method used to record these buildings can be used anywhere with minimal training. The tools involved should be a standard part of every architect's or engineer's equipment and cost very little. If conducted in an organized and systematic way, the results are sufficient to produce good, usable drawings.

During the next phase, evaluation, the drawings and wall profiles generated from these measurements showed outward movement of the upper courses of the walls due to excessive roof loads. Increased precipitation in the region over the last few years prompted local craftspeople to waterproof the roofs by adding layers of compacted mud. These additional layers have drastically increased the roof load, resulting in either sagging of structural members or outward movement of the walls near the ceiling. The drawings also showed outward bulging in several places at the bottom of the walls in the interior. This was caused by excessive moisture swelling the ground outside the buildings, creating a lateral thrust on the lower masonry courses.

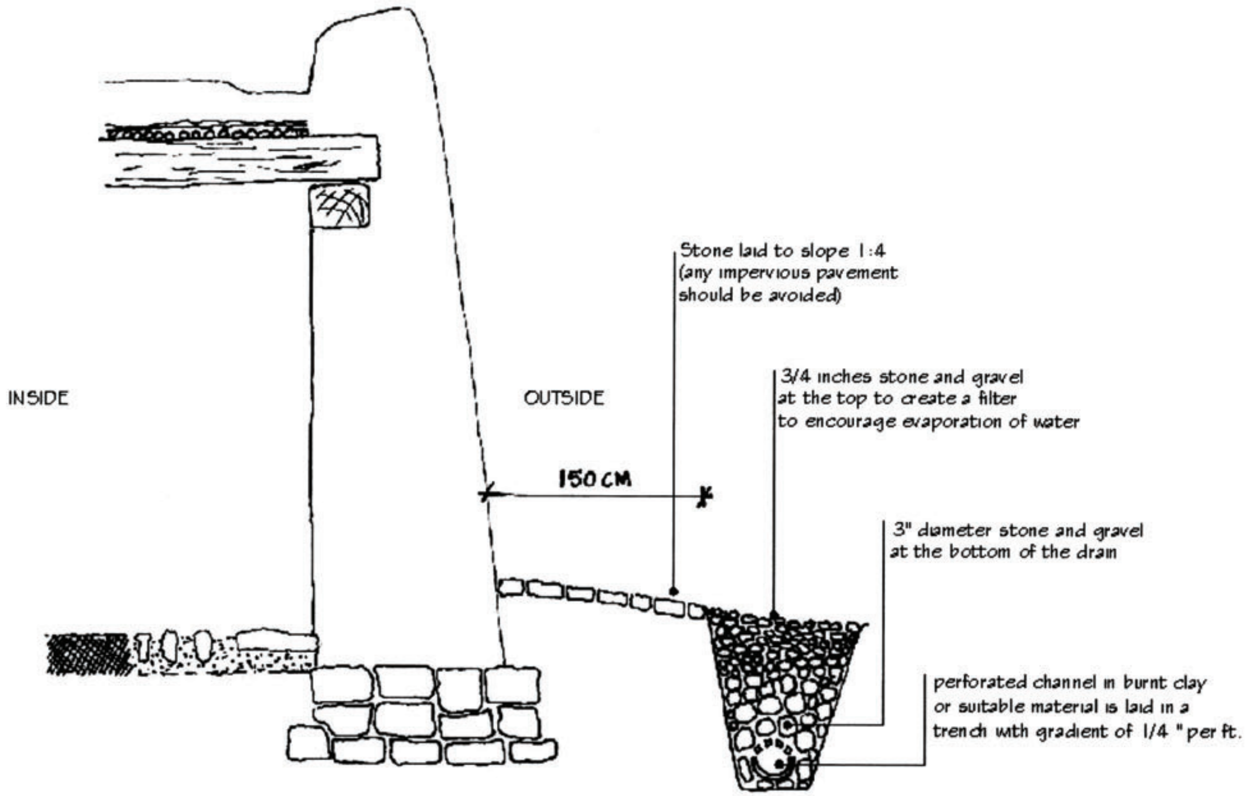


Hand-drawn front elevation of Chango Temple, showing all out-of-plumb measurements at every 50 centimeters. Recording the wall deformation assisted conservators in understanding the causes of deterioration. Drawing: © Sandeep Sikka.



The manually recorded measurements were entered into AutoCAD, a computer drafting program, for further analysis. Drawing: © Sandeep Sikka.

Bulging walls and structural cracks developed due to the horizontal thrust from the surrounding groundwater. Issues of drainage were resolved by sloping earth away from the walls and burying perforated drains. Drawing: © Sandeep Sikka.



Workers burying perforated drains. Photo: © Sandeep Sikka.

An Answer

In the conservation implementation phase of the project, the extra layers of compacted mud were carefully removed from the roof and one thin layer of mud added. Point loads created at the junction of wooden beams and the wall were addressed by inserting continuous wood wall plates to distribute the load more evenly over the entire wall top. Issues of drainage were resolved by sloping earth away from the walls and burying perforated drains to remove the excess water and avoid further stress on the structure. After the structures were stabilized, conservation was conducted on the wall paintings and wood. The final phase, maintenance, was educational and enabled local workers to maintain the structures.

The process of measuring the wall deformations allowed the architect and conservators to become intimately familiar with the buildings. This work and the resulting drawings assisted the project team in forming theories of deterioration and planning the conservation work. The drawings also established a starting point for maintenance and monitoring so that these important religious structures can serve their communities for another thousand years.

Sandeep Sikka is a conservation architect from India currently working in New York. He is a Charles Wallace Conservation Scholar and is completing his PhD studies at the University of Applied Art Institute for Conservation and Restoration, in Vienna. He has studied and worked on the conservation of several historic earthen structures and vernacular architecture in the Indian Himalayas. He was awarded the Frederick Williamson Memorial Grant from the Museum of Archaeology and Anthropology, University of Cambridge, England, and a UK–ICOMOS research scholarship to conduct the work described in this study.

Defining Cultural Landscapes

Geofree Chikwanda

In the Shona tradition of Zimbabwe, great ancestral spirits are responsible for overseeing the well-being of entire regions. It is a commonly held belief that if a natural place is degraded, the ancestral spirit deserts the region and misfortune befalls the community. Natural places anchor those who inhabit the land to their history and culture. They serve to remind people of important events and educate new generations. Preserving these natural places helps to maintain these connections.

How can a cultural landscape be identified and defined to ensure its protection?

Traditional earthen huts of the spirit medium Nehanda Charwe Nyakasikana, in Shavarunzi, Zimbabwe. Photo: © Geofree Chikwanda.

Shavarunzi, Zimbabwe

Mbuya Nehanda, one such nationally recognized ancestral spirit, was a woman who honorably influenced Zimbabwe in the late fifteenth century. In the early 1890s, Nehanda Charwe Nyakasikana, a medium of the spirit Nehanda, was a principal leader in the resistance against British colonization. Upon the collapse of the resistance in 1897, Nyakasikana was arrested for her role in the ill-fated uprising and sentenced to death. Her prophecy that she would rise again was the main inspiration behind the second wave of resistance movements in the 1960s and 1970s that finally led to Zimbabwe's independence.

To this day, the Shavarunzi landscape and the homestead that Nyakasikana occupied are regarded to be of historical, spiritual, and patriotic importance. Strewn with granite hills and ironstone mountains, the area is closely associated with the traditions of the Zimbabwean people and their struggle for independence. This culturally important region, 25 kilometers north of the capital city of Harare, covers more than 17,000 hectares and contains the third largest dam in the country. A contemporary spirit medium, together with her aides, currently occupies a homestead at the foot of one of the hills, where annual ritual gatherings are held to celebrate the symbiotic relationship between nature, history, and the people.

A large portion of this cultural landscape is composed of prime farmland and valuable mineral deposits, including gold. Since the advent of the national land redistribution program in 2000, there has been a steady influx of illegal settlers from the adjacent Domboshava communal lands to the east. Settlements, which are considered taboo, have even been established on the eastern side of Shavarunzi Hill, near the current spirit medium's residence. In addition, wealthy individuals from Harare and the nearby mining town of Bindura, 50 kilometers to the north, have set up mining operations in the area. Heavy excavation machinery has been brought in to quarry gravel and mine gold, and blasting has commenced. These burgeoning settlements and mining activities threaten the spiritual and environmental integrity of the landscape. As the traditional custodians of the land, the spirit medium and her aides approached the Zimbabwean government's Ministry of Mines, Environment and Lands, as well as the Ministry of Home Affairs.

Sketch of Mbuya Nehanda, a nationally recognized spirit who influenced Zimbabwe in the late fifteenth century. Drawing: M. I. Mashamaire.

To protect this important cultural landscape, the spirit medium and her aides, in collaboration with the organization National Museums and Monuments of Zimbabwe (NMMZ), initiated a humble, diplomatic dialogue with the settlers and miners in 2002. It was hoped this approach would encourage respect for the landscape and dissuade exploitation. These discussions were also intended to avoid a backlash from the settlers and miners, who might have felt they were being bullied. At the same time, it was recognized that the landscape and the spirit medium's homestead deserved a rightful place on the country's national heritage register and thus should gain legal protection. NMMZ can invoke official protection only if the landscape is clearly defined and declared a national monument; therefore, a delimitation exercise was needed to identify important sites and boundaries.

The delimitation project was organized into four parts. First, dialogue continued with the various stakeholders, including farmers, miners, settlers, and the spirit medium and her aides. It soon became apparent that this dialogue not only was an important entry into protecting the land but also

Illegal surface strip mining for gold and other minerals using heavy equipment and blasting has disrupted the natural landscape. Photo: © Geofree Chikwanda.

was helpful in identifying boundaries and features such as important hilltops, roads, and corrals. The spirit medium and her aides knew the area and its significant landmarks better than the surveyors, settlers, or miners did. During this dialogue, research was undertaken by a number of government departments to collect old maps that could serve as a starting point for fieldwork. Using these maps, survey data were collected in three separate visits over the course of one year. Finally, all information collected was processed to create a new set of maps, which became part of a legal document presented to the government calling for protection of the landscape.

Illegal settlements, often considered taboo, encroach upon the ancestral landscape. These settlements threaten the spiritual integrity of the cultural landscape. Photo: © Geofree Chikwanda.

Total Station

The main tools utilized for the field delimitation were a total station theodolite and a handheld global positioning system (GPS) receiver. A total station theodolite is a standard survey device that locates points by measuring distances as well as horizontal and vertical angles. It differs from a theodolite in that it measures not only angles but also distances and includes an onboard computer.

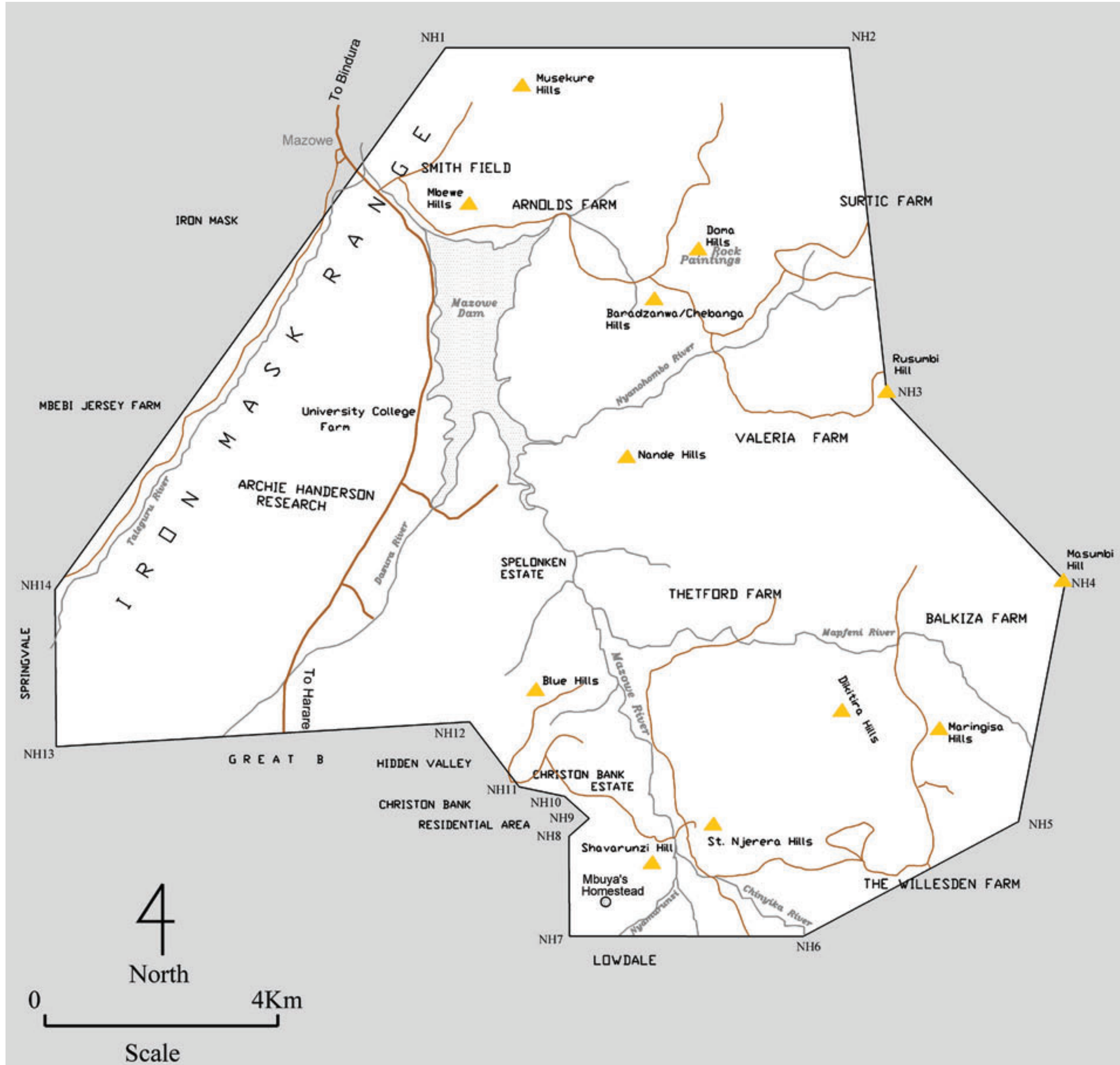
The total station theodolite used in this survey was a Topcon GTS200 series. Placed atop a tripod, it consists of a powerful telescope mounted on a base that rotates both horizontally and vertically. Features such as roads, buildings, and property boundaries are identified by looking through the telescope at a prism or reflector target on a pole held by another surveyor. These features can be as close as 2 meters or up to 5 kilometers away, depending on the telescope. When the surveyor focuses the telescope on the prism, the total station theodolite accurately records the horizontal and vertical angles and distance. Distance is measured with a feature known as electronic distance measurement (EDM). An infrared beam is projected from the total station theodolite, which "bounces" back to its source and, using a timing device, the distance is calculated. Many total station theodolites also have a mode known as reflectorless, meaning that within short distances of 100 meters or less, a prism or reflector is not needed. This allows the instrument to be operated by only one surveyor, which is useful when measuring points difficult to access, such as cliff faces or ridge beams. Trigonometric calculations are then performed by the onboard computer, combining the horizontal and vertical angles with the distance measurement to determine an XYZ coordinate, usually within a centimeter. By recording and then connecting many individual points, lines can be created that describe features such as walls, hills, or boundaries. To record all the features of a large area, the total station theodolite and tripod are moved to new locations, or setups, which are then combined to form a network called a traverse. Measurements taken from different station points along the traverse improve accuracy and allow the combination of all XYZ coordinates to form a complete survey.

The author using a total station theodolite. The total station and its onboard computer calculate the position of a point through trigonometry by recording the horizontal and vertical angles and distance. Photo: Rand Eppich.

The GPS receiver also calculates XYZ coordinates with trigonometry, but by receiving radio signals from orbiting satellites. Although it is not as accurate as a total station theodolite, it is much quicker and very useful in describing large features such as hilltops or rivers. The handheld GPS unit used in this survey was a Garmin 12 with an average accuracy of about 6 meters. Handheld units are generally inexpensive and easier to use but not as precise as professional units, many of which are equipped to receive ground-based radio signals. These signals can improve the accuracy of GPS units to a few centimeters by correcting for inaccuracies or radio signal loss from the satellites. The ground-based signal, called differential, is either sent from existing commercial radio station towers or navigational beacons, or transmitted from a station set up by the surveyors. Differential GPS units are now included in the newest models of total station theodolites to create a "complete" total station.

Field data were collected on three trips. On each trip, surveyors recorded more detailed information to add to the previous data. During these and all subsequent visits, the spirit medium was notified of the surveyors' presence and kept informed of all activities. On the first trip, two surveyors used only the handheld GPS unit with the existing maps (scales 1:5,000, 1:50,000, and 1:250,000). Throughout the initial reconnaissance, these maps were evaluated in consultation with aides to the spirit medium in order to identify the hills and other sites of cultural importance. The existing maps were found to be inaccurate, with many of the hills and landmarks misspelled or unidentified altogether. These sites, in addition to the residence of the current spirit medium, were visited and their coordinates recorded and marked on the maps. Fourteen survey markers (or boundary beacons) were erected at each corner point to delineate the extent of the proposed protected area.

Further field interviews with the aides were conducted during the second and third visits to locate additional areas. These features and the spirit medium's homestead were measured in more detail and with greater accuracy using a Topcon GTS200 total station theodolite. At each subsequent visit, corrections were made on the previous survey. Photographs of each area of interest were also taken throughout as part of the overall project.



Map of the proposed protected area of Shavarunzi, including boundaries, topographic features, settlements, and significant historical and cultural sites. Map: © Geofree Chikwanda.

An Answer

After field measurements were collected, the existing 1:250,000 base maps were scanned. The maps were then edited using AutoCAD 2000, a computer drafting program, to insert any missing features, correct misspellings, and add new measurements. Boundary points and proposed protection lines were also included. Once the first version of the maps was complete, it was reviewed by the surveyors and the spirit medium and her aides. Ethnographers and historians also reviewed the maps along with archival records, and compared this information with the oral evidence collected during the dialogue that had been initiated at the beginning of the project.

In 2005, the maps, oral evidence, and archival research helped NMMZ to craft a sound statement of significance for the proposed national monument. The inclusion of this landscape on the national monuments register is leading to the drafting of a management plan to address conservation challenges. In addition, it is crucial that the settlers and miners remain engaged and informed of the implications of these changes. Much work remains to be addressed, such as an assessment of the impact of new settlements spilling over from Harare, a systematic condition study of waterways, and an examination of the fauna and flora. Protecting this cultural landscape continues to be a large-scale and long-term task requiring an array of resources and the involvement of a variety of professionals and the local community. By defining its boundaries, however, the first step has been taken in protecting this cultural landscape and maintaining the connection between the people, history, and the land.

Geofree Chikwanda was a monuments surveyor for National Museums and Monuments of Zimbabwe, with more than ten years of survey experience using total station theodolites and GPS technology. He died in a tragic accident shortly after completing this work.

View of the endangered Shavarunzi landscape.
Photo: © Geofree Chikwanda.

Mapping Features

Jo Anne Van Tilburg, Cristián Arévalo Pakarati, and Alice Hom

Nearly nine hundred large stone statues, known as *moai,* dot the landscape of the eastern Pacific island of Rapa Nui (Easter Island). They were carved from basaltic lapilli tuff, a consolidated volcanic stone found on the island, primarily in a single crater known as Rano Raraku. The source for fully 95 percent of the known moai, Rano Raraku is a striking landmark partially filled with a marshy freshwater lake. Just over half of the statues carved in Rano Raraku were transported to every part of the 164-square-kilometer island, to be erected on ceremonial sites.

The tuff from which the statues were created is porous and susceptible to deterioration and weathering. That fragility, coupled with the fact that Rano Raraku is a major tourist destination, creates an urgent conservation imperative.

Given the size and steep terrain of the volcanic quarry and the large number of unfinished moai, how can a map be created that records both the location and features of these statues?

The crater of Rano Raraku, with its marshy lake in the background. Photo: Jo Anne Van Tilburg. © Jo Anne Van Tilburg/Easter Island Statue Project.

Rapa Nui

The Rano Raraku archaeological zone is just over 1 square kilometer, including the volcano and its immediately adjacent plain. The zone is located within Hotu Iti, the eastern and lower-ranked of two sociopolitical districts that emerged between 1000 and 1500. The tuff is arrayed in roughly horizontal bands and exposed in irregularly shaped flows (*papa*) on the north-facing upper side of the volcano's interior. The papa slopes 28 degrees in most places and is visually subdivided into two large and spatially discrete areas. Because they are different in elevation and tilt, these areas vary in stone quality, accessibility, and workability. When freshly quarried, the tuff is a distinctive yellow-orange (a color sought for its cultural associations with the chiefly class) but weathers to black.

In 1968, the initial phase of the first islandwide intensive archaeological site survey was begun under the auspices of Chilean governmental agencies. Large quantities of important data on prehistoric land use and subsistence patterns were collected. A more narrowly focused survey identifying and describing the moai was necessary, as these statues are key elements of the ritualized landscape and the focal points of social identity. In 1981, the moai inventory was organized in three phases. The statues contained in the surveyed quadrants of the island were inventoried first, followed by those in the nonsurveyed areas, and then those remaining in Rano Raraku. A detailed map of the Rano Raraku archaeological zone was published by the Universidad de Chile in 1981, but the interior quarries were not mapped. That task was undertaken in 2002 and is described here as the final stage of the inventory.

Moai, the stone statues of Rapa Nui. Photo: Jo Anne Van Tilburg © Jo Anne Van Tilburg/Easter Island Statue Project.

Quarry site showing several unfinished moai within the crater of Rano Raraku. Photo: Jo Anne Van Tilburg © Jo Anne Van Tilburg/Easter Island Statue Project.

Global Positioning System

Global Positioning System (GPS) was selected as the tool that most fulfilled the survey objective and allowed concordance with the 1981 map of the Rano Raraku environs. GPS is a navigation and mapping tool that employs special equipment to receive radio signals transmitted from a network of twenty-four satellites circling the Earth twice a day in precise orbits. It allows the rapid acquisition of detailed and comprehensive data with pinpoint accuracy. GPS is suitable for Rano Raraku's difficult terrain and requires minimal training. Importantly, the documentation team had access to GPS equipment and included a surveyor with experience and expertise.

Other survey tools were considered or tried during the planning stage. A total station was not available, nor did our team include a trained user for that equipment. Furthermore, the rugged, steep terrain and intrusive vegetation covering the statues eliminated the possibility of using a total station, because the line of sight would have been obstructed. Aerial photography to the required level of detail was either not available or insufficient. Traditional methods of sketching and hand measurements were routinely used at other statue sites but were not appropriate for efficient recording of such an extensive area.

Several satellites with known coordinates are orbiting the Earth at an altitude of 20,200 kilometers and are constantly emitting a unique radio frequency with different codes. Ground stations, strategically placed around the world, determine the location of the satellites. These ground stations also correct any distortion to the signal emitted by the satellite as it passes through the atmosphere. The GPS device is a radio receiver and minicomputer that can calculate the trigonometry required to determine its location relative to the satellites. These raw data are directly converted to latitudinal and longitudinal coordinates by the GPS unit.

Two categories of GPS radio receivers range in accuracy. For these two categories, accuracy can be improved to several centimeters with a differential signal, which is a ground-based radio transmitter. This base station transmits radio signals that supplement those from the satellites. Amateur or handheld GPS devices are not corrected by a ground-based station and range in accuracy between 5 and 15 meters. Professional or survey-grade GPS tools involve a ground-based signal to enhance accuracy to several centimeters. In addition, a professional GPS radio receiver has a larger antenna and is set on a 2.5-meter (adjustable) pole to increase the reception. The whole system, consisting of the antenna, pole, and radio receiver, is called a rover. The GPS rover unit receives signals from the satellites and base station.

Sophisticated GPS models, including the Promark 2 and Trimble systems, were used for data collection. These survey-grade models are light and user friendly, have much greater accuracy than handheld units to capture key features of the statues, and are more advanced in that they feature a built-in screen allowing the operator to communicate efficiently with the rover.

A team of seven carried out the survey and included an archaeologist, a surveyor, an artist, a database manager, and several field assistants. Data were gathered in the field over a period of three weeks and then processed in the lab over a two-month period. Minimal training was required to use the GPS unit; however, expertise in field survey methods and a comprehensive database management strategy were necessary.

