


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

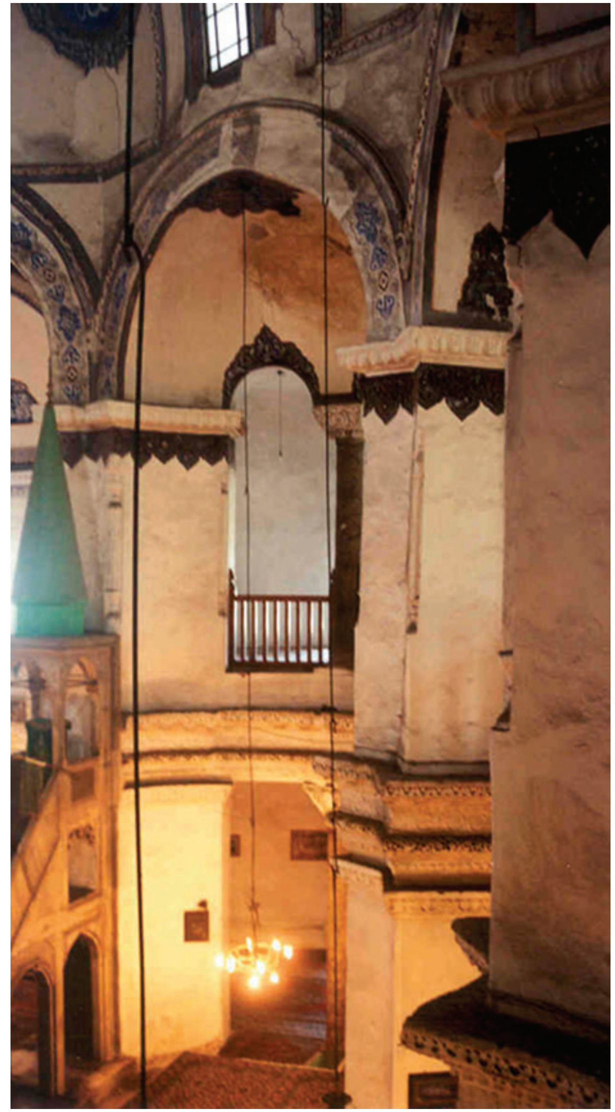
Küçük Ayasofya has an irregular square plan enclosing an octagonal nave, a half-hexagonal apse, and a rectangular narthex. These irregularities may be partly due to the fact that the original church was fit between two existing buildings: the Church of Saints Peter and Paul, and the Palace of Hormisdas, 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.

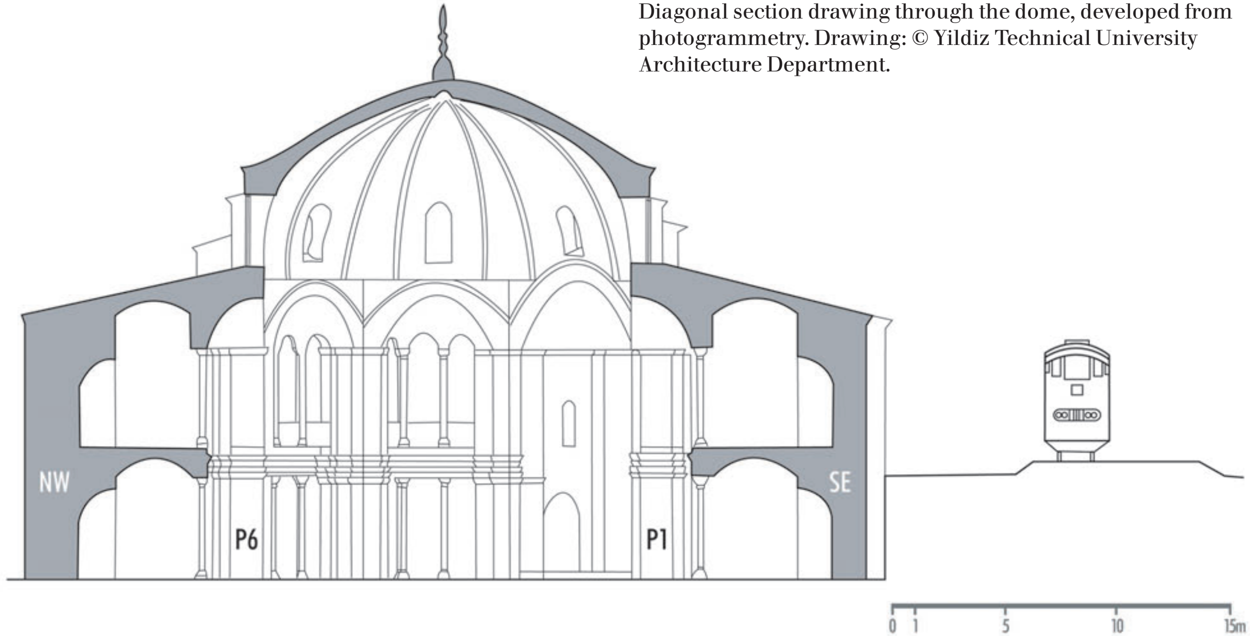
Photogrammetry was chosen because it was the only tool capable of helping the survey team visualize the complex geometry of the dome, understand the load distribution on the support systems, and locate the structural irregularities caused by vertical deviations and rotations. Measurements could be obtained 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.