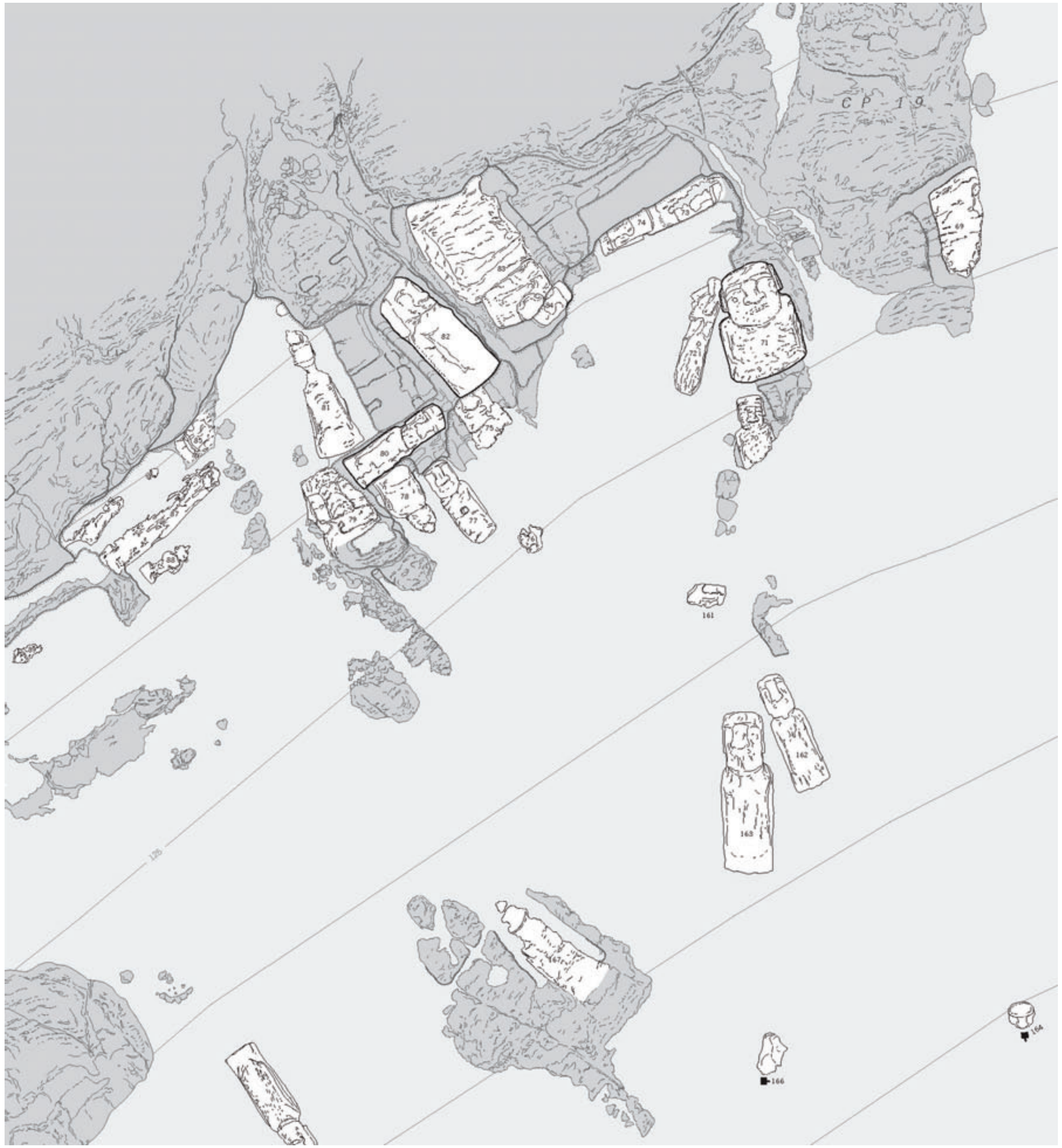
Fieldwork started with a reconnaissance of the statues and the site. The survey was established on the geodetic station known as Easter Island Laser Station – JPL 4008-S. This survey monument, created in 1992, is located 10 kilometers from the main base station and control point network in Rano Raraku. The team archaeologist located the statues and key features; the team artist, who had a trained eye in recognizing features of the statues, sketched the moai; and the team surveyor gathered GPS points.

Cristián Arévalo Pakarati (*left*) and surveyor Matt Bates collecting data using a GPS rover unit. Photo: Jo Anne Van Tilburg © Jo Anne Van Tilburg/Easter Island Statue Project.

The receiver used was a single-frequency system that required no cables and operated on standard batteries. This system is expandable, adaptable, light, and mobile and can achieve centimeter-level accuracy. In the Stop/Go surveying procedure that was used, one of two receivers was stationary and the other–the rover–was mounted on a survey pole. When the rover was held in front of the stationary receiver, contact was established via an infrared port and the units were synchronized.

The rover survey pole was mounted at precise points outlining statues, statue design characteristics, and quarrying or other archaeological features. The point identifications were entered into a handheld data collector by the surveyor and precisely recorded on a detailed sketch map. If the steeper walls of the volcano interfered with satellite transmission, the surveyor had to descend the slope to the control point and re-initialize. About three hundred points per day were collected.

Points were also taken on statues lying on slopes and free of the quarries. Statues standing upright and embedded in the ground lean at various angles from the vertical. Points were taken equidistant in front and behind each of these statues, giving the facing direction as well as the XYZ location. All data were downloaded to a laptop via the infrared connection and the receiver software. GPS points were imported to AutoCAD for manipulation and plotting. The survey was checked on site during data capture and reviewed every night. The data were backed up, archived on the island, and carried back to Los Angeles.



A portion of the finished map, generated from GPS data, showing the location and features of the unfinished moai within the quarry. Diagram: Alice Hom © Jo Anne Van Tilburg/Easter Island Statue Project.

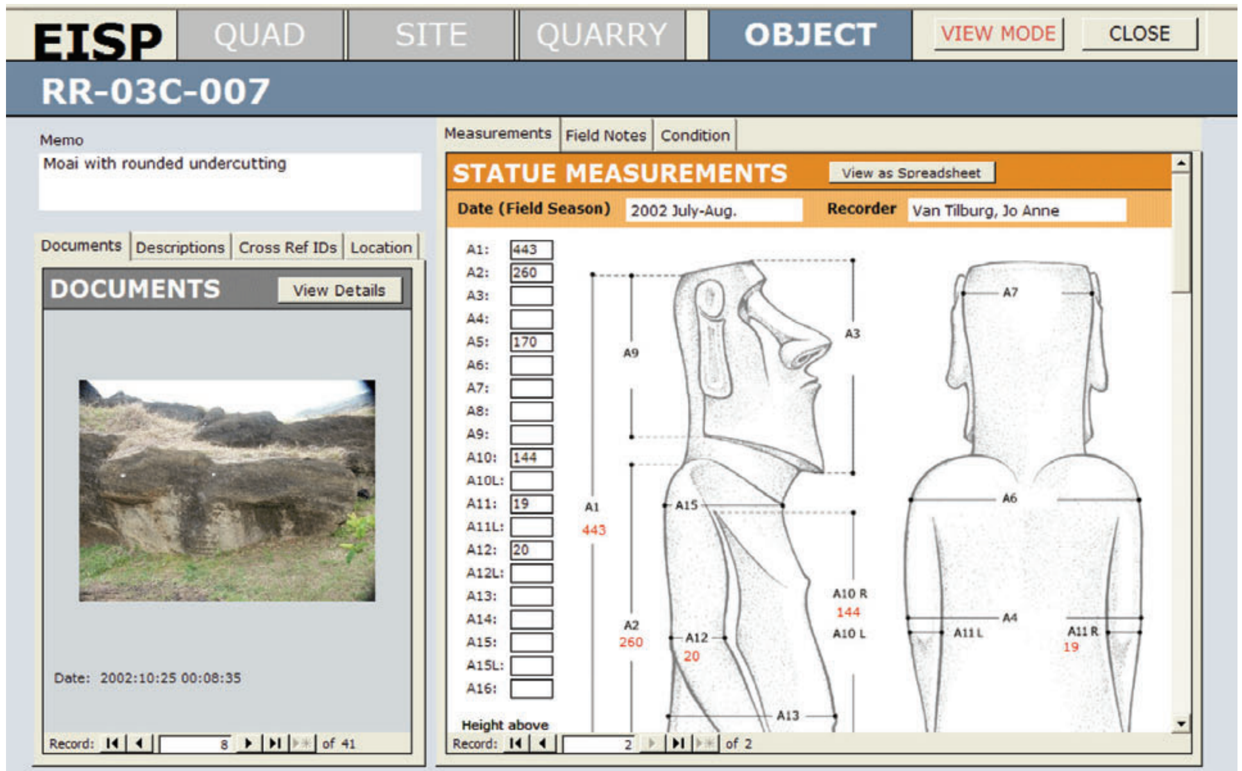
An Answer

Some difficulties were encountered during the survey process, attributed mainly to the difficult access of the rough terrain but also to some hardware failures. The receiver on the first GPS unit frequently dropped the signal and some survey points were lost. Also, data storage and output became increasingly problematic as the amount of information increased. GPS was successful in describing exposed and partially exposed features and in capturing size, proportion, and descriptive details of moai shape. GPS was also extremely efficient in covering a large landscape with a small team and limited time on site.

Upon the team's return from the field, the AutoCAD files were imported into Adobe Illustrator, which allowed for the best line quality in the final version. Work was based on the field sketches that had been scaled and morphed to fit over the survey points. The lines were redrafted with adjusted line weights to create figurative and artistic renderings of the moai rather than schematics. This supported and projected the reality of the quarry as a place not only where the statues were made but also where they were conceptualized as aesthetic objects. The map was reviewed in various draft stages during several field checks and informally by cartographers at UCLA and the National Geographic Society.

The innovative, localized, and visualized topographic and archaeological map of the interior of Rano Raraku will serve as the organizing and presentation tool for the project's massive database. This comprehensive, interactive, and searchable statue inventory and interfacing image catalogue contains more than twenty thousand images and the following categories of information on every

Screenshot of the EISP database, displaying a typical entry.
© Jo Anne Van Tilburg/Easter Island Statue Project.



statue: GPS map locators, site and statue-type definitions, measurements, field notes, stone surface condition reports, cross-reference identifiers, archived historical and ethnographic data, and survey and excavation histories.

Original records are preserved in the Easter Island Statue Project (EISP) archive, with full database working copies at UCLA and on Easter Island. Records are updated regularly. The full database ultimately will be disseminated as a controlled-access Internet feature, available to Chilean statutory authorities, professionals, and the Rapa Nui public. The EISP database is an analytical tool with significant research value. It allows visualization of historical and ecological linkages, supports the analysis of statue-type data in the context of social theory and the semiotics of spatial organization, and examines the statue corpus as a component of ecological, political, and esoteric systems.

Conservation observations of stone color, surface condition, and other variables were collected on all statues documented from 1981 to 2000. In 2002, the data collection categories were evaluated, updated, and consolidated. Initial analysis suggests an alarming rate of deterioration: every statue in Rano Raraku interior is in poor or extremely poor condition, with near-complete erosion and decomposition of stone surface and structural problems. The map, with its mass of linked and illustrative data, will provide a permanent record, enhance understanding of the Rapa Nui cultural heritage, and allow informed management, maintenance, and conservation efforts.

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A Record for Posterity

Alonzo C. Addison

The world's cultural heritage is at risk—from climate change, natural disasters, inadequate conservation, tourism, armed conflicts, and simple neglect. On the arid coastal plain of Peru, the Incan earthen site of Tambo Colorado is facing such threats. The incremental loss of this fragile place is appalling, but worse perhaps is the loss of knowledge about the site and the ancient culture that built it. This is especially disturbing given that we have more tools and methods available today than ever before to record the physical characteristics of a site.

How can the site of Tambo Colorado be fully documented in order to safeguard the knowledge it contains for future generations?

A view of the earthen structures at Tambo Colorado, Peru.
Photo: © J. Paul Getty Trust.

Tambo Colorado, Peru

Situated between Lima and Nazca on Peru's hot, dry south-central coast, the richly painted fifteenth-century earthen adobe and stone ruins at Tambo Colorado are a fascinating glimpse back in time to the days of the Incan Empire. Thirty-five kilometers inland at the base of the Andes, located at the strategic entrance to the Pisco Valley, the site straddles the old Incan road to the highlands of Cuzco. Named *colorado* for its red painted walls, this waystation, or *tambo,* is thought to have been an Incan administrative center built for the integration of the conquered peoples of Ica and Chincha into the expanding empire. Adorned with archetypal trapezoidal doors and niches and featuring some of the original painted plaster, the site is among the best-preserved examples of Incan adobe architecture. Surrounding a large open plaza, the complex features a maze of small rooms and elements of both classic Incan imperial and local Chincha style, as well as extensive pre- and post-Incan vestiges.

Although known to the Spanish conquistadores (who, along with more recent generations, left their marks in graffiti), documentation did not begin until the turn of the twentieth century, when the site was first photographed by the American (Swiss-born) anthropologist and historian Adolph Bandelier. In 1901, the German archaeologist Max Uhle produced maps and took numerous photographs and extensive notes. Uhle's records reveal the sad toll that windborne sand, intermittent rain, vandalism, looting, roadwork, and cattle ranching have taken. Despite deteriorating conditions, a majority of the adobe walls in the prominent structure known as the Northern Palace are still standing, and a surprising amount of paintwork is still visible, both in niches and as large horizontal bands of alternating red, yellow, and white on the outer walls.

Outer wall of the Northern Palace, showing remnants of the original plaster and paint. Photo: © Alonzo Addison.

Example of structural damage to the earthen adobe walls of the Tambo complex. Photo: © Alonzo Addison.

In 2001 (the centenary of Uhle's visit), Dr. Craig Morris of New York City's American Museum of Natural History, Professor Jean-Pierre Protzen of the University of California at Berkeley, and the author launched a research effort to develop an integrated digital record of the site and thoroughly document its condition before it suffered further damage. Over the course of four summers, Professor Julian Idilio Santillana of Peru's Pontificia Universidad Católica, Dr. Maurizio Forte of Italy's Istituto per le Tecnologie Applicate ai Beni Culturali, and a number of graduate students from these schools and institutions worked with UC Berkeley's Center for Design Visualization and Archaeological Research Facility to create an extensive digital record of the main complex and outlying buildings and landscape.

Tambo is a complex site. Ranging across an area roughly 13 square kilometers, it features everything from small artifacts recovered in excavations to hillside burials and large storage sites, as well as painted adobe and stone walls in the main compound. No single technology can suitably record this diversity of materials and range of scale. With the wide variety of tools and techniques available today to capture the geometry and dimensional characteristics of built heritage, the challenge was to select the most appropriate technologies and integrate the results into a complete record for posterity.

Laser Scanning

Given the site's architectural scale and the desire for a detailed dimensional record of the eroding adobe walls, laser scanning was selected as the primary tool for its ability to capture irregular surfaces. Having evolved from developments in measurement devices for mechanical engineering and manufacturing, laser scanners have seen growing acceptance in the past few years for recording archaeological sites. Unlike a surveying instrument, which captures single important points such as the corners of walls, a laser scanner can capture large irregular and eroded surfaces. For architectural-scale built heritage, the speed, accuracy, and "noncontact" characteristics of laser scanning offer new possibilities for acquiring data of 3-D objects.

Three-dimensional laser scanning technologies are generally based on one of three methods: (1) time of flight, a technique by which a laser pulse is emitted from the instrument and the time of (light) travel is measured, from which distance to the object can be determined (since the speed of light is a known constant); (2) phase comparison, in which the instrument emits light with a known frequency and phase, and distance to the object can be determined by comparing the emitted phases to the returned phases; and (3) triangulation, in which an emitter and a receiver, separated by a known distance, record the angle of the reflected laser pulse to determine distance (using the Pythagorean theorem). With these technologies, XYZ coordinates are recorded as millions of individual points. Close together, these points form a dense "point cloud" that represents an object. These individual points must be connected together ("meshed") to create a 3-D model.

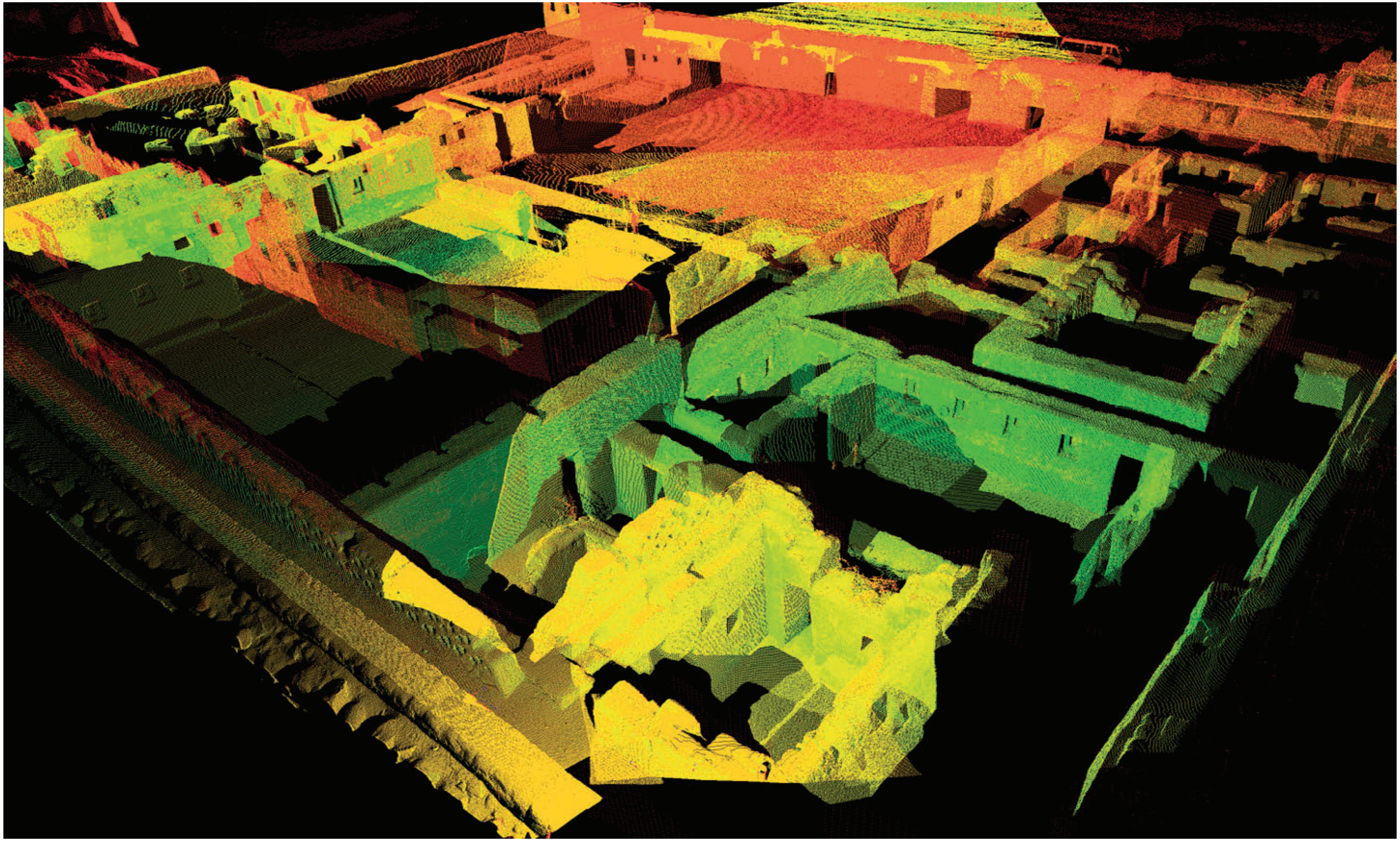
These scanning technologies are used for different purposes based on the distance from the sensor to the object and the speed and level of precision required. Triangulation scanners are best for shorter ranges and for greater precision and detail. Phase comparison is good for short or long range where speed is needed, but at the expense of some accuracy. Time-of-flight technology, also known as light detection and ranging (LIDAR), is used for larger sites and buildings where survey accuracy is needed. Typical distances for long-range systems vary from a minimum of 1 to 2 meters to a maximum of hundreds of meters. This range and resolution makes time-of-flight technology perfect for the recording of architectural- or archaeological-scale features and objects.

There are several important considerations when utilizing laser scanners in built heritage. The choice of device will be guided by type and size of site, required accuracy, budget (costs range from thousands to hundreds of thousands in U.S. dollars), and the goals of the project. Not all laser scanning systems are field operable: battery life, operability in bright sunlight (which can wash out the beam to the point where the return pulse cannot be measured), ruggedness, size, and weight should be considered when selecting a system.

For this project, a Cyrax 2400/2500 (which became the Leica HDS 2500), a long-range (1 to 100 meters) time-of-flight system, was chosen. It was field operable (powered by eight-hour rechargeable battery packs), laptop controlled, and ruggedized, a crucial consideration given the pervasive sand and glare at the site.

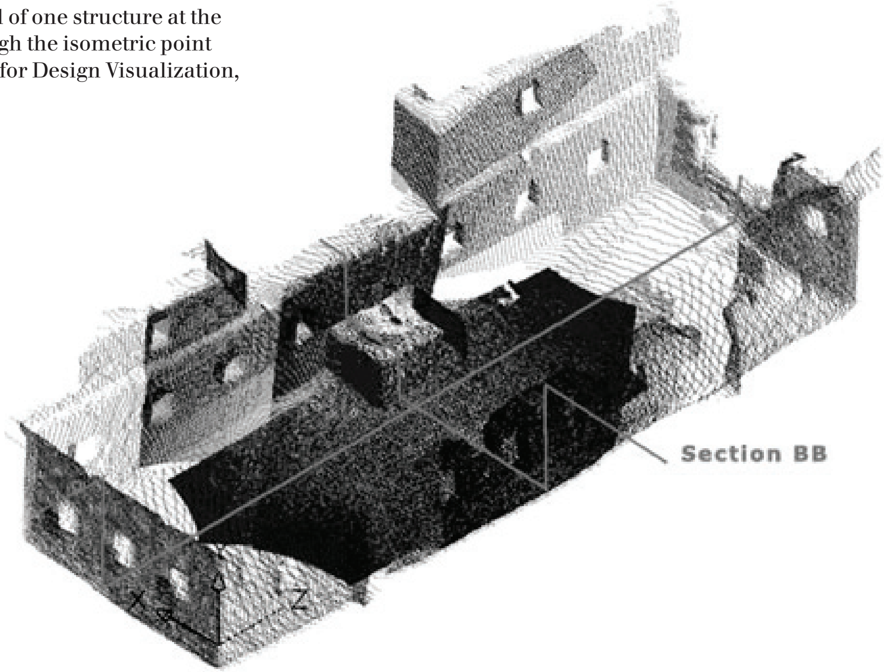
Although laser scanning was chosen as the primary documentation method, given the variety of information needed, a range of other technologies was also used to create a thorough and complete record. Differential Global Positioning System (DGPS) was used with aerial and satellite photography to spatially locate burials and place the laser surveys in context. Some additional close-range overhead imagery was gathered with aerial kite photography. Digital photography with a color chart was utilized to capture Tambo Colorado's vivid paint remnants and to provide "textures" for the laser scans. Panoramic lenses were used to capture QuickTime VR 360-degree images for context visualization. Time-lapse photography and video were also used to record ongoing archaeological excavations. Survey instruments (e.g., a total station theodolite) were used to measure control targets and assemble data from the large number of scans from different positions. Handheld and laptop computers and a custom database were used for data management, and a close-range triangulation laser scanner was utilized for fine details and to experiment with making a layer-by-layer 3-D volumetric record of an ongoing archaeological excavation.

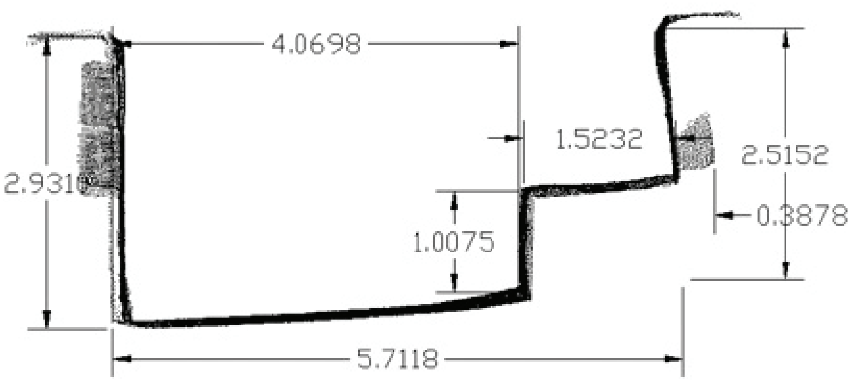
The documentation team at Tambo Colorado preparing to use the Cyrax 2400/2500 (which became the Leica HDS 2500) long-range laser scanner. Photo: © Alonzo Addison.



The point cloud generated by laser scanning technology, representing the Tambo site. Image: © Courtesy Center for Design Visualization, UC Berkeley.

Top: Isolated isometric point cloud of one structure at the site. *Bottom:* A cross section through the isometric point cloud. Images: © Courtesy Center for Design Visualization, UC Berkeley.





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An Answer

Laser scanning provided an ideal solution to record the complex and irregular surface geometry of the remaining adobe walls of this site and its smaller architectural details. As part of an integrated digital tool kit, the technology formed the foundation for a 3-D information archive of current conditions, allowing measurements to be extracted, reconstructions to be visualized, and field notes and photographs to be integrated by location.

Although an important tool in the conservator's arsenal, laser scanning is only one piece of a larger puzzle in base recording and is well suited to being part of a suite of digital technologies. In any project like this one, where data may be in proprietary formats or on limited life-span digital media, it is important to ensure the record will survive. A simple data preservation solution is to print out all information on archival paper and submit it to a library or international archive. A printed record can always be redigitized if the digital records become unusable through equipment or media failure or obsolescence.

Alonzo C. Addison serves as special adviser to the World Heritage Centre, UNESCO, on issues of applied technology. He was involved in developing strategies for one of the first commercially viable laser scanners for Cyra Technologies and its 3-D monument-scale LIDAR scanner in the 1990s. A cofounder of the Virtual Heritage Network, his work ranges from historical visualization to design simulation, information architecture, and collaborative networks. His interests lie in the nexus of digital technology, world heritage conservation, and design, and he has written extensively on these subjects.

CONDITION ASSESSMENT: WORKING WITH INFORMATION

Recording Streetscapes

Salim Elwazani and José Luis Lerma

The Qayseriyyah Souq (market) is a historic ensemble of urban structures in Muharraq, the original capital city of Bahrain. Besides the evident buildings and open spaces of the souq, the ensemble is in an area long considered a cradle of societal transformation and political events in Bahrain's history. Exposed to the elements, neglect, and inappropriate building additions and development, the souq has deteriorated. In 2005, a preliminary study was conducted to assess the souq in order to address these issues.

Under stringent time and financial constraints, how can the souq be recorded quickly to provide information to aid in its revival and conservation?

The corner of Sheikh Hamad Avenue and Tujjar Street, Qayseriyyah Souq, in the heart of Muharraq, Bahrain. The souq suffers from exposure to the natural elements, neglect, and inappropriate development. Photo: © Salim Elwazani and José Luis Lerma.

Qayseriyyah Souq, Bahrain

The Qayseriyyah Souq sits in the heart of Muharraq, the sprawling commercial center of the old capital. History suggests that the construction of Muharraq was at the behest of Sheikh Ahmed Bin Mohammed Al-Khalifa, also known as Ahmed Al Fateh (the Conqueror), in 1810. Later, tribal groups, some formerly nomadic, emigrated from Arabia under the leadership of the Khalifa dynasty and settled in this new place. In a societal sense, the souq is a testimony to this transformation of the inhabitants' way of life and a direct response to their commercial needs. By 1889, urbanization had reached an advanced stage and many of the physical characteristics of the souq seen today had been established.

Roughly rectangular in shape and stretching in a north–south direction, the souq is bounded by paths of contrasting urban character. On the north, the busy, dominant city artery known as Sheikh Hamad Avenue contrasts with a modest pedestrian alley on the south. Traffic-burdened and commercially bustling Tujjar Street, on the west, contrasts with the spacious, lightly trafficked Boomaher Avenue on the east. About 80 meters in length and 30 meters in width, the souq is composed of rather simple one- and two-story structures. The market features a covered central alley running north–south along the ground plan that, with another auxiliary alley, bisects the souq into four parts. This central alley and, to a lesser extent, the auxiliary alley provide access to the inward-facing shops, while the bounding avenues provide access to the outward-facing businesses and upper levels.

The buildings are made primarily of rubble, gravel, and gypsum cement. Wooden members, reed rods, and palm-leaf weaves were used for the roof structures and ceilings. The conditions of the structures within the souq vary markedly, but the buildings are generally in disrepair. The souq suffers from exposure to the natural elements and neglect, and from inappropriate development that affects the integrity of the architectural character. Three-fifths of the buildings have retained their original character and are more than fifty years old, with many estimated to be more than one hundred years old. Vestiges of these important older buildings now predominate only in the poorest and most dilapidated sections of the market. The remaining two-fifths of the buildings have been erected within the past fifty years. It is clear that this newer, historically incongruent class of buildings, particularly those erected in the past decade, are slowly replacing the original structures. A sizable vacant lot within the market clearly shows traces of an original structure that probably was demolished to make way for new construction.

Not only are the still-visible original buildings at risk, but archaeological vestiges also are said to be buried within the souq, including remnants of a historic city wall. Ahmed Al Fateh had decreed that walls be built with three gates. One hypothesis suggests that one of these walls was subsequently adapted as a foundation for buildings at the eastern edge of the souq. A city gate also may have been integrated into the buildings at the northeastern corner of the market.

Map of the Qayseriyyah Souq, showing major avenue boundaries, central and auxiliary alleys, and building components of heritage value. Not only are the original visible buildings at risk, but archaeological vestiges are said to be buried within the souq. Map: Steven Rampton.

Rectified Photography

Realizing the risks to the souq and its importance, the Research and Studies Section of Bahrain's Ministry of Municipalities and Agriculture Affairs conducted a preliminary study for conservation and development. The ministry then commissioned a consultant as project manager to prepare a detailed, implementation-oriented redesign of the souq, taking into consideration conservation issues and urban integration of the historic fabric with the modern surrounding city. This project was one component of a larger, two-phase pilot project, Capacity Building for Enhancement of Urban Governance, funded by the United Nations Development Programme and implemented in collaboration with Bahrain's Ministry of Municipalities and Agriculture Affairs.

Although site plans of the market existed, the project manager lacked information on individual building facades and the extended streetscapes. In order to understand and propose strategies for this complex marketplace, it was necessary to obtain additional information. Facing limited time and financial resources, as this was only a preliminary study, the project manager and a small team composed of the authors and four junior architects were tasked with this work.

The team chose rectified photography for the Qayseriyyah Souq project because it is inexpensive and quick to carry out, requires minimal training, and does not require high-tech equipment. In addition, the resulting images of each building facade could be later converted into measured drawings. Rectified photography is based on the concept of bringing the surface of an object, say a building facade, and the plane of the image (photograph) into parallel. Rectification removes

Unrectified photograph of a storefront, taken at an angle. Photo: © Salim Elwazani and José Luis Lerma.

Rectified photograph of the same storefront. Rectification removes perspective, angle, and camera lens distortion to create an image that is on one plane and measurable. Photo: © Salim Elwazani and José Luis Lerma.

Mosaic of Souq West elevation on Tujjar Street.
Photos: © Salim Elwazani and José Luis Lerma.

Mosaic of Souq North elevation on Sheikh Hamad Avenue.
Photos: © Salim Elwazani and José Luis Lerma.

perspective, angle, and camera lens distortion, and creates a measurable image that is on the same plane as the building. This method is the most appropriate when the building surface is geometrically flat. Buildings having multiple flat surfaces positioned in different planes can also be rectified: each plane is separately rectified, then brought into one reference plane. Rectified imagery worked particularly well in the souq, as the building facades are relatively flat and images had to be taken at extreme angles with a wide-angle lens in the narrow streets and alleys.

Image rectification can be carried out with or without measurement control points on the object. Control points can be measured using a tape measure or with survey instruments (total station). These measured distances correct the angle or tilt in the original image while retaining the correct proportions of the building. Without these control points, it is still possible to rectify an image by visually approximating its shape and proportions; however, accuracy is compromised.

Rectified images have several advantages in the field of architecture, urban planning, and conservation. Not only do they provide measurable images of flat surfaces that show surface material conditions, but they also can be stitched together to form an entire facade elevation of a large building or several adjacent buildings. Other recording tools, such as a total station or stereophotogrammetry, can provide some of these results; however, they are time consuming and somewhat expensive, and require specialized training.

Constrained by the limited time available to deliver a final product (only twelve days total, including training for the junior architects), the project manager was asked to prioritize the areas needed for rectified photography. In addition to the immediate area of the souq, he chose several adjacent street scenes for their value and impact on the overall study, resulting in an even tighter time frame to accomplish the work. The team decided to divide the work into three parts: images to be rectified, images that could be rectified in the future, and pictorial photographs not to be rectified but to provide context.

The project began with a day of touring and exploring the souq with the directors of the participating organizations and the project manager. For five days, images were captured and building measurements taken. Then, in the time remaining, images were rectified. The team prepared a final report and collaborated with the project manager on his preliminary study. The junior architects received training throughout the entire process of acquiring and processing the data.

An Answer

Images were captured using a Canon EOS D60 digital camera with a resolution of 6.3 megapixels and a 15mm Sigma wide-angle lens mounted on a small tripod. Image capture was initiated from across the street at one end of the building row, typically coinciding with a street corner. As the photographer moved toward the other end of the building row, a series of digital images was captured in such a way as to maintain an overlap of 20 to 30 percent between images of adjacent buildings. The team also emphasized the continuity of the linear "scene," including empty lots, alleys, and objects between buildings. This type of information was as important as the buildings in order to assess the souq and carry out the preliminary study in an urban environment.

Uniform lighting conditions were taken into account, as well as precautions such as avoiding photography of moving objects in front of the facades. Multiple frames of the same areas were taken in order to ensure complete coverage and to capture enough detail. Care was also taken to keep the camera level, and attempts were made to maintain a uniform distance perpendicular to the buildings. These measures later minimized corrections to the rectification process. While collecting the images, the team also took several horizontal and vertical measurements of the buildings by hand, noting significant features to be used as control points.

In this case, the camera's automatic image numbering system was used as the identifier for each image, correlated by hand on a map of the souq. This linkage enabled the retrieval, selection, arrangement, and measurement of the series of sequential images. Rectification of selected images was carried out in a repetitive, structured procedure using Adobe Photoshop CS2 (Creative Suite). The procedure began by rectifying a series of adjacent images of each separate building facade, using the souq map and the measurements taken in the field. Using the overlap between images, individual rectified images were then fused into a combined image called a mosaic. This process produced a new, expanded mosaic of the entire streetscape. Color processing was necessary in order to maintain some homogeneity throughout the composition. Panorama Tools, a free plug-in added to Adobe Photoshop CS2, was also used to correct lens distortion. Adobe Photoshop CS2 software has a special filter called Lens Correction that performs the same correction function.

The team strove to establish a rate of progress that would help the project manager realistically estimate the amount of work that could be accomplished in a given time. The documentation process resulted in more than two hundred images, of which twenty-six were rectified and combined to produce mosaic streetscapes of the souq. It also resulted in some general context images, but more important, it yielded more than one hundred fifty images that could be rectified in the future, an important consideration given the limited time available for the preliminary study. The pace of the work was rapid, as it was unclear from the outset how fast the photography and rectification would proceed.

Although more work is required, rectified photography provided the project manager, the city, and the ministry with another dimension to the Qayseriyyah Souq beyond the site plan and single unrectified images. It allowed the streetscapes to be viewed in their entirety in a measurable, organized way to improve conservation planning and design.

The parties involved also sensed the potential value of continuing the work beyond the souq and enriching their presentation and reports.

The photo rectification work also fulfilled the needs of the larger project with future capacity building through the training of the junior architects. While the training component was intense and time consuming, and distracted somewhat from the primary goal of recording the facades of the souq, it was a valuable exercise that holds promise for future projects. The junior architects formed the nucleus for continuing the work and creating additional streetscapes of the souq as well as other sections of the city. To reap additional benefits, another training program should be initiated to include other tools beyond rectified photography.

The digital rectified images and combined mosaic images also provide a lasting, measurable record of the Qayseriyyah Souq as rapid changes take place even today.

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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.

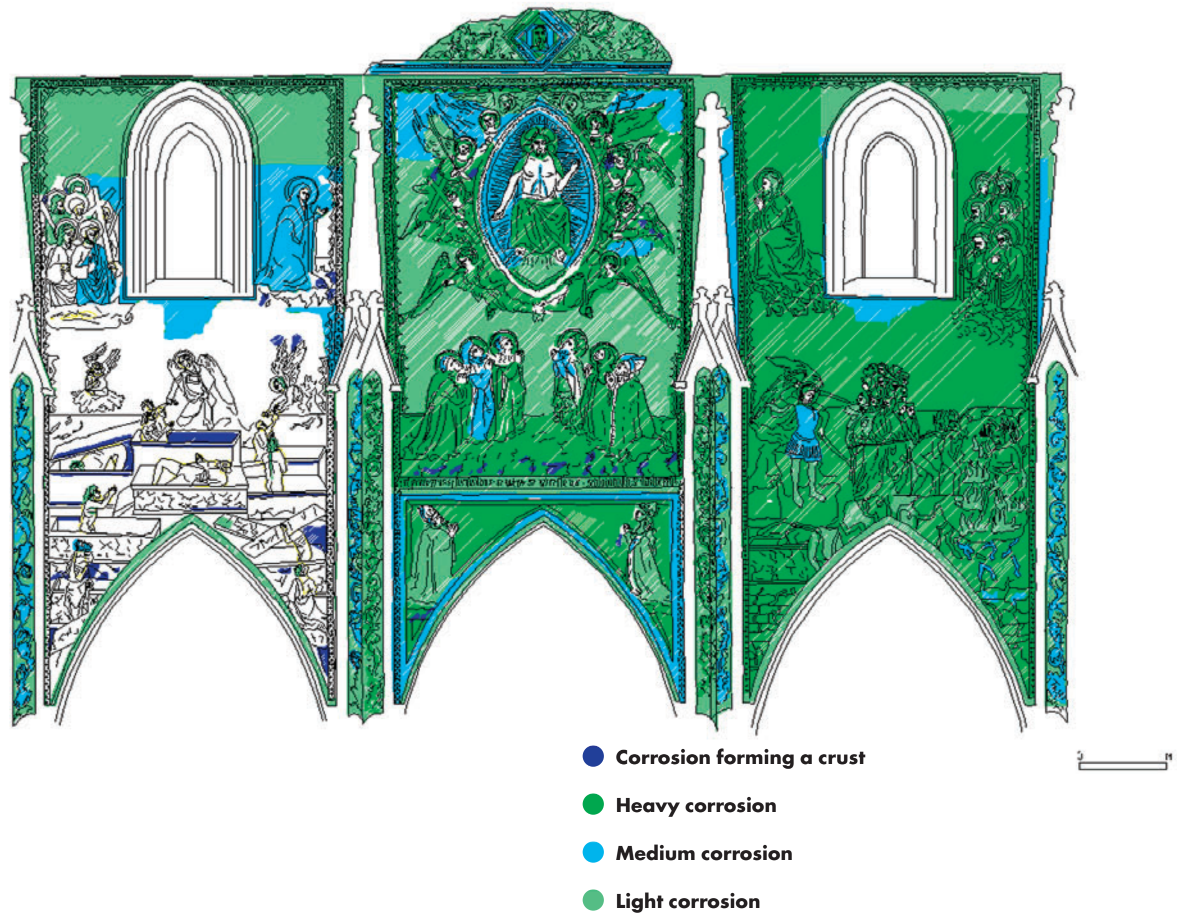
Conservators at St. Vitus Cathedral inspecting the mosaic, recording conditions on transparencies overlaid on rectified photographs of the facade. Photo: Dusan Stulik.

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.

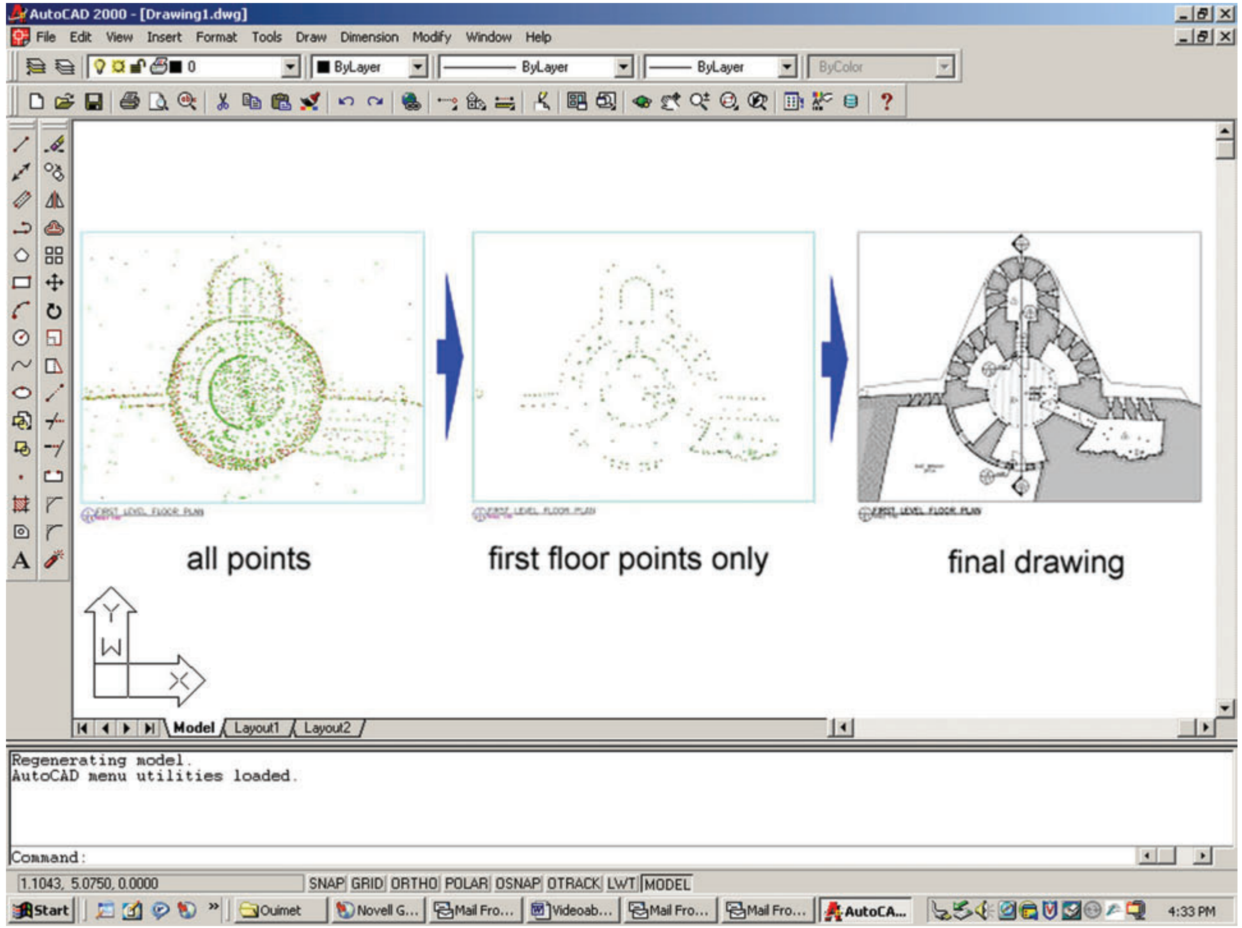
Fort Henry is strategically located on the trading routes between Montreal, Ottawa, and all points west. In the background, the Rideau Canal leads to Ottawa; in the foreground, the St. Lawrence River leads to Montreal. Photo: © Fort Henry National Historic Site of Canada–Archives.

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



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.

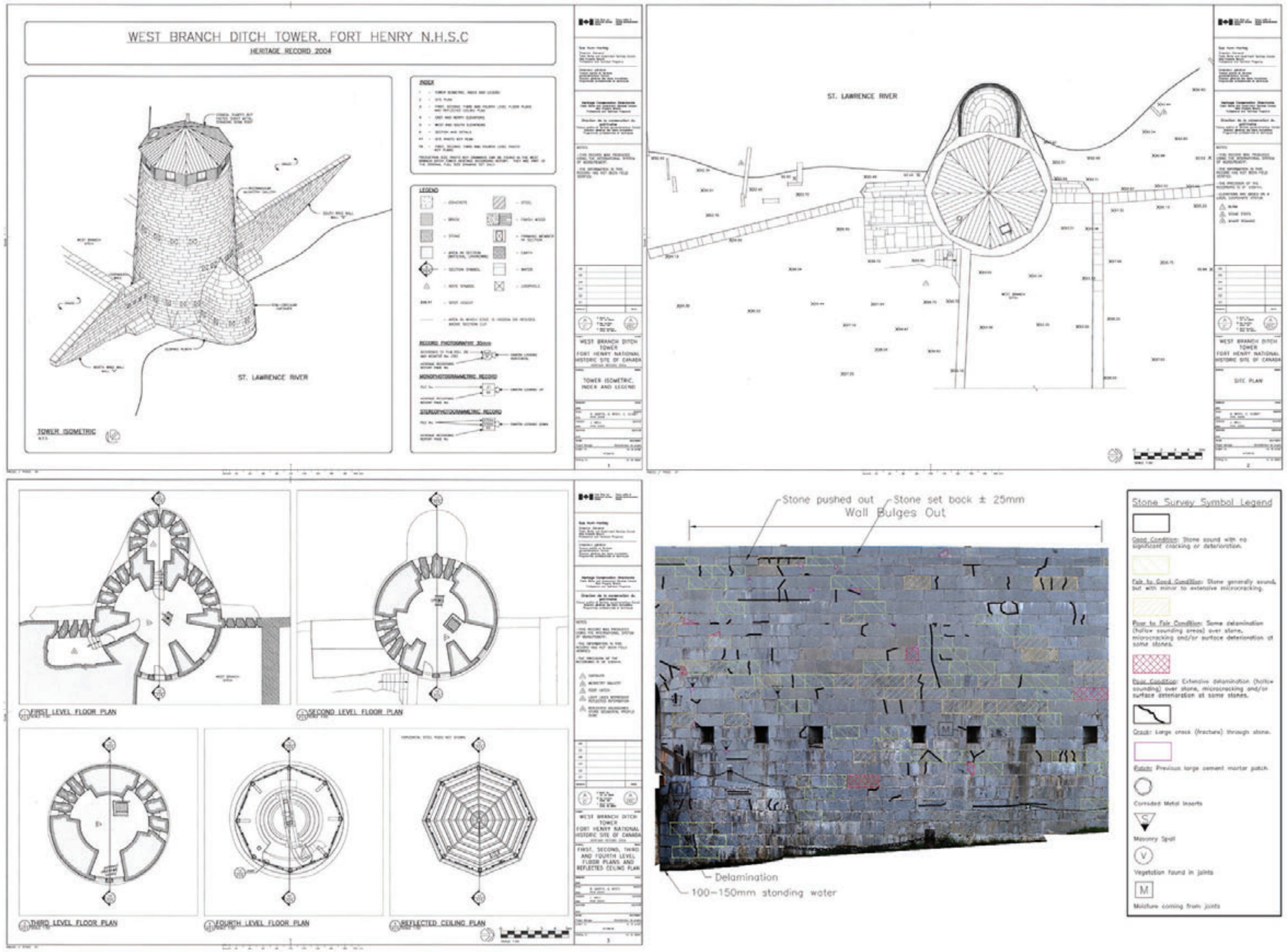
Survey with the total station theodolite was also the primary method for collecting the measurements of the curved exterior surfaces of the branch ditch towers. Measurements from each of the four floors, window openings, roof outlines, and other features were placed onto separate layers. This gave the 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.

Inspecting Sites

Kevin L. Jones

Rising above the lush landscape of New Zealand, *pā* are Maori fortified settlements built on natural earth formations. Beginning in the mid-sixteenth century, they were built with soil ramparts, terraces, and agricultural areas and usually surrounded by deep defensive ditches. Important archaeological sites, pā embody the *mana,* or spirit, of ancestral Maori chiefs. Over the past century, urban development, farming, overgrazing, and erosion have endangered many of these sites.

With more than 6,600 of these fragile pā located in mostly remote areas, how can their condition be recorded, monitored, and assessed, and conservation interventions planned?

This illustrated example was completed with the assistance of Stephen Lamb, senior resource planner, Environment Bay of Plenty, New Zealand. The Papamoa Hills Regional Park Management Plan (November 2006) was an invaluable resource for understanding the history, issues, and conservation approach of Te Uepu and Environment Bay of Plenty.

The terraces and transverse defensive ditch of the southern platform of Karangaumu pā (pre-European Maori fortification), Papamoa Hills, near Tauranga, North Island, New Zealand. Photo: © Environment Bay of Plenty, New Zealand.

Karangaumu pā, New Zealand

The Papamoa Hills at the Bay of Plenty, near Tauranga on the North Island of New Zealand, are historically and culturally significant, as they are believed to be one of the first landing sites of the Maori in the late 1300s. Nine fortified pā were built at Karangaumu, on top of these hills. These pā were of strategic importance to the Maori because of their commanding views of the ocean, islands, and low-lying coastal plains. Built primarily as a stronghold against attack, they were also used as living and storage places, as well as centers for learning, crafts, and horticulture. The pā on these hills are unique in that there are few examples of Maori sites so numerous and well preserved, and in so small an area.

However, the hills are under threat from surrounding development, nonnative plant species, and growing tourism. The soft soil is also vulnerable to erosion from water, wind, and grazing. Livestock grazing maintains the open grassland environment and prevents nonnative trees from damaging the site, but at the same time it causes erosion from the concentration of sheep tracks near gates, watering troughs, and roads. Although existing farm roads are a common cause of damage to pā, they do provide a route through steep ground and restrict livestock to places already damaged.

It is not known how the Papamoa Hills passed from Maori ownership to the British Crown. However, in the 1890s, John McNaughton, an early settler, purchased the hills that include most of the site of the present-day park. Used for more than a hundred years as a sheep and cattle ranch, the McNaughton family fortunately recognized the historical and cultural value of the land and eventually endeavored to protect it.

In 2003, the family sold the land to three local authorities (two local councils and one regional council). The land is now owned solely by the regional council, Environment Bay of Plenty, and is managed as a regional park on behalf of the Bay of Plenty community. Joint management with local iwi/hapu peoples ensures that the cultural aspects of land use are incorporated into operational decisions. Papamoa Hills Regional Park is known also as Te Rae o Papamoa, the name for one of the prominent pā. The name means "the forehead of Papamoa"; Papamoa was an ancestor of the first Maori to settle in the area.

To provide guidance in how this important site should be used, both a management plan and a heritage conservation plan were needed. The management plan focuses on how the land is used, while the heritage conservation plan specifically addresses how the heritage and archaeological features are to be protected. These plans were written in conjunction with Te Uepu, a caucus of the four iwi/hapu groups created to advise on Maori culture and tradition. A record of the 135-hectare site was required to support the plan and to fully understand the physical characteristics and factors affecting its condition. This record was also needed for monitoring, the process of recording conditions at intervals to determine the nature and rate of change and whether intervention is needed. In addition, New Zealand law, through the Resource Management Act, requires local and regional governments to monitor environmental factors.

Prominent lateral defensive ditch and terracing on Karangaumu pā. Photo: Kevin L. Jones © New Zealand Department of Conservation.

Aerial Photography

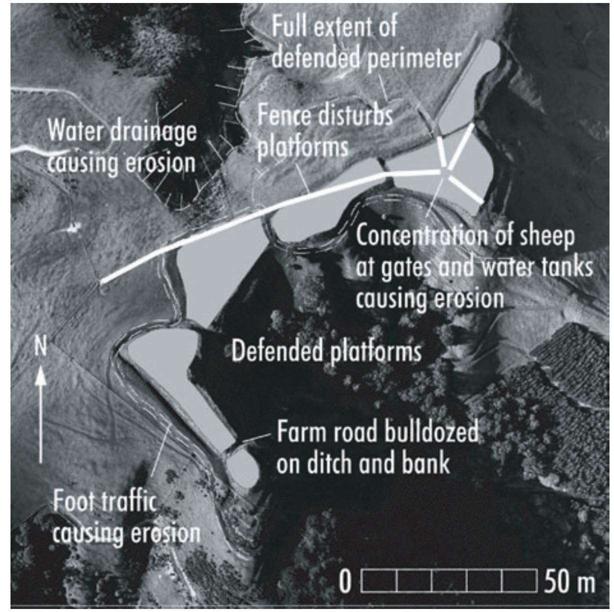
Aerial photography provides an efficient and effective means of quickly documenting the condition of a large site or a number of sites. They document many relevant matters relating to the physical state of a site and can also show disturbances such as urban sprawl, farming activities, looting, and forest encroachment. In addition, aerial photographs, if sufficiently detailed, can be a substitute for conventional mapping and for monitoring purposes.

There are two general sources for obtaining aerial photography: archival research and commissioning flights. Archival research is a cost-effective means of acquiring images of a site taken for reasons such as road engineering and national topographic mapping programs. Photographs taken for this purpose often are of very high quality and at an original scale ranging between 1:10,000 and 1:50,000. They also have great value simply because they may show sites before the sites are modified.

Commissioning flights is the second source for obtaining aerial images. These images can be vertical (straight down) or oblique (taken at an angle). Professional companies usually take vertical images by using expensive, extra-large-format film or digital cameras mounted in the belly of a small airplane. This conventional aerial photography has become somewhat expensive to commission but provides excellent resolution and up-to-date data.

A less expensive option is oblique (or near vertical) photography. Oblique images are taken during a flight by the copilot or passenger. These photographs can be taken with either small-format (35mm) or medium-format (120mm or 6 × 6 centimeter) film cameras or a high-resolution (10 megapixel) digital single lens reflex (SLR) camera. Oblique images have many advantages for mapping and monitoring areas of the size of most archaeological sites or building complexes. Although more difficult to map or scale because they are not vertical, they are nevertheless sufficient in that they reveal many details and conditions of earthwork archaeological sites and can cover areas up to 600 meters across. They are particularly effective in monitoring sites over time and can cover numerous sites (fifty or more) in the course of one well-planned flight lasting two to three hours. The cost per site monitored is lower than visiting remote sites as part of a vehicle-based ground crew, where access may take as long as two to three hours, and the number of sites visited per day would seldom be more than ten.

Because the Papamoa Hills extend over a large area that is difficult to access, large-format vertical aerial film photography was commissioned to record the entire site, earthworks, and archaeological features of the park, including some of the surrounding areas. The significance of the site required an image that could be accurately measured and then used as a base map for planning interventions. The final images were created from scanned aerial contact prints shot with a Leica RC30 metric camera system fitted with forward motion compensation (FMC), during a series of flights in the summer of 2003 and 2004 by Fugro Airborne Surveys, a private aerial photography company. These images were then digitally orthorectified, or aligned, to remove irregularities and distortions in scale caused by the camera lens, film, plane, or terrain. They were also georeferenced with real-world coordinates obtained from existing maps and ground control measured points. This allowed for the seamless addition of multiple



Vertical aerial photograph of Karangaumu pā, on the Papamoa Hills. Photo: Kevin L. Jones © New Zealand Department of Conservation.

The author preparing to take oblique aerial photographs of pā on the North Island of New Zealand. Photo: Kevin L. Jones © New Zealand Department of Conservation.

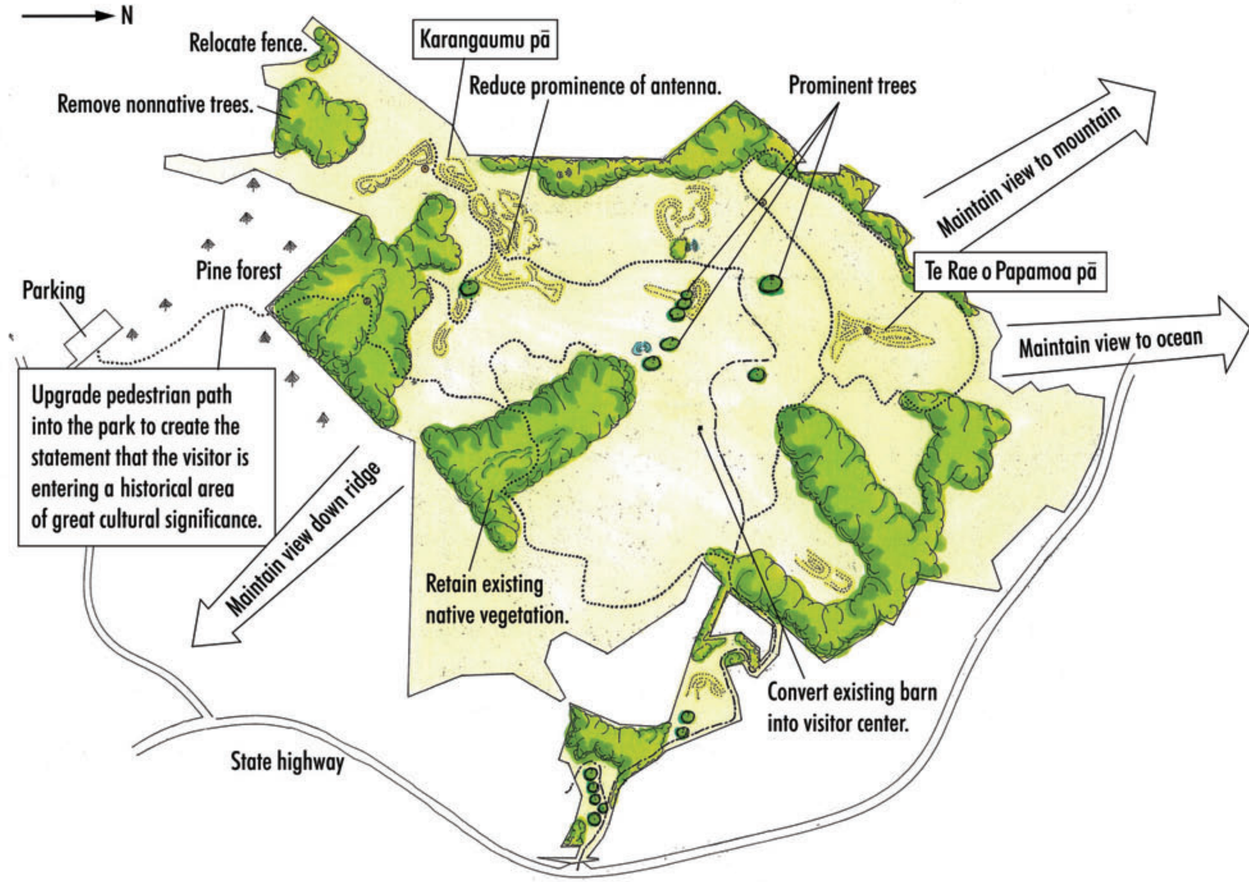
distortion-free images that could be accurately measured and related to surrounding areas. All photos were then quality checked for color, contrast, and accuracy.

Technologies that compete with aerial photography include ground plans drawn in conventional ways, such as with survey instruments (total stations) or Global Positioning System (GPS). Aerial surveys can also use radiation emission sources such as laser scanners (LIDAR, light detection and ranging). Where a site is obscured by vegetation, conventional ground plans are essential as aerial photographs may reveal little. Although these technologies provide highly detailed topographic contour plans and line drawings, they still lack the information obtained from an aerial photograph. Often these technologies must be used in combination. Recently, low-cost digital satellite imagery (Digital Globe) has begun to compete in convenience with aerial photography; however, images obtained from airplanes are still much higher resolution (approximately several centimeters per pixel) than those obtained by the most advanced commercial satellite (approximately 1 meter per pixel).

Conservation planning for archaeological sites needs cost-effective and flexible tools for recording conditions. Aerial photography is just such a tool: large sites can be quickly recorded, revealing many features and conditions not readily seen from the ground. In addition, aerial photography can also assist in economically monitoring numerous remote sites. If taken periodically, such images can show deterioration and alert managers to impending losses. Aerial imagery can also indicate the extent of subsurface sites or features, such as the slight depressions, or terraces, of earthwork fortifications.

Orthophotographic aerial photography of the entire Papamoa Hills Regional Park. Photo: Fugro Airborne Surveys © Environment Bay of Plenty, New Zealand.

The interpretation of the aerial imagery of the Papamoa Hills guided the conservation recommendations for the management plan of the park. The aerial images of Karangaumu pā, to the west of the site, revealed several conservation issues: a farm road had been bulldozed through the pā from the southeast along the lateral ditch and bank defenses; gates, water tanks, and fences on the northern platform concentrated grazing sheep, leading to erosion; gullies on the northwest side have slowly eroded the slope; and minor erosion has resulted from people walking on the main platform down to the central transverse ditch area.



Landscape concept design for Papamoa Hills Regional Park. Drawing: Landscape Company Limited © Environment Bay of Plenty, New Zealand.

An Answer

In November 2006, a draft of the Papamoa Hills Regional Park Management Plan was completed using aerial photographs to locate features and describe threats. Aerial photographs also served as the base map for proposed conservation of the archaeological sites. To preserve the archaeological remains and the landscape of the park, it was recommended that sheep grazing be carefully managed in order to maintain good grass cover, and that farm-fencing patterns be reconsidered. Erosion from animal behavior can be corrected by a thorough review of the water supply areas and shelters in the available paddocks and the creation of less damaging alternatives. In some cases, the simple removal of an unnecessary fence would be adequate, allowing access to water and improved shelter without damaging the pā. Placement of visitor facilities, access, and parking was planned using the aerial images. The photographs were also used to note important views, prominent trees, and nonnative species for the landscape design.

Overall, aerial photography proved to be a valuable tool for the Papamoa Hills Regional Park Management Plan. The methods demonstrated in this example have potentially wide applicability in other countries with surface-visible archaeological sites and suitable ground conditions (grass, desert, planes), and where military authorities will allow widespread aerial photography. Archived historical aerial photographs may allow for longer-term monitoring.

Kevin L. Jones is an archaeologist in the Research, Development and Improvement Division of the New Zealand Department of Conservation. He is the author of a book on New Zealand aerial archaeology and is writing a field guide to New Zealand archaeology for the Penguin Group. He has conducted extensive field research and has been involved with World Heritage policy in the Pacific.




DATA MANAGEMENT: ANALYZING INFORMATION

Structural Assessment

Gorun Arun

At the southern edge of Istanbul, only 20 meters away from the Sea of Marmara, stands the oldest surviving Byzantine edifice still in active use: Küçük (Little) Ayasofya Mosque. Begun in 527 by the emperor Justinian, the structure marks an important stage in Byzantine building technology and is generally considered a precursor to the Hagia Sophia, built in 532. Due to numerous human-made changes, differential soil settlement, vibrations from seismic activity, and the neighboring railway, many cracks and deformations have developed at Küçük Ayasofya, threatening its stability.

How can these structural failures be accurately measured, investigated, and interpreted?

This illustrated example is based on a project to determine old and new deformations at Küçük Ayasofya Mosque conducted by the author and A. Alkiş, H. Demirel, R. D. Düppe, C. Gerstenecker, and M. Hovenbitzer.

Küçük Ayasofya Mosque, in Istanbul, showing the railroad tracks in the foreground. The active tracks are only 5 meters from the building. Photo: © World Monuments Fund.

Küçük Ayasofya, Istanbul, Turkey

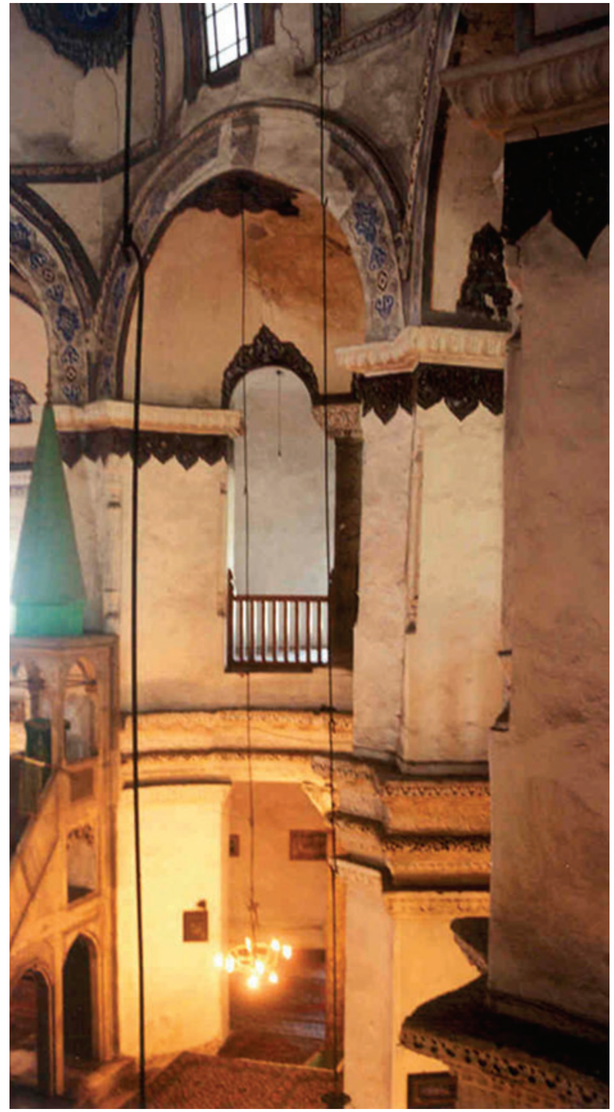
Küçük Ayasofya has an irregular square plan enclosing an octagonal nave, a half-hexagonal apse, and a rectangular narthex. These irregularities may be partly due to the fact that the original church was fit between two existing buildings: the Church of Saints Peter and Paul, and the Palace of Hormisdas, one of Justinian's residences. An ambulatory skirts the nave on the ground floor, with a spacious gallery above. Eight imposing polygonal piers mark the vertices of the nave, which opens onto four semicircular niches toward the corner. The dome crowning the nave is made of sixteen slices of alternating flat and concave surfaces that create a unique undulating appearance when viewed from outside the church.

Nothing remains of the lavish interior decoration of marble and mosaics, which was damaged during the Iconoclast movement in the ninth century and the Latin invasion in 1204. Yet, the church remained an important pilgrimage center throughout the fifteenth century. It was converted to a mosque in 1504 and is still used for prayer today. In 1870, a railway, which still sustains heavy traffic, was built 5 meters between the South Sea walls and the building. A highway was constructed in 1955 by landfilling the coast in front of the South Sea walls.

Compression of the infilled soil has interfered with drainage of the groundwater and has affected the stability of Küçük Ayasofya. Large cracks have appeared in the northeast and southeast vaults of the dome, threatening the structural safety of the mosque. The vibrations from train traffic and, ultimately, the Izmit earthquake (August 1999, magnitude 7.4) increased the width of the cracks and caused wall plaster to fall. In imminent danger of collapse, Küçük Ayasofya was placed on the 2002 and 2004 lists of the most endangered World Heritage Sites by the World Monuments Fund.

Out of concern for the survival of the building, a multidisciplinary team of fourteen experts instigated a project in 1994 to analyze the structure in order to understand its failures and prepare a conservation plan. This was the first time that local and international structural engineers, hydraulic engineers, geologists, chemists, planners, photogrammetrists, and architects collaborated on the conservation of Turkish cultural heritage, which was usually left to conservators and conservation architects. After an initial visit, it was decided that the building and its environment required an extensive survey. Each discipline conducted a separate analysis. The data and findings were then gathered and shared for evaluation. The various disciplines carried out historical and architectural surveys; investigated the physical, chemical, and mechanical properties of the building materials; performed soil and structural analyses; and measured the effects of vibrations from the train traffic. Later, architects and photogrammetrists agreed to carry out additional surveys to bolster the initial results.

The objectives of the architectural survey were to qualitatively and quantitatively describe the deformations occurring in the building. To understand the structural design and its potential failures, it was necessary to study the complex geometry of the dome. The deformations and the propagation of the cracks were measured and monitored over time to pinpoint the effects of these failures.



Interior view of pillars supporting the dome of Küçük Ayasofya. A free-hanging line indicates how far the center pillar is out of plumb. Photo: C. Gerstenecker © Küçük Ayasofya Project.

Stereophotogrammetry

Photogrammetry is a survey technique in which a 2-D or 3-D object may be measured from photographs taken from slightly different positions. These stereographs, usually taken in pairs, provide two different views of the same object that mimic the perspective of human binocular vision. Measurements are extracted from the stereographs, and 3-D information is reconstructed using computer software. These measurements are verified against target points that are placed on the object and measured using a total station theodolite.

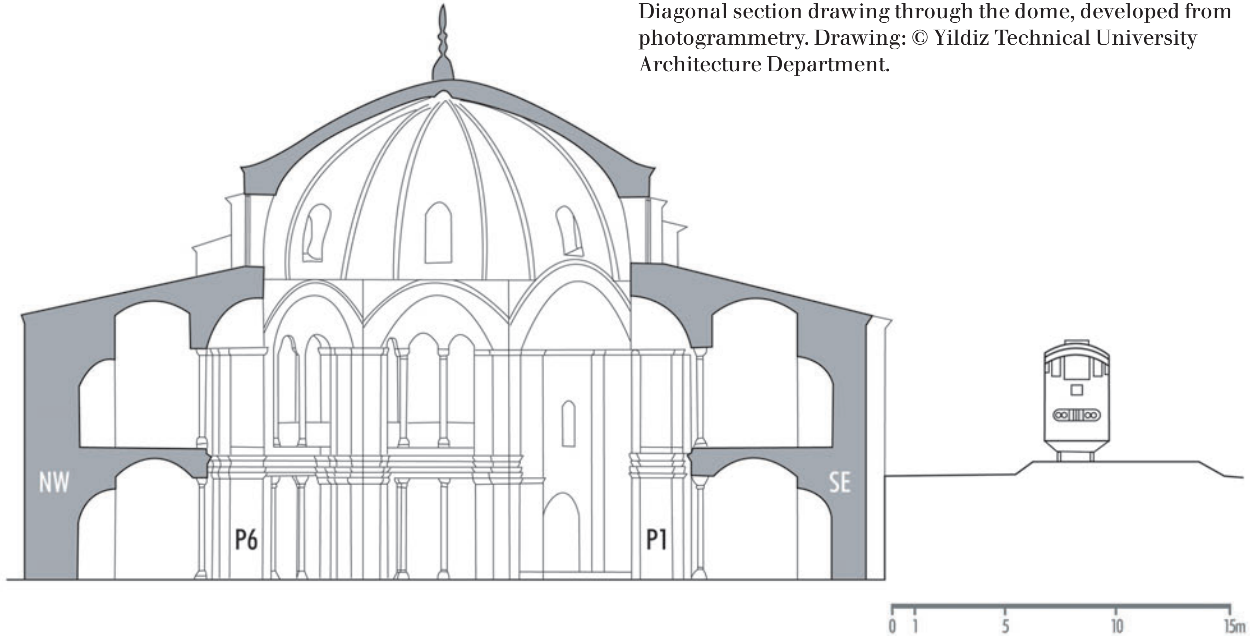
Photogrammetry was chosen because it was the only tool capable of helping the survey team visualize the complex geometry of the dome, understand the load distribution on the support systems, and locate the structural irregularities caused by vertical deviations and rotations. Measurements could be obtained directly from the photographic record, without building scaffolding and even without being on site. From these measurements, a 3-D model could be generated to analyze the dome. Furthermore, the mosque had been photogrammetrically surveyed earlier, in 1979. With the new data, it was possible to compare, monitor, and analyze changes in deformation and crack propagation.

Other possible tools for this survey were hand survey and laser scanners. Measurements taken by hand would have been time consuming and inaccurate in precisely recording the geometry of the dome. Laser scanning was not available at the time the survey was carried out and would be too costly today for the budget of the project. Photogrammetry was the highest technology available at the time of the survey to satisfy the objectives of the project. Despite budget constraints, equipment and experts were locally available.

A pair of stereographs of the dome, taken looking straight up. Note the large number of cracks. Photo: A. Alkiş © Küçük Ayasofya Project.

Technicians in the photogrammetric lab. Photo: © Gorun Arun.

The documentation of Küçük Ayasofya was carried out in three phases by three or four experts, a technician, and two trained students. First, in 1994, the geometry of the dome was accurately documented. Targets were placed on the pillars and walls of the gallery. Over the course of two days, forty stereographs were taken of the dome using a Zeiss UMK 1318 universal wide-angle metric camera. This model was chosen because of the height of the dome. In addition, control points were measured with a total station theodolite, an instrument that computes vertical and horizontal angles. The photographs were produced from glass plates and processed in the laboratory. A contour map was then generated using a Zeiss Topocart D stereoplotter. A stereoplotter optically projects a 3-D image of the pairs of stereographs. From this image, contour lines are traced, thereby providing an accurate topographic model from which to extract measurements. The model was created in two weeks and manually digitized in ten days.

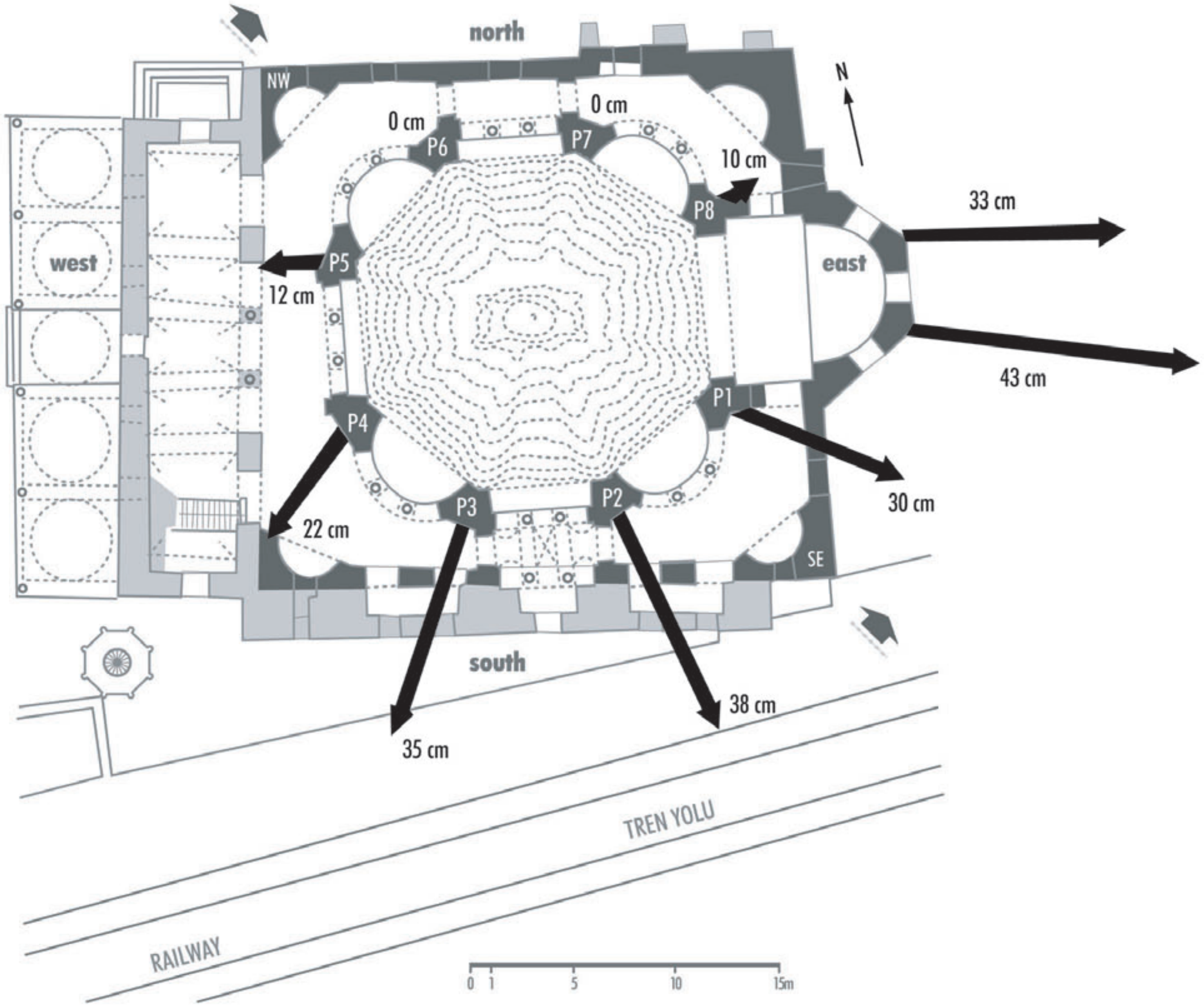


Diagonal section drawing through the dome, developed from photogrammetry. Drawing: © Yildiz Technical University Architecture Department.

In 1995, the second phase began. Deformations in the structure were documented by establishing a deformation network composed of two subnetworks. Inside the building, more than four hundred control points were set up in the potential zones of deformation. The coordinates of these points were measured using a total station theodolite. The second subnetwork was established outside the building by using Global Positioning System (GPS) reference points inscribed in the World Geodetic System 1984. The movement of the monitored sites is relative to the reference sites. Fieldwork was carried out in five days and processed in ten days. Deformation of the dome and of the structural elements, such as piers and columns, was computed based on the collected data.

Finally, in 1998, the third phase was completed, and consisted of monitoring the state of the interior and exterior of the building with digital photogrammetry. A digital metric camera with a built-in réseau plate that corrects film distortion was used in combination with different types of wide-angle lenses to cover a large angle of site; a tele-objective lens that flattens the image was also used specifically to examine the cracks. More than one thousand stereographs were taken over five days. Again, control points were measured with a total station theodolite. The photographs were processed and plotted using software that automatically restituted the stereographs into a 3-D model by directly extracting the 3-D coordinates based on the control points. The data of 3-D point clouds were then transferred to a line drawing that could be processed by any CAD software. The stereophotographs were also compared to the images taken during the 1979 survey.

The 1995 survey revealed extensive vertical out-of-plumb of the pillars in the southeast direction, as well as horizontal inclination of the dome base toward the southeast. The load of the dome could account for such deviation. However, based on the model generated in 1994, the unusual geometry of the dome was quite apparent, with its alternating cylindrical and elliptic, parabolic surfaces. Based on this design, it was clear that the groin vaults alleviated the load of the dome to almost half that of a hemispherical dome. Therefore, the dome was not responsible for the deformations in the building. From the 1995 survey, it was determined that the structure was affected by



Floor plan and topography of the dome, acquired from photogrammetry. Vectorized column displacement identifies both the direction and distance that vertical structural members have shifted. Drawing: © Yildiz Technical University Architecture Department.

rotation settlement of the foundation and the supporting elements. This was also observed in the difference in dome inclination between the north–south and east–west directions. Crack propagation was evaluated by comparing the 1979 and 1998 surveys. The main crack on the northeast vault of the dome had not changed, whereas the crack on the southeast side had extended.

The survey of Küçük Ayasofya Mosque was a pioneering collaborative effort to preserve Turkish cultural heritage. The expertise and technology available for the different components of the survey provided excellent results. Some of the shortcomings, however, were attributed to the organization of the team rather than to technical difficulties. Because so many different disciplines were involved, there were at times discrepancies in terminology. For example, to architects and engineers, the dome base refers to the junction point between the dome and a different architectural element; to photogrammetrists, the dome base is where the curvature starts. Therefore, the first collection of data points was incomplete and needed correction. In the future, a glossary should be compiled to establish a common terminology.

An Answer

Structural engineers and restoration architects used the results of the documentation to identify the causes of the mosque's structural failures. It was concluded that the accumulation of water in the area of the landfill has affected the bearing capacity of the soil in the southeast portion of the building. The active failure of the building urgently requires preventive interventions. First, it was advised to install temporary tension devices on the exterior of the structure and beneath the dome, and scaffolding inside the mosque to protect visitors. Also, areas of the dome in danger of collapse needed to be shored. Frequent monitoring and further soil analysis would help in developing permanent strengthening measures for the southeast part of the building. The project team recommended that the soil be strengthened by core drilling.

The results of the entire project were given to the local governing entities. A consulting team, independent of the survey team, has undertaken the task of conservation, focusing on repairing cracks and mitigating the effects of deformation rather than remedying the causes of the structural failures.

Gorun Arun is an architect and engineer who has evaluated many historic masonry structures using photogrammetry. She received her first degree in architecture from the Istanbul State Academy of Fine Arts and her doctorate from Yildiz Technical University, Istanbul, where she is currently a professor and vice rector for research and planning. She is a member of the International Association for Shell and Spatial Structures (IASS) and the International Scientific Committee for the Analysis and Restoration of Structures of Architectural Heritage (ISCARSAH). Her research activities focus on diagnosing structural problems of existing buildings.

City Inventories

Francesco Siravo

The Stone Town of Zanzibar, the largest and best-known historic settlement in East Africa, is the result of a complex stratification of spaces and uses dating back two and a half centuries. Its monuments, buildings, and public areas are a testament to the many influences that created a unique blend of history, culture, and architecture before and after the establishment of the sultanate of Zanzibar in the nineteenth century.

With the increased use of modern materials and the rapid pace of development, how can a thorough inventory and assessment of this historic area deepen our understanding of the urban fabric and become a tool for the formulation of an integrated conservation plan?

The work featured in this illustrated example was made possible through the support of the Historic Cities Support Programme of the Aga Khan Trust for Culture. It appears in this publication courtesy of the Aga Khan Trust.

Aerial view of the Stone Town peninsula, Zanzibar. Photo: © Javed Jafferji.

Stone Town, Zanzibar

The town of Zanzibar was established on the main island of the Zanzibar archipelago, where the tropical climate, fertile soil, plentiful water, natural harbor, and ready supply of building materials provided all that was needed for eventual urban development. As a product of an ancient pattern of Arab maritime trading and settlement, Zanzibar cultivated an urban tradition that exists to this day.

Initially, trade concentrated on slaves, spices, tortoiseshell, ivory, wood, and wax. In the 1830s, export was broadened with plantations of clove, coconut, and gum copal. Burgeoning demands for trade from Americans and Europeans, coupled with the growing population of the court of the island's Omani Arab sultan, generated a boom in building activity between 1810 and 1860. The first stone buildings, erected to house the royal family, were a novelty on an island where most of the population lived in mud huts.

In 1873, the new, civic-minded sultan, Sayyid Bargash, abolished slavery and took an active interest in the town, initiating various public improvements, including roads, an aqueduct, and several important new buildings. Over the following decades, despite numerous cholera epidemics, the termination of the slave trade, and a hurricane that devastated clove and coconut production, Zanzibar continued to prosper, mainly because of its key position as a transit port. Construction and growth continued, and an 1892 survey noted the presence of 1,506 stone buildings and 5,179 mud huts.

Zanzibar's historic area was traditionally known as the Stone Town. Its imposing multistoried stone buildings distinguished it from the surrounding city of mud-and-wattle thatched construction. Today, the Stone Town measures approximately 87 hectares and accounts for only about 5 percent of greater Zanzibar's total area. An estimated 16,000 people live in the town's historic core, but size and population are misleading indicators of its importance. Within its confines are concentrated the vast majority of Zanzibar's public and commercial facilities, and it is here that land values are highest and pressure for development and change the greatest. Scores of new structures were built in the 1980s, and more than a third of the old buildings were substantially altered by the early 1990s. Most of the town's remaining historic structures were in poor condition, and dozens of old buildings had collapsed. These adverse developments raised concern about the future of the Stone Town, which represents an irreplaceable asset not only for Zanzibar and its residents but also for East Africa as the region's largest and most important historic urban area.

In recognition of the Stone Town's significance, the Zanzibari government initiated a conservation plan in an effort to reverse the decline and guide future development. The plan was prepared over a period of two years as a joint effort of the Zanzibar Stone Town Conservation and Development Authority (STCDA) and the Historic Cities Support Programme of the Aga Khan Trust for Culture. The conservation plan was formally adopted by the Zanzibari government in 1994.

The methodological premises of the Zanzibar plan are based on the practice of integrated planning. In the past, planners viewed a historic area as a collection of monuments and buildings to be preserved as relics of the past, whose value was not considered part of its current use or surroundings. Other aspects of the urban fabric, such as open spaces, infrastructure, transport systems, land use, and tenure issues, were also viewed as separate, unrelated components or not considered at all. This piecemeal approach is largely responsible for the poor results often obtained in planning historic areas. Contrary to this, the basic premise of successful urban conservation planning is that monuments, historic buildings, and other aspects of the urban fabric must not be treated out of context. They must be reintegrated with all other components that comprise a historic urban area in order to understand and identify their interdependent relationships and ensure their continued vitality and long-term preservation.

Surveying and understanding these different components is essential to formulating a program of action and implementing specific conservation and development measures. It is also the basis for providing answers to the important questions a plan must address: What are the problems and the main deficiencies in the present organization of the historic area? What sustains its economy, and what depresses it? Which economic activities are compatible with its historic character? Which services and public facilities are lacking that should be provided in the future? Where is it necessary to enforce conservation measures and restrict new construction? What kind of new development is acceptable, and where is it acceptable?

A typical street in the Stone Town, showing the area's characteristic narrow alleyways, plastered facades, wooden shutters, and projecting roof eaves. Photo: © Steve Outram.

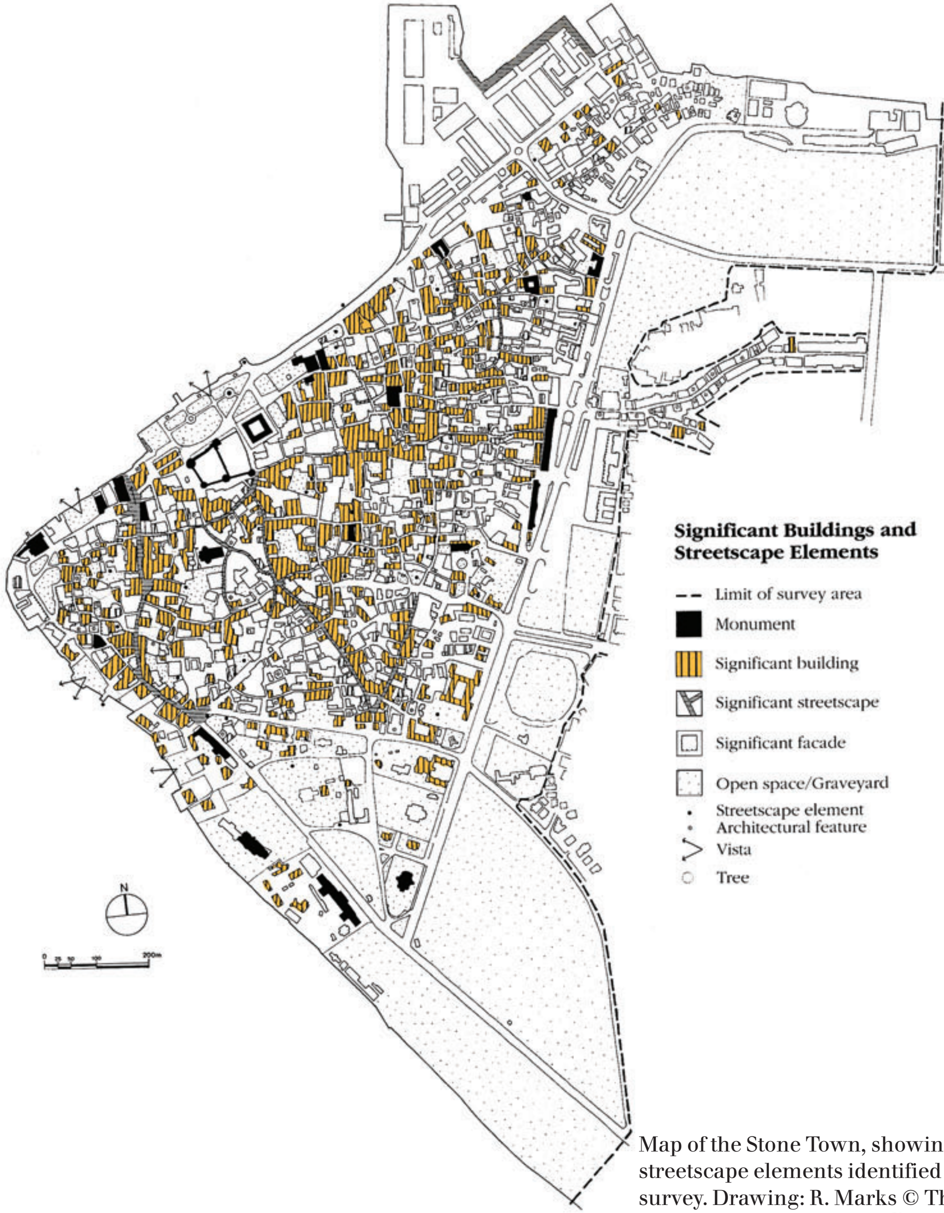
Urban Studies

In providing an answer to the aforementioned questions, an urban study helps shape a coherent vision of the historic area and identify the general planning measures and specific actions required. Reconnaissance of the Stone Town historic area concentrated on six key issues. The first two, buildings and open spaces—the solids and voids that constitute the urban fabric—are the essence of the historic city and embody its character. The remaining four—people, land use, traffic, and infrastructure—determine the functioning of the historic core and have a direct impact on its long-term survival and well-being.

The first key issue—how to deal with traditional buildings—is one of the most difficult problems faced by public administrations in historic cities. This is not surprising, considering how much building methods and materials have changed since the early twentieth century. This impasse can be overcome by deepening our understanding of historic structures. The more this analysis is based on tangible features and observable transformations, the easier it will be to establish the criteria and guidelines needed to protect and rehabilitate the old structures. The Zanzibar building survey focused on four aspects: typological character, building condition, architectural significance, and transformations to historic buildings. For the first aspect, the survey identified the major building types in the Stone Town according to recurrent features and original use. This was important in establishing, at a later stage, the design criteria and building guidelines needed to protect and rehabilitate the different types of historic structures. The second aspect, an assessment of building conditions, was the basis for evaluating the state of Zanzibar's historic structures and their recurrent conservation problems. The analysis helped determine the scope, extent, and provisional cost of future rehabilitation works. Third, the study identified significant buildings and architectural elements that are significant examples of their type and represent architectural, historical, or cultural achievements. This was the basis for the selection of listed buildings and features designated for special protection. Finally, based on previous records and direct observation in the field, the study recorded and evaluated the most common alterations made to historic buildings. Prevailing trends were assessed with a view toward designing planning strategies to counteract the inappropriate transformation of the historic fabric.

Open spaces and streets—the second key issue in the survey—are often overlooked in favor of monuments and buildings. There is no doubt, however, that many of the special qualities of a historic place are best embodied in its vistas, green areas, interior courtyards, fountains, and other cityscape features. This public and semiprivate realm is made up of countless details and minor, often unnoticed features (e.g., paving, edges, individual trees). These features are also the most fragile and usually disappear first through improvised road paving campaigns or misguided public "beautification" programs. For this reason, the Zanzibar urban study paid special attention to recording the individual elements that contribute to the historic townscape and should be monitored and protected as such. In particular, the survey recorded significant streetscapes and facades that retain the best of the Stone Town's traditional appearance, scale, and proportions, and that are noticeable for their cumulative contribution to the town's character. In addition, surveyors identified individual architectural features, such as traditional carved doors, balconies, verandas, and teahouses, as well as hundreds of examples of plasterwork, tile work, and wooden fascia boards that have a strong impact on the streetscape. Other streetscape elements, distinct from buildings, were recorded as an intrinsic part of Zanzibar's urban fabric. Such elements included old tombs, fountains, trees, vistas, street paving, gateways, wrought-iron fences, and so forth. Finally, open green areas, including parks, gardens, lesser green areas, and graveyards, were identified as precious assets within the densely knit fabric of the Stone Town. Graveyards in particular provided an important record of the different communities, families, and personalities who have inhabited the town and contributed to Zanzibar's history.

The effectiveness of a conservation plan depends to a large extent on how well its policies and measures respond to the needs and expectations of residents and other users, the third key issue. For this reason, the survey of the Stone Town included interviews with a significant 10 percent sample of households living in the historic area. The findings provided information about household size, employment, tenure, occupancy, in- and out-migration, schooling, and access to public services. Further information was solicited regarding the residents' ability and willingness to contribute to upgrading the buildings and improving their surroundings. The data were the basis of the projections for population growth in the Stone Town. Other useful information was gathered from the business community, particularly regarding the potential for commercial growth and increasing employment. Altogether, this information was valuable in designing incentives and creating a policy environment conducive to private investment in the historic area.



Map of the Stone Town, showing significant buildings and streetscape elements identified during the course of the survey. Drawing: R. Marks © The Aga Khan Trust for Culture.

Land use, the fourth key issue, is a crucial and sensitive aspect of planning and managing historic areas. Recording and analyzing the location and distribution of activities and building uses, as well as public facilities–particularly for health, education, and recreation–helped determine the present and future requirements of Zanzibar's central area. Particular attention was given to assessing the compatibility of existing uses with traditional buildings and to identifying conflicting land uses

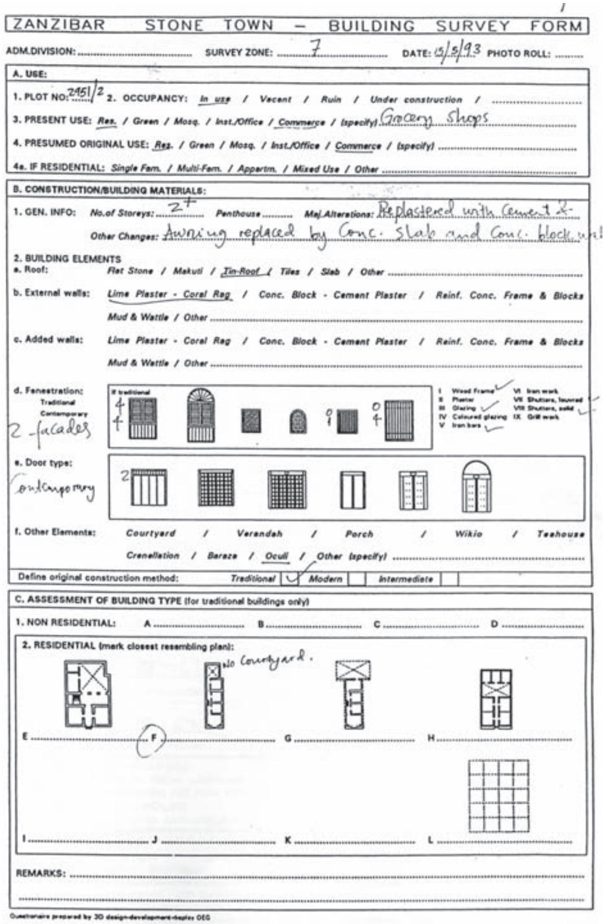
Plan of an urban block in the Kajificheni neighborhood. This typical block contains a mix of building types, including Arab houses, groups of Indian shopfront buildings, and an L-shaped communal tenement structure. Drawings: R. Marks © The Aga Khan Trust for Culture.

and activities. Eventually, the study of existing uses formed the basis of the plan's land-use proposals, including the identification of existing buildings that could accommodate proposed public facilities. Updated information was gathered on land tenure and building ownership in order to quantify private, public, and religious ownership and document occupancy and tenure patterns. Data were collected from the Land Registry, Municipal Council, and the files of the Waqf and Trust Commission (the entity entrusted with religious properties in the Stone Town). An understanding of ownership patterns and forms of tenure was important, as these are often complex and affect implementation of the plan's recommended policies and initiatives.

Finally, the key issues of traffic and infrastructure were considered in relation to the particular conditions of the Stone Town. With respect to traffic, special attention was given to transportation options, available parking, flow of traffic and bottlenecks, road conditions, pedestrian safety, and damage to historic property. Investigations recognized that the Stone Town, like other traditional settlements, worked well in the past because spaces were concentrated and the activities that took place within them were highly integrated and within pedestrian reach. The study verified conditions under which the use of private cars could be discouraged in favor of carefully worked out incentives and controls, including peripheral parking, more public transport, and the reinforcement of pedestrian and other nonmotorized alternatives.

Investigation of the town's infrastructure focused on the supply of electricity and fresh water, as well as on drainage and sewage disposal systems. In addition to direct observation in the field, the study consisted of collecting information and maps of existing and proposed infrastructure works and interviewing the technical personnel directly involved. Overall, the study confirmed the limited need for capital financing of new installations as opposed to raising funds to maintain and upgrade the existing infrastructure. Accordingly, the information was used to determine the capacity and adequacy of existing systems, ascertain which remedial measures should be put into effect, and identify a series of infrastructure improvements that would be environmentally appropriate and have limited impact on the historic structures.

The field survey of Zanzibar's Stone Town was carried out from June to December 1992 to update previous surveys and gather new information needed for the formulation of the conservation plan. All investigations were conducted on a plot-by-plot basis by teams of three or four. The town was divided into eighty-three survey areas corresponding to the eighty-three blocks comprising the historic area. Several forms were completed concurrently to cover the various aspects and key issues discussed above. These included a block survey form, a building survey form, and forms documenting building conditions and streetscape elements. Altogether, the information gathered provided a complete inventory of the urban fabric and its condition. All data were cross-checked in the field and subsequently transferred to a revised base map and into a specially created database. Throughout the study, an effort was made to consult government and municipal officials as well as interview residents regarding their ideas and opinions.



ZANZIBAR STONE TOWN – BUILDING SURVEY FORM

ADM.DIVISION: .... SURVEY ZONE: 7 DATE: 15/5/93 PHOTO ROLL: ....

A. USE:

1. PLOT NO: 2451/2 2. OCCUPANCY: In use / Vacant / Ruin / Under construction / ....

3. PRESENT USE: Res. / Green / Mosq. / Inst./Office / Commerce / (specify) Grocery shops

4. PRESUMED ORIGINAL USE: Res. / Green / Mosq. / Inst./Office / Commerce / (specify) ....

4a. IF RESIDENTIAL: Single Fam. / Multi-Fam. / Appartm. / Mixed Use / Other ....

B. CONSTRUCTION/BUILDING MATERIALS:

1. GEN. INFO: No.of Storeys: 2+ Penthouse .... Maj.Alterations: Replastered with Cement &

Other Changes: Awning replaced by Conc. slab and Conc. block wall

2. BUILDING ELEMENTS

a. Roof: Flat Stone / Makuti / Tin-Roof / Tiles / Slab / Other ....

b. External walls: Lime Plaster - Coral Rag / Conc. Block - Cement Plaster / Reinf. Conc. Frame & Blocks / Mud & Wattle / Other ....

c. Added walls: Lime Plaster - Coral Rag / Conc. Block - Cement Plaster / Reinf. Conc. Frame & Blocks / Mud & Wattle / Other ....

d. Fenestration: Traditional / Contemporary — 2 - facades

If traditional: I Wood Frame / II Plaster / III Glazing / IV Coloured glazing / V Iron bars / VI Iron work / VII Shutters, louvred / VIII Shutters, solid / IX Grill work

e. Door type: Contemporary

f. Other Elements: Courtyard / Verandah / Porch / Wikio / Teahouse / Crenellation / Baraza / Oculi / Other (specify) ....

Define original construction method: Traditional ✓ / Modern / Intermediate

C. ASSESSMENT OF BUILDING TYPE (for traditional buildings only)

1. NON RESIDENTIAL: A .... B .... C .... D ....

2. RESIDENTIAL (mark closest resembling plan): No Courtyard.

E .... (F) .... G .... H ....

I .... J .... K .... L ....

REMARKS: ....

Questionnaire prepared by 3D design-development-deploy OEG

Example of a building survey form prepared for the plot-by-plot investigation of the Stone Town. Courtesy S. Battle © The Aga Khan Trust for Culture.

An Answer

The study and survey of the Stone Town established the basis for the formulation of planning proposals. Graphic information collected through the block study forms resulted in the first map to show every built structure in the Stone Town as well as the internal configuration of each block. As such, it provided an essential tool for subsequent planning. The newly established database contained records of each building, including cadastral data, land-use information and ownership, and condition, architectural significance, typology, materials, construction, and distinguishing architectural features. The database can be updated periodically to keep track of changes and, over time, facilitated the formulation and implementation of policies and action programs.

The planning proposals were based largely on information collected during the survey. This included controls on the use and development of land; measures to protect individual buildings, street elements, and open areas; and measures to develop and improve parcels of land and other, larger spaces in the central area. The planning framework also included a set of measures designed to improve infrastructure, parking, and circulation of vehicular traffic in and around the Stone Town. These proposals were complemented by a set of new building regulations that constituted an integral part of the plan.

These various components should be considered as complementary overlays of a single planning strategy; taken together, they constitute the basic tenets of the Zanzibar Conservation Plan. Ultimately, studying the historic area of Zanzibar began and ended with the town's physical fabric: from an assessment of its conditions to the establishment of the framework for the protection and improvement of the old structures and physical environment throughout the historic area.

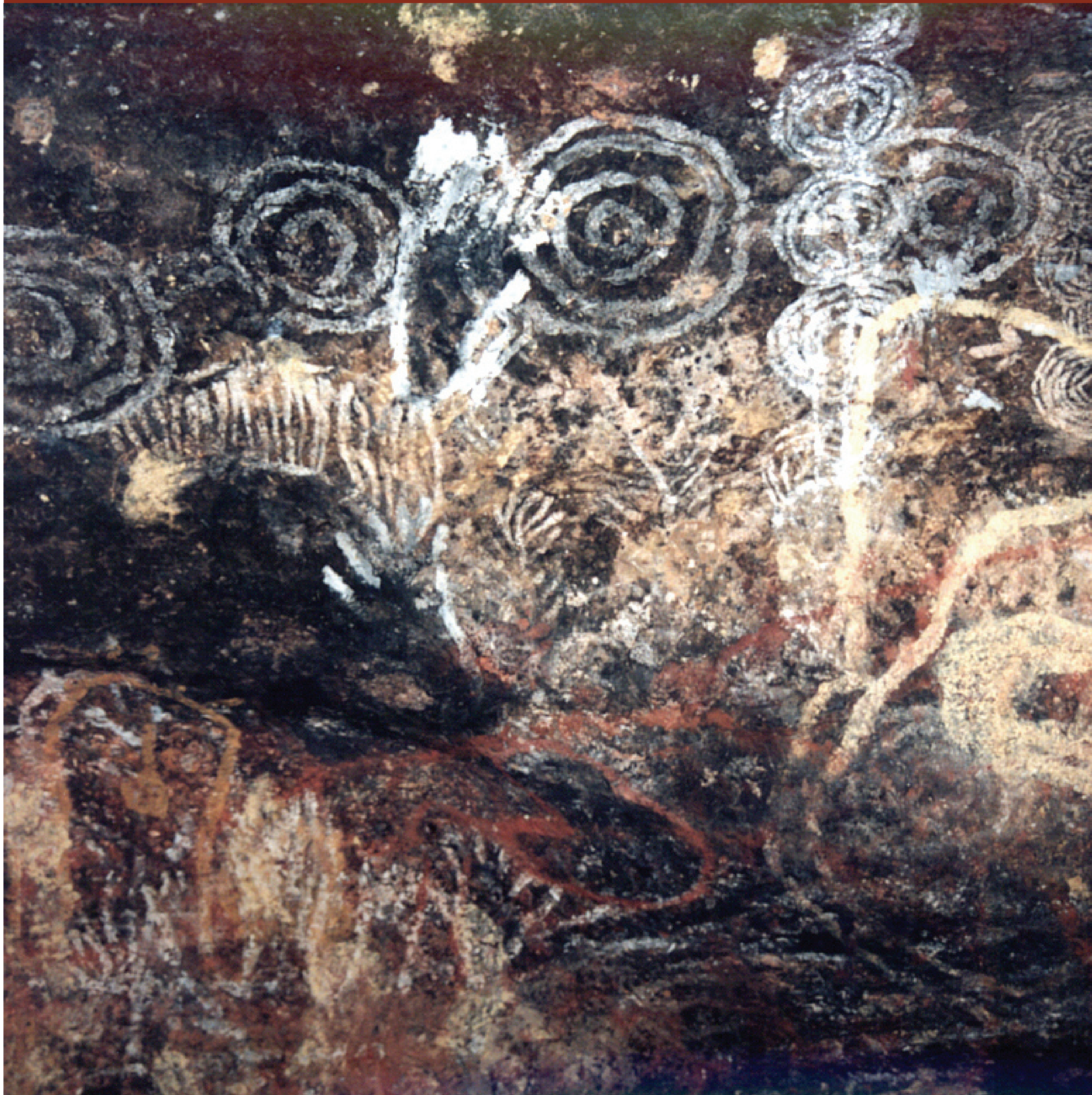
Francesco Siravo is an architect specializing in town planning and historic preservation. He received his professional degrees from the University of Rome "La Sapienza," and specialized in historic preservation at the College of Europe, Bruges, and Columbia University, New York. Since 1991 he has worked for the Historic Cities Support Programme (HCSP) of the Aga Khan Trust for Culture, Geneva, with projects in various Islamic cities, including Cairo, Mostar, Samarqand, and Zanzibar. Before joining the HCSP, he served as consultant for local municipalities as well as governmental and international organizations, including UNESCO and ICCROM. His previous work includes participation in the preparation of conservation plans for the historic areas of Rome, Lucca, Urbino, and Anagni, in Italy, and for the old town of Lamu, in Kenya. He has written books, articles, and papers on various architectural conservation and town planning subjects, including "Zanzibar: A Plan for the Historic Stone Town" (1996) and *Planning Lamu: Conservation of an East African Seaport* (1986).

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

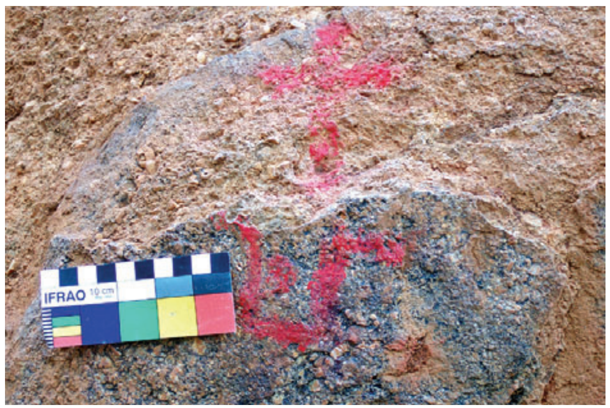
Jutting upward and rising more than 300 feet from the surrounding arid plain, the rock formation known as Uluru is a dominating presence in the Australian landscape. Made of sandstone, it is a unique formation noted for its changing colors as light is reflected throughout the day. Located almost at the 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.



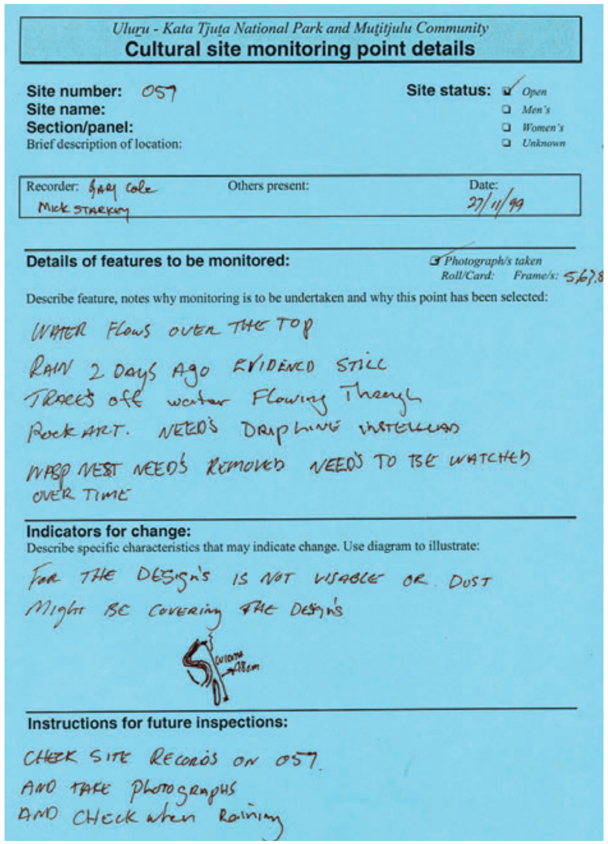
Red graffiti obscuring rock art at Uluru.
Photo: © Mick Starkey.

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 EVIDENCED STILL TRACES off water Flowing Through ROCK ART. NEED'S DRIPLINE 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.

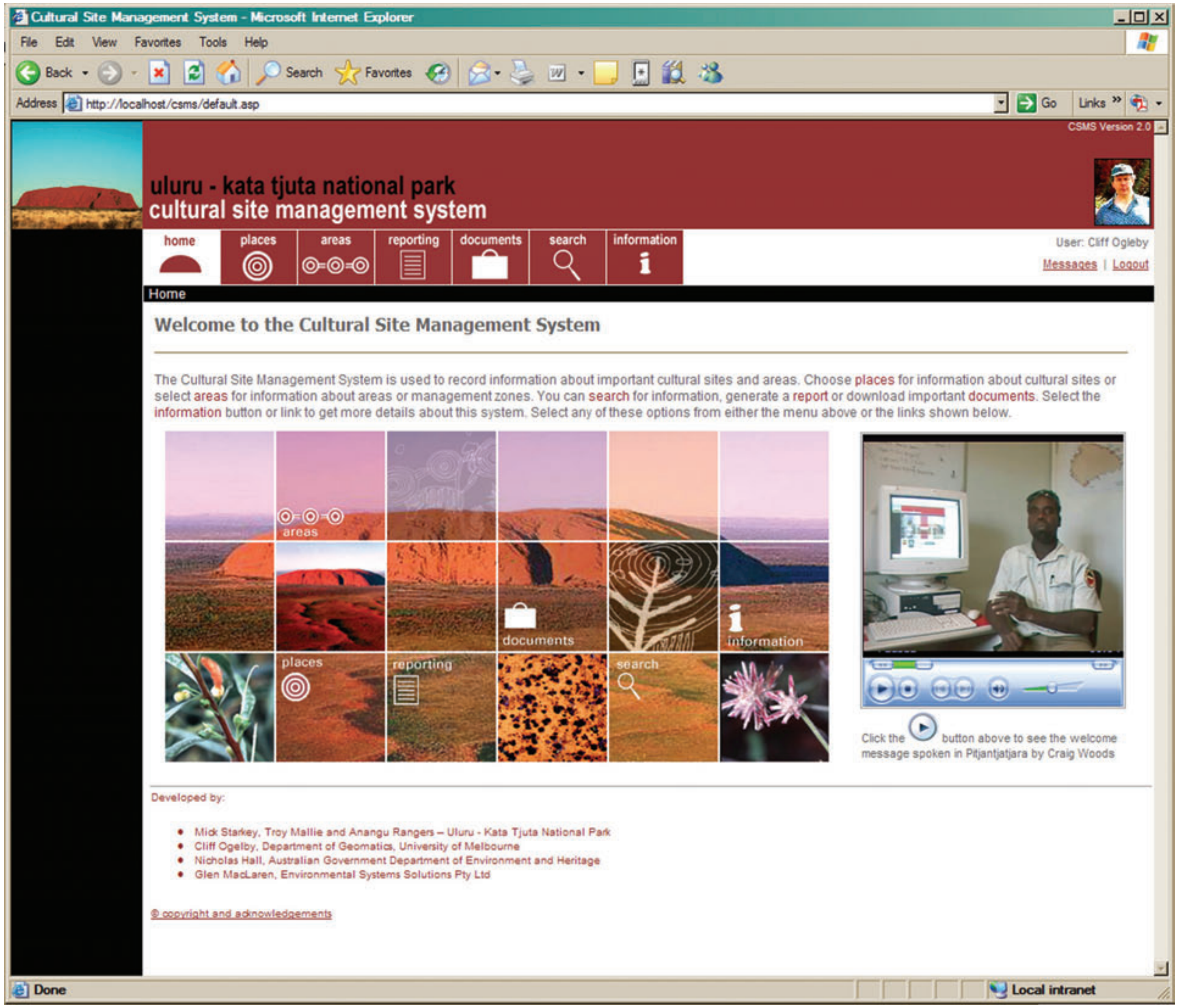
Creation of the database required several phases. First, a team of ten to twelve people, comprised of Anangu elders, park rangers, and surveyors, advised on the design of the database and reviewed all previous information over a two-week period. Second, this information was scanned and other features 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.



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).

Planning Interventions

Frank Matero and Judy Peters

In 1788, New Orleans, Louisiana, lost many of its citizens to an epidemic and a great fire. Burying the dead in densely populated areas was believed to contribute to outbreaks of disease; therefore, by royal decree a new cemetery was established outside the city limits. Today, St. Louis Cemetery No. 1 is now at serious risk through physical deterioration, neglect, theft, and impact from increased tourism.

How can informed decisions be made regarding the cemetery's preservation and long-term development, given the large number of tombs and various levels of condition and significance?

St. Louis Cemetery No. 1, with city view of New Orleans in the background. Photo: Kyubong Song © University of Pennsylvania Architectural Conservation Laboratory.

St. Louis Cemetery No. 1, New Orleans

St. Louis Cemetery No. 1 was established in 1789 outside the northern ramparts of the colonial city of New Orleans, in a marginal and swampy area. The necropolis contains approximately seven hundred tombs, tomb ruins, and markers in small, urban-like precincts owned by individuals, families, and societies. These tombs vary in type and style but are made mostly of soft, handmade, local brick and clay-lime content mortars, covered with hydraulic lime or natural cement stuccos. Most tombs are above ground because of the prevailing French and Spanish mortuary traditions and high water table and were designed for multiple and sequential burials. In a traditional burial, the vault opening was loosely filled with mortared brick, then sealed with a marble closure tablet. On the tablet were listed the names and dates of each burial; over time, this reflected the history of several family generations. When space was needed for another burial, the vault could be reopened only after at least one year and one day. The remains were removed from the coffin, burned, and then pushed to the back of the tomb or below the vaults.

Over the centuries, the cemetery shared the neighborhood with the living. Today, it has become a major tourist attraction on the edge of the popular French Quarter. The site is a microcosm of New Orleans history, reflecting social and cultural diversity. St. Louis Cemetery No. 1 is a living cultural landscape and a dynamic space where religious devotion and cultural tourism coexist. It is the earliest surviving urban Creole cemetery in Louisiana and one of the few cemeteries in the United States to be accepted to the National Register of Historic Places (July 30, 1975). It is also one of the sites of Save America's Treasures, a national effort to protect America's threatened cultural treasures.

Like many early Creole aboveground cemeteries–long appreciated and promoted as historic sites, as well as traditional burial places–St. Louis Cemetery No.1 is currently experiencing renewed visitor popularity through heritage tourism. With this revived interest come commercialization, overzealous restoration, and vandalism, in addition to existing neglect and abandonment. The site is now at serious risk through loss of physical integrity and historical character, as well as changing social and cultural contexts.

The conservation project was developed in two phases to assess the site and its context and to address the immediate practical and long-term management issues related to the landscape and its features. The first phase focused on documentation, recording, and analysis of the urban cemetery landscape and its context over time. This phase was completed through visual mapping and surveys of the cemetery and resulted in the development of practical conservation guidelines for the care and maintenance of this necropolis and its features (e.g., tombs, paths, vegetation). Called the Dead Space Project, it was a multidisciplinary academic exercise carried out by faculty and a group of twenty-three students from the Departments of Historic Preservation and Landscape Architecture of the University of Pennsylvania School of Design, Tulane University's School of Architecture/Preservation Studies, Save Our Cemeteries, Inc., and the Roman Catholic Church of the Archdiocese of New Orleans. Funding was provided by grants from the Louisiana Division of Historic Preservation, the Office of Cultural Development, and the Samuel H. Kress Foundation.

The second phase utilized the guidelines and condition analysis from the first phase to stabilize emergency conditions and implement the conservation plan in a section of the cemetery. This phase included research, field testing, and conservation treatments with a grant from Save America's Treasures and funding from the Samuel H. Kress Foundation.

The Bergamini tomb, dated 1865, showing areas of loss as well as soiled and weathered marble. Photo: Frank Matero © University of Pennsylvania Architectural Conservation Laboratory.

Geographic Information System

The historical changes in boundaries, design, use, and condition were critical elements to capture and illustrate for this complex landscape. A Geographic Information System (GIS) was chosen because it is an effective descriptive, analytical, and communication tool to map and assess this cemetery and prioritize necessary work. GIS is a geographic database that combines spatial information in graphic form with tabular data.

The project began with preliminary archival research of the history of the site, tomb types, and common deterioration conditions, followed by field reconnaissance to identify and verify the typologies, materials, and conditions specific to the site. This served as the groundwork for the sitewide survey of all the tombs and markers. In preparation for the survey, an illustrated manual was compiled to define terminology, and descriptive survey forms were designed with fields to qualitatively assess the features of the cemetery and to quantitatively rank conditions. A relational database was designed in Microsoft Access with all desired survey fields and the ability to connect plots to the cemetery GIS base map as well as to past tables of survey data, images, and inscription records.

The GIS base map was prepared using ESRI ArcView 3.2 and AutoCAD 2000. Historic aerial photos, records and maps, and hand-drawn cemetery plot maps were digitized and georeferenced to known spatial coordinates of field survey measurements and current city parcel data. Layers were created at the individual tomb and landscape feature level, and additional historic layers were developed through the manipulation of the historic

Example of a typical partial record created in Microsoft Access. Courtesy Judy Peters © University of Pennsylvania Architectural Conservation Laboratory.

PNTHNOC	GEO	ID Name	Street	First Date	Last
12	6V-2	Bergamini	Alley No. 1R	1865	1899

Military Mkr	Current Status	Perp. Care	Context	Orient
None	Exists from 1981	☐	Contiguous	S

No Comment

Biographical

No Info

Path Prox.	Path Material	Drain Prox.	Grade	Alignment
Close ((1-5 ft.)	Asphalt	Distant (10+ ft.)	None	Sunken

Marker?	Representation	Interments	Alterations
	Family	Inactive	Restored

Tomb Type	General Comments	Color	Lt. Red Evident	Height Ft In	7	8
Pediment Tomb	Recently restored by Upenn. Red color evident					

ARCHDIOC: ANo IR12

	Addition	Alteration	Material	Condition	Material Integrity	Formal Integrity
Primary Structure	☐	☐	Brick	3	3	3
Roof	☐	☐	Brick	3	3	3
Stucco		☑	Tan	3	3	
Surface Finish			Many	2	3	
Tablet System				2	2	
Ornament				2	3	

references. The sequence provided a chronology of the site. The final site map identified all existing tombs and site-defining features such as topography, vegetation, and drainage systems.

After receiving training in the use of the map and forms, survey teams of two each were assigned to specific sections of the cemetery for the four-day field survey of conditions and integrity of both tomb and landscape features. Example criteria included tomb type, assessed age, retained original material, structural integrity, various condition issues, and significance. Members of each team entered their survey data into the prepared user-friendly database forms over a two-week period upon returning from the field survey trip.

ESRI ArcView software was used to generate the GIS because it is the predominant software worldwide and was licensed as the primary repository for the Dead Space Project documentation. The database and the digital site map were linked through an Open Database Connectivity (ODBC) translator, available through Microsoft Windows operating system. ODBC allows several independent data sources to be accessed simultaneously. Through this link, ArcView could query the database directly, regenerating the link between the GIS and the database each time the GIS program loaded. With the introduction of 8.0 and subsequent versions, ArcView can directly use an Access database as its internal geodatabase for even simpler data connections.

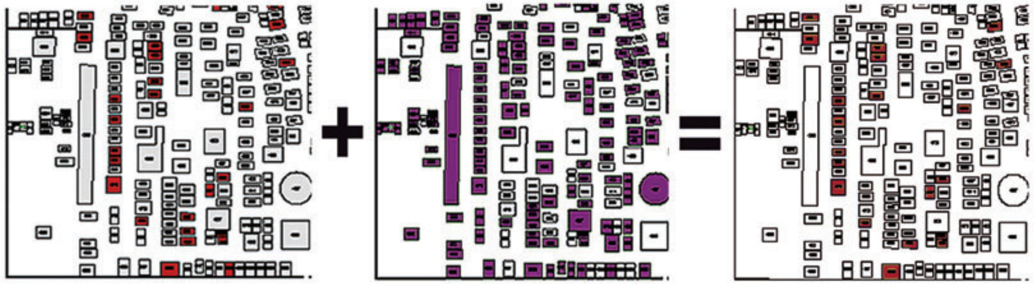
As this project was completed within the structure of a graduate school studio, the actual development of the database, GIS, and finalized survey forms and manuals occurred over the course of a semester. Simple location maps and the most basic structure of the database were created within a two- to three-week period for use during the field survey trip. Fully developed tools were finalized a few months later, after the data were available for analysis, and required students trained in both GIS and database development.

GIS provided visualization and analysis of the site over time and through any combination of criteria recorded in the survey to analyze conditions of the tombs and to prioritize conservation interventions. Once data became available to the digital map, material, condition, and significance attributes could be visually and quantifiably analyzed through queries and calculations. Using the graphic mapping interface, data were analyzed interactively and presented in dynamic map layers for both assessment and presentation purposes. Conditions were sorted, mapped, and mathematically combined and compared with many factors such as urgency, location, material, and cost. Interactions between conditions yielded new visual information for determination of root causes. Through the built-in database, extensive reports, summaries, and graphs were generated. These tools ensured that the conservation plan was based on a combination of qualitative and quantitative values.

Several alternatives to GIS were considered. Paper-based surveys entered into a spreadsheet or a simple database are appropriate tools with which to compile data but lack spatial representation. Furthermore, a paper-based survey alone is difficult to retrieve or query. Computer-Aided Design and Drafting (CAD) was also considered but would have resulted in only a static image lacking qualitative information on the site features.

GIS allowed spatial analysis of a large body of information and made the data visible, searchable, and retrievable. However, data collection could have been done more efficiently by using a handheld computer or personal digital assistant (PDA) with the loaded database of drop-down fields, limiting data entry time and errors. Furthermore, a smaller survey team would have been preferable to reduce conflicts in data collection and misinterpretation of the illustrated manual. Overall, the same methodology can be applied to large urban or cultural resources landscapes and could be implemented at other cemeteries in New Orleans.

Final digital site map used as the GIS spatial interface. Each tomb can be queried for characteristics such as date of construction, level of significance, or name of occupants. Map: John Hinchman © University of Pennsylvania Architectural Conservation Laboratory.



GIS can be queried to add maps together. A query for tombs in a poor state of conservation (*left*) can be combined with or added to a query for tombs of high significance (*center*) to provide a map of tombs that must be worked on first (*right*). Maps: © University of Pennsylvania.

An Answer

Because of the benefits of a multidisciplinary approach and the use of GIS, various aspects of St. Louis Cemetery No. 1 were explored, including the physical evolution of the site over time and the mapping of cultural influences on tomb location, type, and style. Existing conditions and treatment recommendations were studied through spatial analyses of the data. It was possible to map out patterns of historic development in the evolution of the cemetery and make hypotheses concerning building pathologies.

For the second phase, the grant from Save America's Treasures for field testing and conservation allowed focused work on the site. The first-phase GIS was used to identify tombs in need of emergency stabilization. Using spatial maps of condition, an alley was defined of highly significant tombs. Funding and conservation resources were then focused on alley 9L to demonstrate the range of treatments required throughout the site and to show the results possible through implementation of the conservation plan. The work was completed in 2004. A recent treatment assessment after Hurricane Katrina showed that the project work protected all the tomb structures very effectively and provided useful biocidal resistance to fungal growth due to the high use of traditional lime-based products.

Copies of the GIS, images, and database reports rest in the Historic New Orleans Collection–open to the public–in the Louisiana State Historic Preservation Office, and at the University of Pennsylvania. Because the GIS readers available today were not readily available then, the GIS native files have not been made publicly accessible. However, clickable interactive maps created through the GIS and the searchable database were made public on the Internet through a project Web site at www.noladeadspace.org. Originally, the main users of this information were members of the Save America's Treasures project team in directing conservation and maintenance work. Today, the material is routinely accessed by cemetery tour guides looking for site background information, as well as by genealogists and other researchers of New Orleans. This application of GIS is a successful example of its broad benefits to the field of conservation and is currently used as a didactic example in graduate programs on historic preservation.

The Bergamini tomb, after restoration. The masonry and associated stone and metalwork were stabilized and conserved. Photo: Frank Matero © University of Pennsylvania Architectural Conservation Laboratory.

Frank Matero is a professor of architecture and department chair of the Graduate Program in Historic Preservation and director of the Architectural Conservation Laboratory and Research Center at the University of Pennsylvania, Philadelphia. He has lectured internationally and published extensively on architectural conservation.

Judy Peters was a Kress Architectural Conservation Fellow working on the Save America's Treasures project with the Architectural Conservation Laboratory and Research Center at the University of Pennsylvania, Philadelphia, where she is now an adjunct faculty member teaching GIS for historic preservation.

Virtual Solutions

José Luis Lerma and Carmen Pérez

Whenever conservation work is ongoing, there is the possibility of discovering unique and impressive features from previous periods. In June 2004, during conservation of the baroque high altar in the Cathedral of Valencia, a member of the conservation team found Renaissance frescoes hidden above the false baroque vault.

Should the baroque vault be removed to expose the Renaissance frescoes? How can documentation aid in the technical and ethical decision making involved in resolving this issue?

A Renaissance angel, revealed within the baroque dome at the Cathedral of Valencia, Spain. The fresco had been hidden above the vault for centuries. Photo: © José Luis Lerma.

Valencia, Spain

The Cathedral of Valencia is one of the most important and venerated buildings in the city. Like most Spanish cathedrals, this 1262 structure exhibits a number of styles, including late Romanesque, Gothic, Renaissance, baroque, and neoclassical. Each of the three portals belongs to one style: Romanesque, Gothic, or baroque. The cathedral is mainly of early Gothic style, the main chapel is in the baroque style, and the two lateral chapels are neoclassical. The 68-meter-high octagonal bell tower, situated next to the main facade, is also Gothic and was built by Andrés Juliá between the end of the fourteenth century and the beginning of the fifteenth century.

In 1472, following a fire, the bishop of Valencia decided to redecorate the Gothic high altar in the Renaissance style. Renaissance frescoes were painted on the intrados of the Gothic vault by two Italian masters, Francesco Pagano and Paolo de San Leocadio, in 1474. They depict angels playing instruments against a golden, raised, starry blue-sky background. In 1682, during another redecoration, this time in the baroque style, these beautiful frescoes were hidden. Unlike other periods, baroque architects did not scrape off the frescoes but left a distance of between 0.5 and 2 meters, thus preserving the paintings over the centuries. The distance between both vaults is maximum at the keystone and increases toward the starting voussoir.

The Renaissance frescoes were discovered on June 22, 2004, when the main chapel and its high altar were being conserved. Although information regarding the redecoration was documented and archived in the Antigüetats, or Book of the Cathedral, the frescoes were believed to be in poor condition or forgotten. The frescoes are considered one of the most important examples of early Renaissance art in Spain. The general integrity of the frescoes has been well preserved over the centuries. However, certain areas presented color alterations and surface soiling due to candle smoke, humidity, and pollution. Cracking and flaking resulted in some material loss and required urgent conservation treatment.

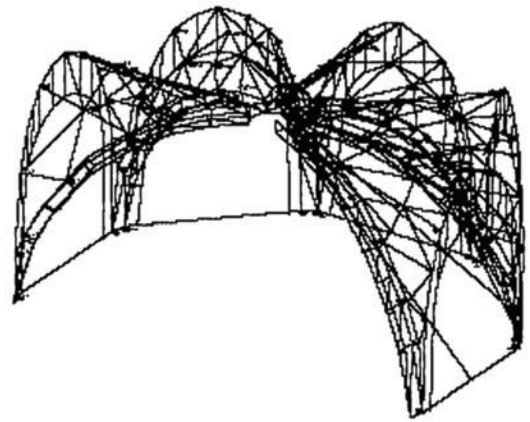
Following the discovery, conservators made small holes in the baroque ceiling to photograph the wall paintings. This attempt to document the frescoes failed because of the steep curvature of the vault, tight space, and general lack of light. However, it was essential to document the extent, beauty, and condition of the entire Renaissance ceiling in order to produce a record that would support conservation initiatives.

The goals of the documentation project were to provide a photographic record of the Renaissance frescoes to assess their condition, and to provide a composition of photographs that could visualize and model the Renaissance frescoes on the high altar. Because of the complexity of the architecture and assessment of previous documentation efforts, it was clear that a different approach was needed. The curved geometry of the space required the creation of a model that would allow viewing of the frescoes from many different perspectives.

The void between the domes inside the cathedral. The space was too narrow to view the paintings in their entirety. A camera inserted into the space was able to capture multiple details for later compositing of the entire scene. Photo: © José Luis Lerma.

Construction of the 3-D digital model required mapping the images to their positions on the digital structure. Photo: © José Luis Lerma.

A wire frame model over which the composite image of the entire scene was draped. Drawing: © José Luis Lerma.



3-D Modeling

The decision was made to create a 3-D digital model. This model could then be used before the conservation plan was designed and implemented. 3-D computer modeling was a necessary step to fulfill the original goal of creating a 2-D photographic record of the entire scene.

3-D computer modeling software uses XYZ coordinates to build a series of meshes that can be formed into different shapes to represent architectural elements. Images of the actual architectural elements can then be draped or projected over the surface of these meshes. The resulting images can be displayed and rotated on the computer to be viewed from different perspectives. This model can then be unrolled to view the photographic assemblage in 2-D. After an initial reconnaissance visit and assessment of the previous recording efforts, a feasibility study ratified the decision to create a 3-D model based on the complex geometry of the space.

Recording conditions created several constraints that limited the choice of tools to create a 3-D model. Lighting conditions made the survey process quite difficult. Furthermore, conservators made eleven unevenly distributed holes, each measuring less than 300 millimeters in diameter, thus limiting the type and size of equipment that could be used. Other tools were considered to document the entire ceiling. Endoscopic cameras, typically used in the medical field, were suggested because they could fit through the holes and navigate through the air space. However, these devices have a high level of lens distortion and low resolution. Laser scanning was also considered, but the equipment would have been too large to fit through the holes.

Data collection of images and spatial features was followed by processing this information using photogrammetric and graphic editing software packages. FotograUPV, a photogrammetric software developed at the Higher Technical School of Geodesy, Cartography and Topography, Polytechnic University of Valencia, was used to process the raw data. This led to the creation and presentation of the 3-D model before the restoration plan for the main chapel was developed.

The pictures of the curved surface of the frescoes were foreshortened. In order to create a distortion-free flat image, the images were projected onto the curved surface of a 3-D model. This model could then be unrolled to provide a 2-D image. 3-D modeling was also preferred because data could be collected quickly in the field using handheld instruments. The gathered information was relatively accurate and had good resolution. The modeling software package was inexpensive and easy to use, and the final model allowed the user to view the vault from different angles and visualize different conservation scenarios.

On-site work was carried out during two full days and included image collection and point measurements. A 6.3-megapixel digital single lens reflex (SLR) Canon D60 camera and a Sigma® 15mm super wide-angle lens were used. The camera was mounted on a tripod to avoid blurring. All the pictures of the Renaissance ceiling were taken at a fixed distance and at convergent angles. When possible, normal images of the baroque vault were also captured. An on-site calibration was performed to determine all the orientation parameters. 3-D coordinates for the targets were measured with a reflector-less total station theodolite. Therefore, angle and distance measurements were obtained for the targeted points to create a stable coordinate system.

Photogrammetry was undertaken for the purpose of creating the computer model from which the configuration of the Renaissance frescoes could be reconstructed. The goal was not to create architec-

Modeled reconstruction allows a visualization that removes the baroque dome while maintaining the ribs of the baroque vault, with views into the Renaissance dome. Photo-model: © José Luis Lerma.

tural drawings and sections of the altar but rather to make a realistic 3-D visualization. Information processing and the creation of the model took four months.

Color enhancements between overlapping images were required to guarantee picture continuity in both pre- and postprocessing. A numbering system was designed to record the set of ninety-five images collected for this project. The numbering system determined not only orientation and angle of the pictures but also outline, clearness, and illumination quality. Using the commercial graphic editing software Adobe Photoshop, images were rectified, color adjusted, and stitched to create a photomosaic of the baroque reredos, the Gothic arches, and the Renaissance frescoes.

The raw coordinates of the measured points were used to create two 3-D models, one of the baroque vault and vertical walls, another of the Gothic vault with the Renaissance frescoes. Finally, the textured images were projected over the wire frame of the models.

Virtual Reality Modeling Language (VRML) was selected for the visualization and interaction of the reconstructed model. VRML is a file format for describing interactive 3-D objects. It is designed to be used either on the Internet or on local computer systems. Once "inside" the model, the user can choose different modes of navigation (walk, fly, or examine) and different viewing perspectives. For ease of navigation throughout the visual photo-model of the Renaissance frescoes, some viewpoints were defined at specific locations, and animations of various fly-throughs were implemented.

The physical constraints of the space between the vaults and poor lighting conditions affected the recording process. Automatic image manipulation software was not suitable for color and orientation adjustments. The use of manual graphic editing software extended the processing time. Rectification with this type of software, usually used for 2-D data, was more difficult with the 3-D data for the Renaissance frescoes. In addition, use of this tool required extensive knowledge of the geometry of the objects.

The cathedral's Renaissance dome, before the removal of the baroque vault. Photo: © José Luis Lerma.

An Answer

The stitched image of the Renaissance photo-mosaic was projected back to the original input view in order to simulate the visualization of the beautiful, colorful frescoes when viewed from the bottom of the high altar. Different scenarios were also visualized on the 3-D models, with various surface projections to simulate several conservation proposals. Further image-based reconstruction features suggested by the conservators, such as keystone and ribs, were draped over the model.

This virtual reconstruction and visualization allowed architects, conservators, historians, engineers, and decision makers to analyze and predict future interventions on cultural heritage objects and sites and their surroundings prior to restoration and conservation. Graphic documentation, visualization, and modeling of the initially occluded Renaissance frescoes were vital in persuading professionals and stakeholders of the need to dismantle the baroque vault not only for viewing the paintings from the early Renaissance period but also for their conservation.

In 2005, the baroque vault was carefully dismantled except for the ribs. Each feature was numbered and safely stored in such a way that future reconstruction of the vault will be possible after conservation of the frescoes. In addition, the photogrammetric survey constitutes an archive that could guarantee the replacement of both the baroque vault and the Renaissance paintings either in the high altar of the cathedral or in another context.

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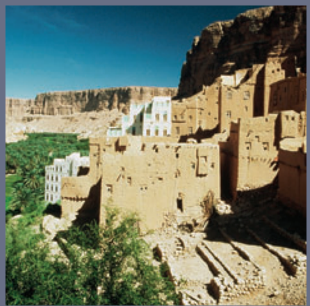
Carmen Pérez is an art restorer and professor of fine arts in the Department of Conservation and Restoration, Polytechnic University of Valencia, Spain. She is the current secretary-general for ICOMOS Spain, director of restoration works at the high altar of the Cathedral of Valencia, and director of the Valencian Institute for Conservation and Restoration of Cultural Heritage. Dr. Pérez has authored more than fifty papers in magazines and journals.



OTHER TOOLS FOR INVESTIGATION AND MONITORING

Overview of Diagnostic Indirect Tools for Conservation

John A. Fidler

Tools and techniques for the surveying, recording, and documentation of historic places are part of a diverse and complicated field. When applied in the service of conservation rather than for academic research purposes or as part of an archaeological investigation, the application of the equipment and methods to achieve specific conservation-related outputs becomes particular and essential, driven by the needs of the architects, engineers, and conservators involved in the conservation process.

Too often the dialogue between surveyors and conservators becomes mired in the technical language of their respective professions—language that neither party fully understands—often leading to differing expectations. When conservation professionals do not have the option of delegating surveying, recording, and documentation to others, or wish to deliver these components themselves, the integration of actions is often more successful. The problem comes with larger, more complicated projects in which specialist equipment, software and data manipulation, and other complexities are required for cost-effective delivery. This section attempts to define and explain the types of tools available and place them in a conservation context, prior to describing their function and use in more detail.

In conservation, there are two distinct areas of survey and recording, with a degree of overlap between them:

1. **Metric surveying and recording.** This area is used to establish the quantifiable physical disposition of form and space. Base documentation can be employed in subsequent complementary phases of a conservation project to map historical, technical, and other data for assessment, analysis, and synthesis of information to create a plan, then inform, guide, and instruct others in taking conservation action.
2. **Diagnostic surveying and recording.** This area is used to locate, isolate, assess, or monitor physical phenomena affecting the heritage asset. Additional documentation can overlay base documentation and further inform the conservation project's development in relation to buried or concealed features, deforming or moving components and providing indications about their condition and performance in time.

Some tools, such as tape measures, levels, and total station theodolites, involve direct handheld or hand-eye relationships with the operator that are generally simpler to understand and use and are cheaper to operate than indirect tools. Indirect technology such as radiography or thermography—often from the medical, aviation, or military arena—requires specialized operators and software as well as expensive equipment whose documentation needs to be interpreted for the conservation team to benefit from the data. Although many pieces of equipment and their associated software are being simplified by their manufacturers to the "point-and-shoot" kind of format of, say, a digital camera, they remain expensive items usually contracted temporarily or deployed as part of a subcontractor's hardware. The following is an overview of the diagnostic indirect tools available for conservation.

Water Optical and Digital Endoscopy

The simplest way to describe endoscopy is to use the analogy of a periscope: it enables operators to look through a long, rigid, or flexible tube inside the fabric of a building through holes as small as 4–5 millimeters in diameter. Until the recent development of tiny digital cameras with motorized focusing, endoscopy used light-guide bundles of fiber-optic cables to transmit light into cavities, collect received light, and pass images back to the eye. With range-finding optics, the equipment can be used to determine the location or dimensions of cavities or objects, assess the condition of concealed pipes or fixings, or aid the routing of wiring within composite construction.

Water, Plumb, and Laser Leveling

To assess the trueness, level and relative levels, and plumb or vertical nature of an element of construction–for example, subsiding floors, leaning walls, or sagging beams–a variety of levels can be employed for repeatable measurements. The simplest and one of the oldest construction tools is the plumb bob. A heavy weight is suspended on the end of a long string or wire, which is hung vertically from the top of a structure. The base of this pendulum is then suspended in water or oil to minimize movement. The vertical line can be measured at fixed points against the structure to determine the lean of the wall. Laser plumb bobs are used in the same way.

The term *laser* is an acronym for light amplification by stimulated emission of radiation. Lasers emit light in a narrow, well-defined beam within a coherent set of wavelengths, and over short distances are extremely straight. Used horizontally, lasers can be used to align features, determine disposition or deflection, and measure angles. A simpler, cheaper tool is the water line level, which consists of a flexible, small-diameter plastic or rubber hose pipe with open ends to which plastic or glass ends are added. The hose is filled with water and the two ends moved up or down, even around corners, and the horizontal level is determined by equalization of atmospheric pressure.

Oblique Angle and Color Filter Photography

A simple method of finding concealed doorways or window reveals under plastered or stuccoed walls is to use oblique angle or color filter photography. Oblique angle photography captures subtle shadow lines of inconsistencies and changes of plane in plaster surfaces. Color filter, or colored light, photography captures partial and different reflectances in surfaces and helps to reveal patches and changes in surface under coatings.

Infrared Photography and Thermography

Infrared film photography is being superseded by thermography or thermal imaging, a type of infrared imaging used to discern concealed openings and other anomalies under the surfaces of historic facades and internal paneled walls. Thermographic cameras detect radiation in the infrared range of the electromagnetic spectrum (roughly 900–14,000 nanometers, or 0.9–14 μm) and produce images of that radiation. Because infrared radiation is emitted by all objects based on their surface temperatures, thermography makes it possible to “see” variations in temperature caused by different materials, voids, and other changes of construction.

Radiography

Shorter energy wavelengths are necessary to deploy radiographic imaging to “see” concealed objects within the historic fabric and record it on film. X-ray radiography in the range of 15–33 kilovolts can be used to find and assess the condition of timber framing under plasterwork, or of floor construction without lifting carpets. Linear accelerator (LINAC) radiography and gamma radiography have also been employed in the megavoltage range to locate and quantify steel reinforcement in bridge decks or corroding buried wrought iron in the stonework of lighthouses and country houses.

Magnetometry

Magnetometer surveys are a type of geophysical mapping technique that relies on the stability of the world’s relatively static magnetic field. These surveys can detect anomalies caused by cultural objects interfering with that magnetic field. They can be used to locate long-forgotten conduit systems, as well as pipes, cables, or remains buried in the ground.

Metal detectors are employed for pachymetry (e.g., thickness) measurement in masonry structures by utilizing electromagnetic induction to detect underlying metalwork. They are used especially in the construction industry to detect and size steel reinforcing bars buried in concrete, as well as pipes and wires buried in walls and floors. In its simplest form, a metal detector consists of an oscillator, which generates a current that passes through a coil, producing an alternating magnetic field. If a piece of metal, which is electrically conductive, is close to the coil, eddy currents will be induced in the metal; this in turn produces an alternating magnetic field of its own. If another coil is used to measure the magnetic field (acting as a magnetometer), the change in the magnetic field due to the metallic object can then be detected.

Ultrasound Pulse Transmission

Ultrasound surveys and testing, or sonography, constitute a diagnostic imaging technique used to measure the thickness from one side of solid, dense, homogeneous materials and to detect flaws and anomalies in their interiors. The technique has been used, for example, on the Houses of Parliament, in Britain, to measure the thickness of corrosion layers on the underside of the cast-iron roof without lifting the panels. It is a nondestructive testing process utilizing sound frequencies in the 2–10 megahertz range, though for special purposes other frequencies are used; for instance, lower-frequency ultrasound (50–500 kilohertz) to inspect lower-density materials such as wood. In France, the technique is used to assure the quality of quarry stone before processing by searching for concealed cementation lines and fossil anomalies that may break or cause misalignment of saws during cutting.

Pulse Radar

Radar is an acronym for radio detection and ranging. When fired at the ground or at a thick masonry structure, long-wave radiation is partly reflected at the surface, partly absorbed, and partly transmitted through the construction. Reflections and echoes from this energy are transmitted back to the receiving antennae, and the time delays in transmission and losses in signal strength are compared to those in the original signal to reveal changes in the data. When interpreted, radar information can locate and measure the distance between and size of inconsistencies and anomalies within a structure. The geometry of such concealed or buried objects–for example, wrought-iron cramps in stone masonry, reinforcing bars in concrete, or ceramic pot fillers in concrete floor construction–can reveal the nature and sometimes the condition of these materials.

Radio Emission or Electrolocation Cable/Pipe Detection

All live electrical cables, and all electrically conducting materials through which an electrical current can be induced, will emit an electromagnetic field in the range of 50 hertz to 400 kilohertz (from low- to high-frequency power) that can be detected by a radio detector. As the energy travels a given distance, and if the detection devices have two radio antennae set at a precise distance apart, the depth within the ground, wall, or floor of the cables or metalwork can be calculated. This electromagnetic time domain reflectometry is used to locate modern electrical systems that are in need of replacement in historic buildings. Once identified, removal of the system can be carried out without excessive damage to the original fabric.

Stress-wave Transmission (impact-echo)

Using transducer technology, surface and subsurface vibrations in structures can be detected and used to determine anomalies, voids, and other construction problems in otherwise homogeneous construction. First, the heads of the transducer are placed on either side of a masonry column, for example, or along the side of a historic railway's viaduct. The structure is then hit or impacted with a known measured force or drop hammer so that the superstructure vibrates and measurements can be taken of the signals. If there are asymmetrical patterns in the signals, estimations can be made of construction voids and their location and depth within the fabric.

Transducer Movement Sensing

Linear variable differential transducers and accelerometers are devices that translate physical structural movements (displacement and shear) and vibrations into electrical signals that can be collected and analyzed. The pistonlike transducers are fixed across cracks on a building. Wires are then attached that lead to a data logger or convenient interrogation point. The "piston" arm is made of ferrous magnetic material and moves freely backward and forward within an electrical coil as the crack on the building moves. This alters the electrical voltage of the system and the resultant changes are registered on the data logger. Automated systems with telemetric connections monitor historic bridge movements in many cities today. The Tower of Pisa, in Italy, was monitored in Watford, England, in real time using these devices, which measured rate and degree of the tower's tilt, subsidence, and crack and arch deformation.

Many of the aforementioned devices use nondestructive or keyhole surgery techniques to aid conservation of valuable historic fabric. Some devices are expensive to purchase and use, others more economical to buy or lease when needed. But none is a substitute for a keen eye, patient assessment, and human logic, all of which will always be needed to conserve the best of the past for the future.

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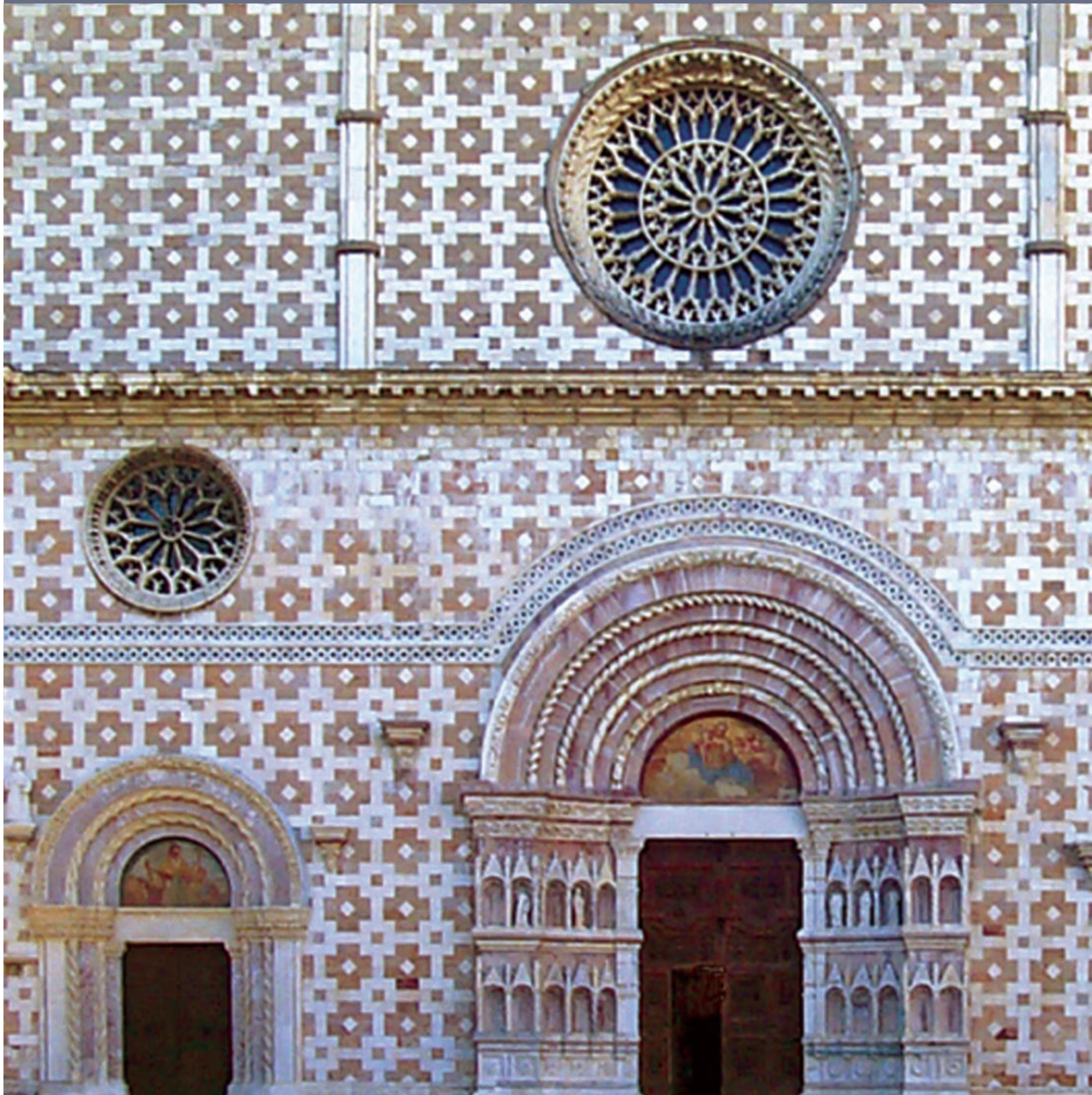
Subsurface Conditions

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

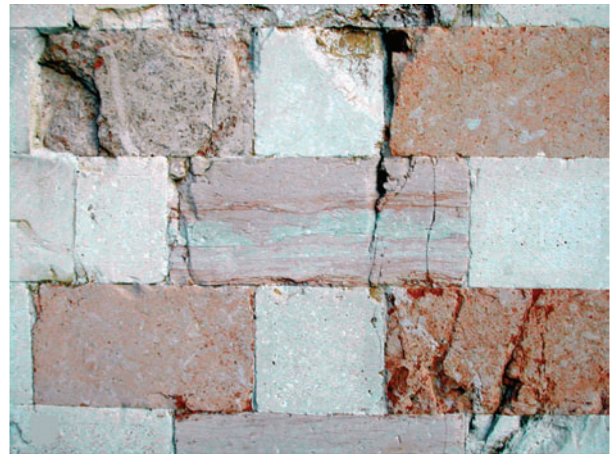
The Basilica of Santa Maria di Collemaggio stands on the site where a traveling hermit named Peter of Morrone, founder of the Celestine order, spent the night after meeting with the pope. The Virgin Mary appeared to the hermit in a dream and asked him to build a church in her honor. Construction of the 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.

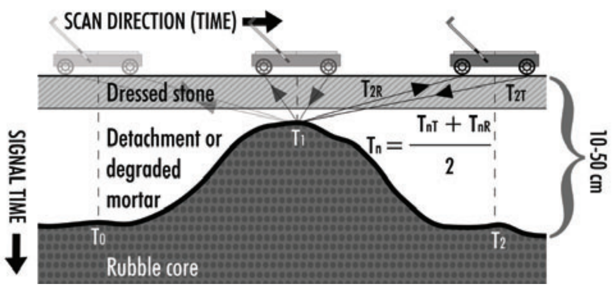
Ground-penetrating Radar

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.

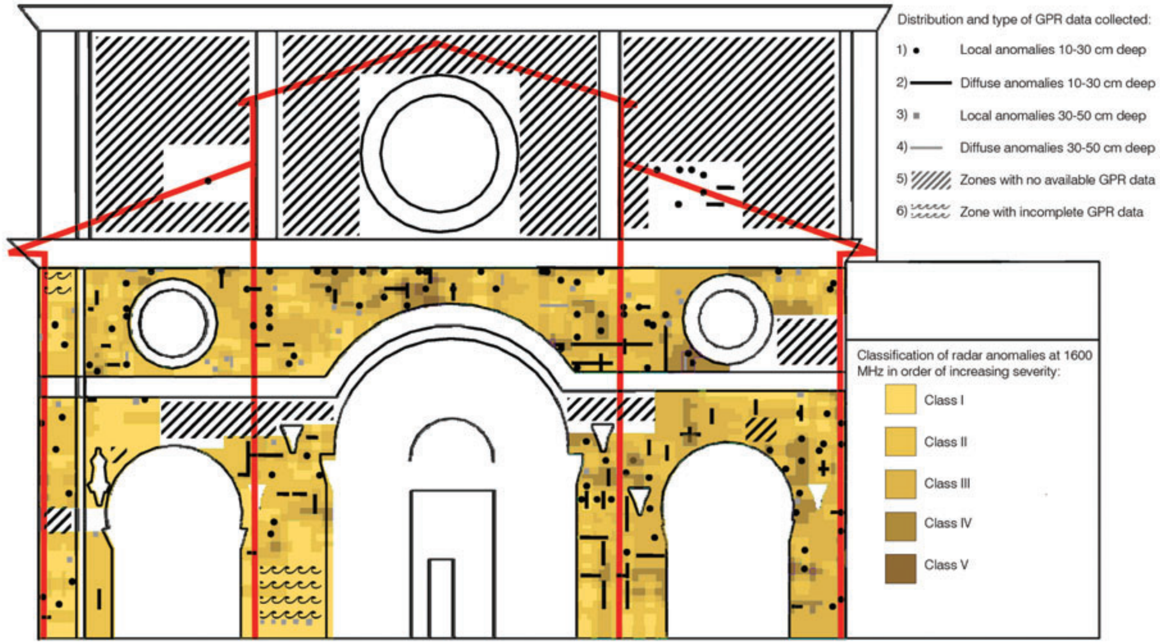
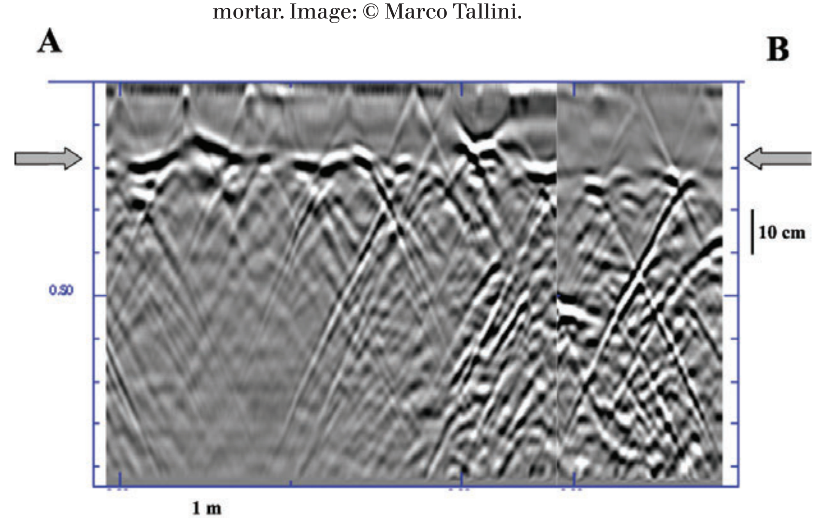


Diagram of the basilica, showing radar anomalies (1600 MHz) after filtering and rasterizing. Colors show anomalies classified according to increasing gravity (classes I–V). Diagram: © Marco Tallini.

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.

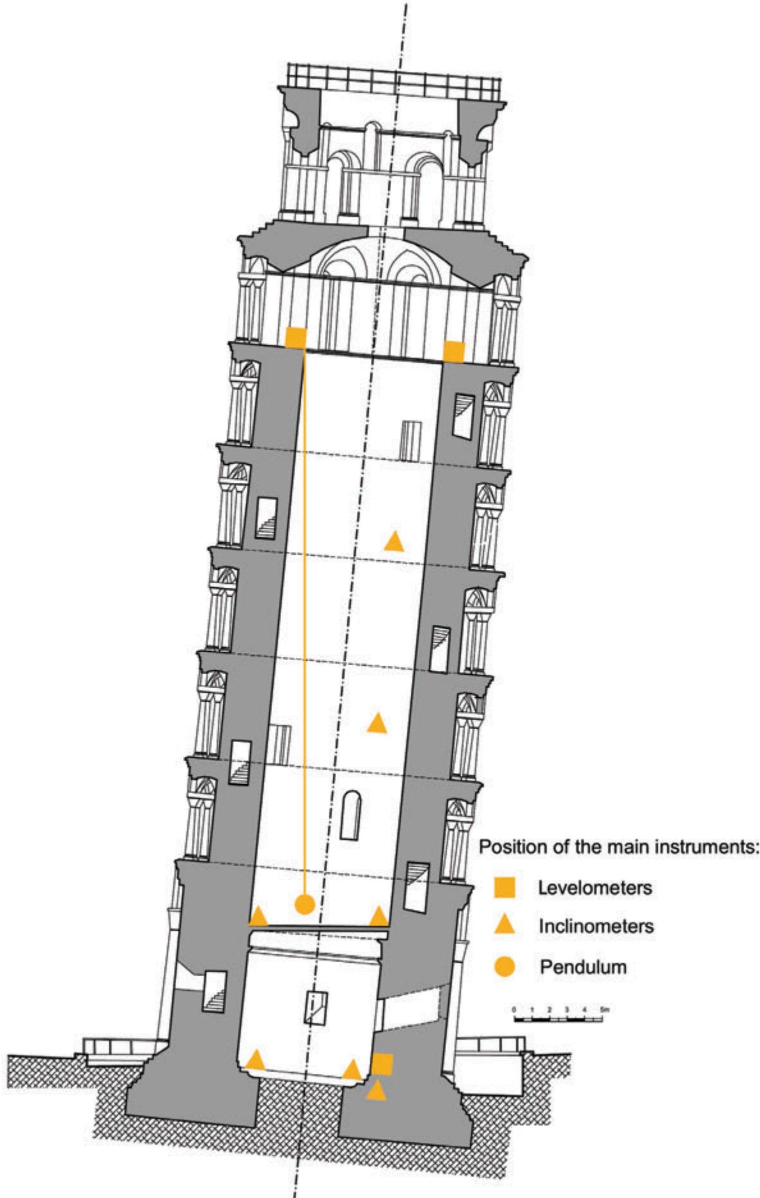
Automated Monitoring System

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.

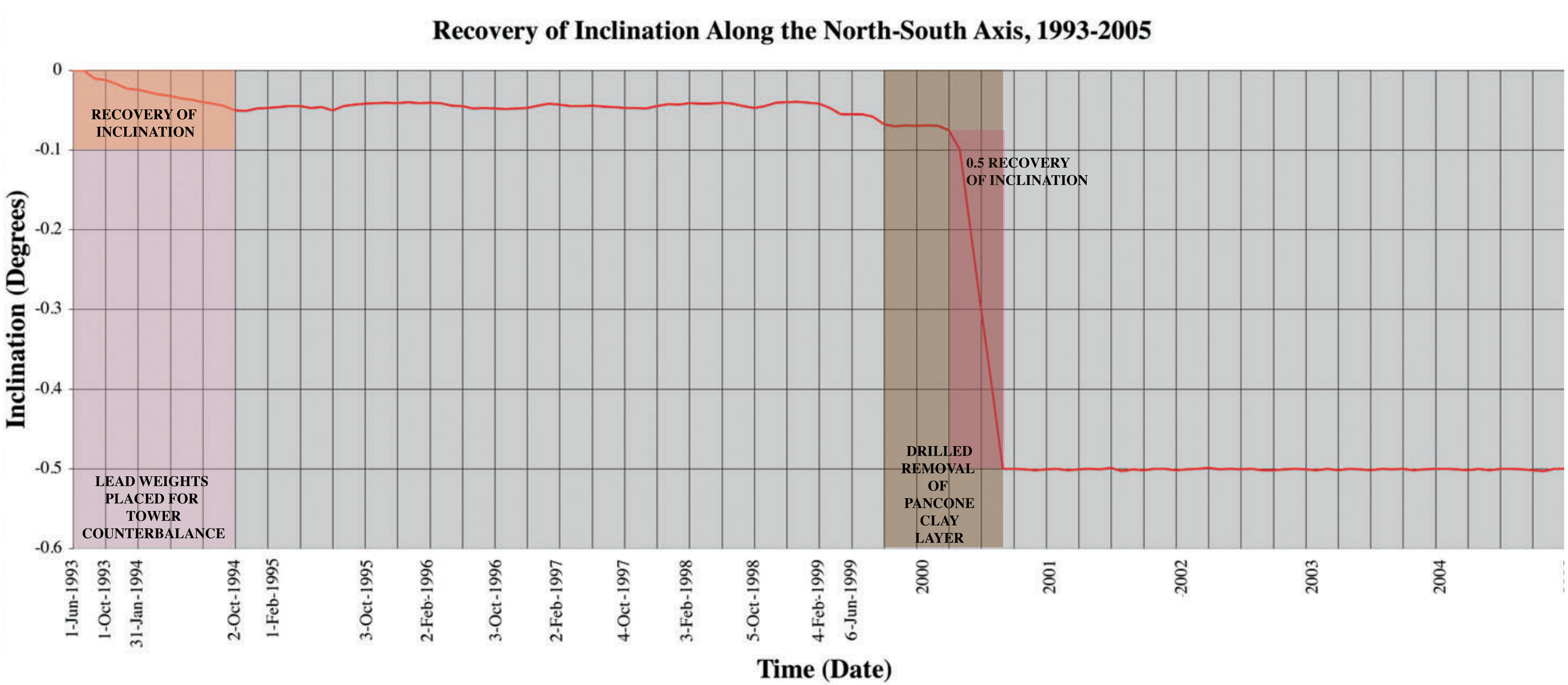
movement is due to a strong wind, a sunny day, or, more important, their intervention or an impending failure. A weather station was positioned on top of the tower to record wind direction and speed, ambient temperature, and radiation from the sun. Thermometers were placed inside the masonry on different 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.

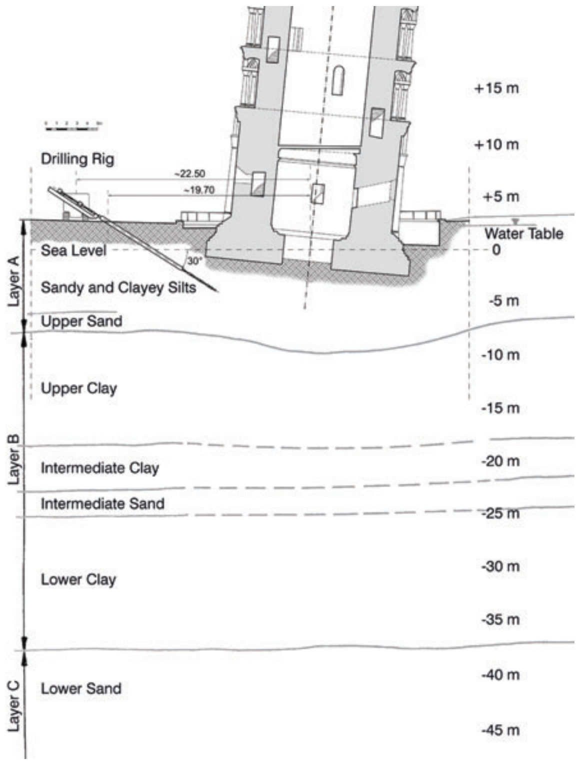


An Answer

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.

Traditional Techniques

Caterina Borelli

For centuries in the Hadhramaut Valley, in southern Yemen, the sole means of construction was mud brick. In response to the changing needs of the local communities and the development of the paved road network, new materials and technology have been introduced that threaten to transform the built environment and erase a timeless tradition of local building techniques.

How can these building techniques and traditional skills be recorded? How can this record help conserve this unique built environment?

This illustrated example was part of a project done in collaboration with architectural conservator Pamela Jerome. A technical paper on the subject was also published.

View of Wadi Do'an, at Al Gorha. The village's traditional earthen construction allows the structures to blend in to the surrounding cliffs and contrasts with the green valley floor. Photo: © Pamela Jerome.

Modern concrete and block constructions in Wadi Hadhramaut. Photo: © Pamela Jerome.

Abandoned historic building in Wadi Hadhramaut, in disrepair. Photo: © Pamela Jerome.

Hadhramaut, Yemen

Wadi Hadhramaut is an inland valley in a desert region that consists of a network of smaller, subsidiary valleys. Villages are built along the edges of the lush, cultivated valleys, and houses blend into the surrounding landscape .

Centuries of building with local mud, straw, and lime have created a landscape of incredible multi-storied buildings that reflect a refined construction technology. In 1982, UNESCO recognized the unique natural and cultural environment of the wadi and included it in its nomination of the walled city of Shibam as a World Heritage Site.

The lack of resources and the remoteness of the region restricted economic development, and the built environment remained unchanged until the early 1990s. Following the unification with North Yemen, more attention was given to the area. Roads were paved to facilitate access to the Indian Ocean and inner valleys. Water, electricity, and cement became more easily available. To provide for the resulting building boom, new building techniques were introduced, reflecting the changing needs of the population.

The practice of traditional building and maintenance techniques began to fade away. Where skill and time were once essential to building with mud bricks, less experienced masons can now build with concrete in a matter of days. Historic buildings have been neglected, abandoned, and left in disrepair. Every step of the traditional building process known by the local masons, and their oral histories and impressions, needed to be documented to produce a durable and informative record.

Video Technology

Documentary video was the tool chosen to thoroughly record the buildings, construction technique, and living heritage of Wadi Hadhramaut. Structure and production were conceived based on preparatory research and on the interaction between the filmmaker and the architectural conservator Pamela Jerome. The filmmaker served as director, producer, camera operator, and sound person. The architectural conservator conducted the interviews, wrote an academic paper describing in detail the building technique, and advised on the content of the video. The filmmaker visually translated the issues and points of relevance that surfaced from this interaction with the architectural conservator, making informed decisions that gave the film greater value. As part of the preproduction phase, a scouting trip was conducted to establish contacts and determine if it was possible for a woman to travel freely in the area and carry out this project. Finally, fund-raising to cover the

Field equipment used to make the documentary video, including a mini–digital video camera (DV cam pictured), tripod, extra rechargeable batteries, microphones, and various tools for work in the field. To protect the equipment from dust and sand, the camera and tapes were stored in resealable plastic bags. Photo: © Caterina Borelli.

Recording the video documentary on site in Wadi Hadhramaut, Yemen. Photo: © Caterina Borelli.

Series of stills from the documentary, showing workers in Seyoun creating mud bricks for new construction. Soil is gathered and mixed with straw and water. The mixture is spread out evenly in a mold, which is lifted immediately. The mud bricks are then left to dry in the sun for a week. Photos: © Caterina Borelli.

Series of stills from the documentary, showing workers erecting a new building. After the stone foundation is laid, the mud bricks are stacked to build a wall. Photos: © Caterina Borelli.

Series of stills from the documentary, showing the completion of a building. Workers are finishing off the new roof with mud. Photos: © Caterina Borelli.

Series of stills from the documentary, showing the process involved in maintaining traditional buildings in Hadhramaut. First, limestone rocks are fired in kilns. The resulting product, quicklime, is then slaked and used to waterproof, decorate, and white-wash earthen buildings. This practice is carried out regularly as part of the ongoing maintenance. Photos: © Caterina Borelli.

project's cost was an important and challenging endeavor that was partially met through a grant from the American Institute for Yemeni Studies.

Small-format video was used because it produces a broadcast-quality product, is small and portable, and is relatively inexpensive. Filming the documentary took two months and was conducted with a Sony Handycam VX1000 on a sturdy, fluid-head tripod. Often no electricity was available, so it was essential to have on hand a number of extra rechargeable batteries to power the camera. Various lenses were used, the most valuable being a wide-angle. Strong natural light was abundant, eliminating the need for supplemental lights; however, under certain circumstances a silver reflector was used to harness the natural light. In addition, a polarizing lens filter was used to enhance the natural light.

Sound was extremely important, and three different types of microphones were used to cover all situations. Two wireless radio microphones including a lapel microphone were used for interviews. A Sennheiser shotgun microphone captured more precise areas of sound. Headphones were used to check the sound recording in the field. The recording medium was Sony high-grade mini–digital videotapes. These tapes and the camera were placed into resealable plastic bags to protect them from sand and dust. Each tape was carefully labeled and protected from erasure by using the switch on the videotape. At the end of each day of filming, a diary entry was made of where and when the video was captured. Canned air was used to clean the camera every night.

Ongoing maintenance efforts in Hadhramaut also involve plastering the exterior of buildings with mud to conserve the mud-brick construction. Photo: © Caterina Borelli.

An Answer

More than thirty-five hours of video were shot. With the help of an assistant, the footage was extensively logged and the time code noted for every scene, interview, and sound. A backup of the tapes was made. The footage was then assembled into a rough-cut version that was reviewed by the filmmaker over a two-month period. After decisions were made regarding content and storyline, the footage was input into an Apple Macintosh computer and edited by a professional editor using Media 100, a computer software program. Excerpts from historic travelogues were later inserted to underline changes in the local environment. Technical content, language, and texts were verified during postproduction. Editing took approximately four months.

The final product is a one-hour documentary, *The Architecture of Mud,* in which every step of construction, from laying the foundation to the final quicklime waterproofing, is described in images and in the words of local masons and workers. It offers a thorough record of the built environment: villages, housing interiors and exteriors, and local traditions. The documentary was premiered at the Museum of Modern Art, in New York City, and has received accolades from professional conservators and filmmakers.

Video technology proved to be a very effective tool in many ways. First and foremost, it provides the necessary visual documentation should the need arise to recall a particular technique, consistency of material, work order, or style. Upon completion of the documentary, an Arabic version was screened in Yemen. During the screenings in the villages, the master builders who were present expressed their approval by spontaneously commenting for the audience. This communicated to the workers the importance of their craft and emphasized its significance worldwide. Positive reaction to the film created a climate of dialogue, trust, and respect, and has paved the way for implementation of new collaborative projects in the region.

Furthermore, because it addresses a general audience, the documentary reached far more people than expected and has been used as a didactic tool in academia and in museums around the world. The film provides a general foreign audience the opportunity to rethink some of their preconceptions of the regions and cultures of the world. At the same time, an informed foreign audience can find in the work many opportunities to reflect on issues related to architecture, preservation, ethnography, visual anthropology, Indian Ocean trade, and Middle Eastern studies.

Caterina Borelli is an independent director and producer based in New York and Rome. Her latest documentaries focus on the relation between architecture, tradition, and conservation. She has recently completed a documentary on the architecture of Asmara, the capital of Eritrea, focusing on the recognition of heritage in places with a colonial past.

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.

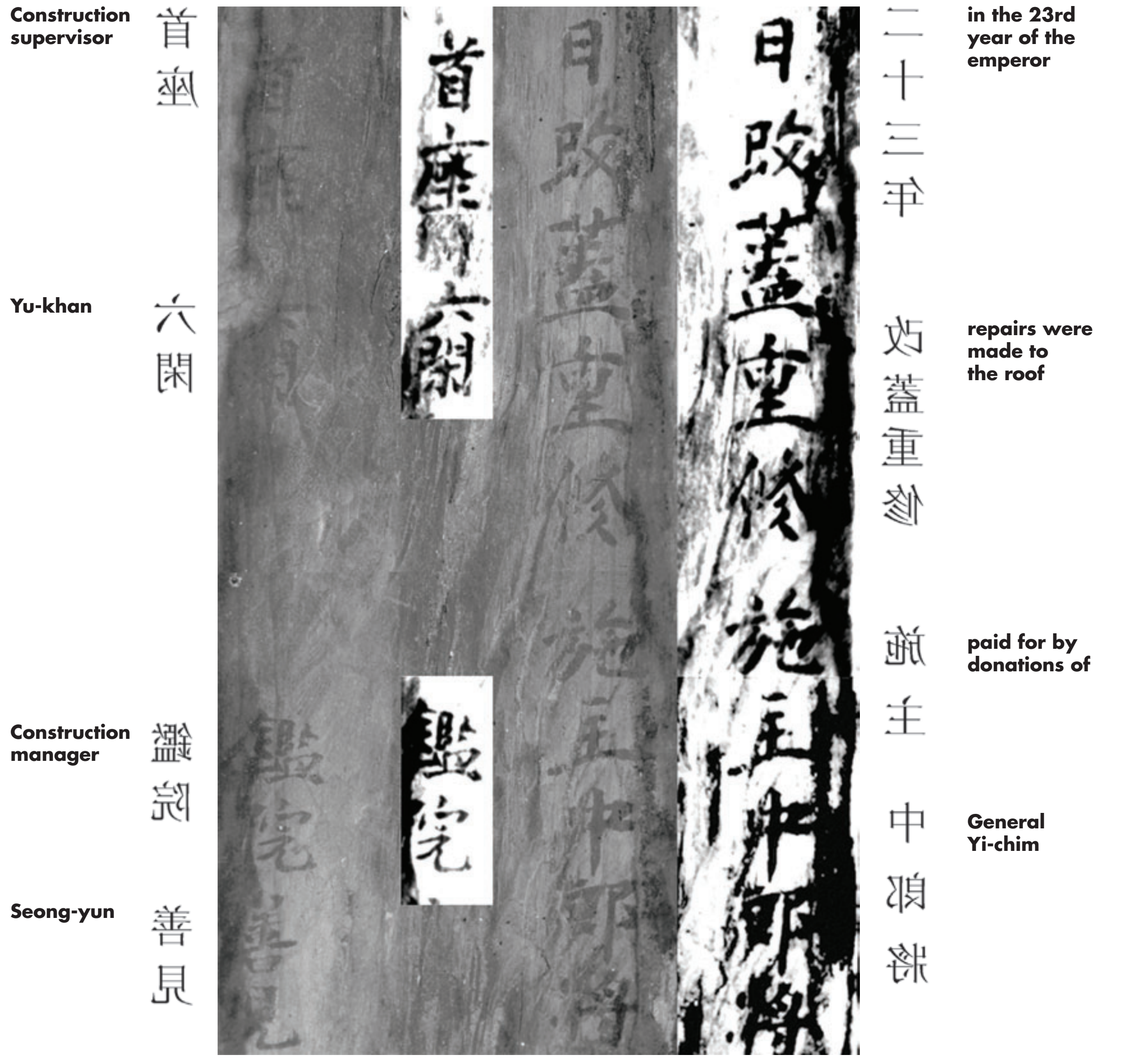
IRR instrumentation is affected by environmental conditions such as ambient temperature and humidity and is very sensitive to light and motion. Therefore, members of the study team carefully controlled their surroundings by positioning the instrument on a flat, stable work surface and maintaining uniform 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.

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APPENDIX

B

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International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM)
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GLOSSARY

Aerial photography. Aerial photography is the capturing of images of a site or location from an aircraft. It provides an efficient and effective means of quickly documenting the condition of a large site or a number of sites. It documents many relevant matters and, if sufficiently detailed, can be a substitute for conventional mapping and for monitoring purposes. There are two general sources for obtaining aerial photography: archival research and commissioning flights. Archival research is a cost-effective means of acquiring images of a site taken for other reasons such as road engineering or national topographic mapping programs. Aerial images obtained by commissioning flights can be vertical (straight down) or oblique (taken at an angle). Professional companies usually take vertical images by using expensive, extra-large-format film or digital cameras mounted in the belly of a small airplane.

Automated monitoring system. An automated monitoring system contains a large number of different sensors and devices that collect various data measurements. These include but are not limited to inclinometers, to measure the degree of inclination; levelometers, to measure differential settlement; weather stations, to measure wind speed and direction and ambient temperature; and strain gauges, to measure crack propagation. These devices usually are connected to computers to give continuous data to engineers.

Computer-Aided Design and Drafting. Computer-Aided Design and Drafting (CAD) is software into which measurements, data, and images from multiple tools and methods can 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, CAD allows images to be imported and data added manually or input directly from survey instruments. Data can be displayed in different ways, including 2-D orthographic projections or 3-D isometric, or perspective, views. Information can be divided using multiple layers, or views, which can then be recombined in various ways.

Database. A database 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 that allow the data to be linked together and queried in various ways. The database can connect the separate pieces of information together.

Geographic Information System. A Geographic Information System (GIS) is a geographic database that combines spatial information in graphic form with tabular data. It is an effective descriptive, analytical, and communication tool to map and assess sites and prioritize necessary work.

Global Positioning System. A Global Positioning System (GPS) is a navigation and mapping tool that employs special equipment to receive radio signals transmitted from a network of twenty-four satellites circling the Earth twice a day in precise orbits. It allows the rapid acquisition of detailed and comprehensive data with pinpoint accuracy. Two categories of GPS radio receivers range in accuracy. For these two categories, accuracy can be improved to several centimeters with a differential signal, which is a ground-based radio transmitter. This base station transmits radio signals that supplement the radio signals from the satellites. Amateur or handheld GPS devices are not corrected by a ground-based station and range in accuracy between 5 and 15 meters.

Ground-penetrating radar. Ground-penetrating radar (GPR) is a nondestructive technique that uses electromagnetic waves to investigate the underground or internal structures of natural and human-made objects. It has been used successfully in investigating the characteristics of and damage to walls and masonry structures, such as voids, detachment, cracks, leaks, and deteriorated mortar joints. GPR has a good level of accuracy and is easy to handle and transport. 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, which are reflected in the return signal.

Infrared reflectography. Infrared reflectography (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. IRR 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.

Laser scanning. Laser scanning uses various scanning technologies to provide a 3-D record of a surface. In general, these technologies are based on one of three methods: (1) time of flight, in which a laser pulse is emitted and the time of light travel is measured; (2) phase comparison, in which the instrument emits a known frequency of light and compares the returning phases; and (3) triangulation, in which an emitter and receiver are separated by a known distance and the angle of the reflected laser is used to determine distance. With these technologies, XYZ coordinates are recorded as millions of individual points. Close together, these individual points form a point cloud from which a "mesh" can be generated to create a 3-D model.

Manual recording techniques. Manual recording techniques use tools such as plumb bobs, measuring tapes, and paper and pencil to record buildings or sites. Although often labor intensive, these techniques are readily available and allow the study of buildings or sites in great detail. Usually this method of recording provides sufficient information and accuracy with which to begin conservation.

Photogrammetry. Photogrammetry is a survey technique in which a 2-D or 3-D object may be measured from photographs taken from slightly different positions. These stereographs provide two different views of the same object that mimic the perspective of human binocular vision. Measurements are extracted from the stereographs, and 3-D information is reconstructed using computer software and hardware.

Rectified photography. Rectified photography is based on the concept of bringing the surface of an object, say a building facade, and the plane of the image (photograph) into parallel. Rectification removes perspective, angle, and camera lens distortion, and creates a measurable image that is on the same plane as the building. It is inexpensive and quick to carry out, requires minimal training, and does not require high-tech equipment. Image rectification can be carried out with or without measurement control points on the object. Control points can be measured using a tape measure or survey instruments (total station). These measured distances correct the angle or tilt in the original image while retaining the correct proportions of the building.

Sketch diagram. A sketch diagram is an investigative and interpretative drawing tool that combines various methods of recording to understand a site, building, or object. The diagram represents the relationships between elements in order to understand how they interact. It also facilitates communication about these key elements.

Three-dimensional computer modeling. 3-D computer modeling is software that processes XYZ coordinate points and builds meshes that can be formed into different shapes to represent architectural elements. Images of the actual architectural elements can then be draped or projected over the surface of these meshes. The resulting images can be displayed and rotated on the computer to be viewed from different places.

Total station theodolite. A total station theodolite is a standard survey device consisting of a powerful telescope mounted on a base that rotates both horizontally and vertically. An operator can locate points by measuring distances through an electronic distance measurement (EDM) device as well as horizontal and vertical angles. Trigonometric calculations are performed by an onboard computer, combining the horizontal and vertical angles with the EDM to determine an XYZ coordinate. A series of points can be combined to form lines and planes, thus representing the object being recorded.

Transparencies. Transparencies are clear plastic sheets used as overlays on which conditions can be recorded. They provide a simple but systematic method of recording conditions manually over a printed and scaled image base map. Conditions are then digitally scanned and incorporated back into the base map.

Urban study. An urban study is a detailed survey of a historic urban environment. It provides answers to important questions related to problems, deficiencies, and economy, and identifies general planning measures and specific actions required. Reconnaissance of the historic area focuses on six key issues. The first two, buildings and open spaces–the solids and voids that constitute the urban fabric–are the essence of the historic city and embody its character. The remaining four–people, land use, traffic, and infrastructure–determine the function of the historic core and have a direct impact on its long-term survival and well-being.

Video technology. Video technology is an electronic tool used to capture and process a large number of images and sound in sequence. It is therefore the ideal tool to record motion and processes. Video is also referred to as the technology used to edit and transmit images and sound.

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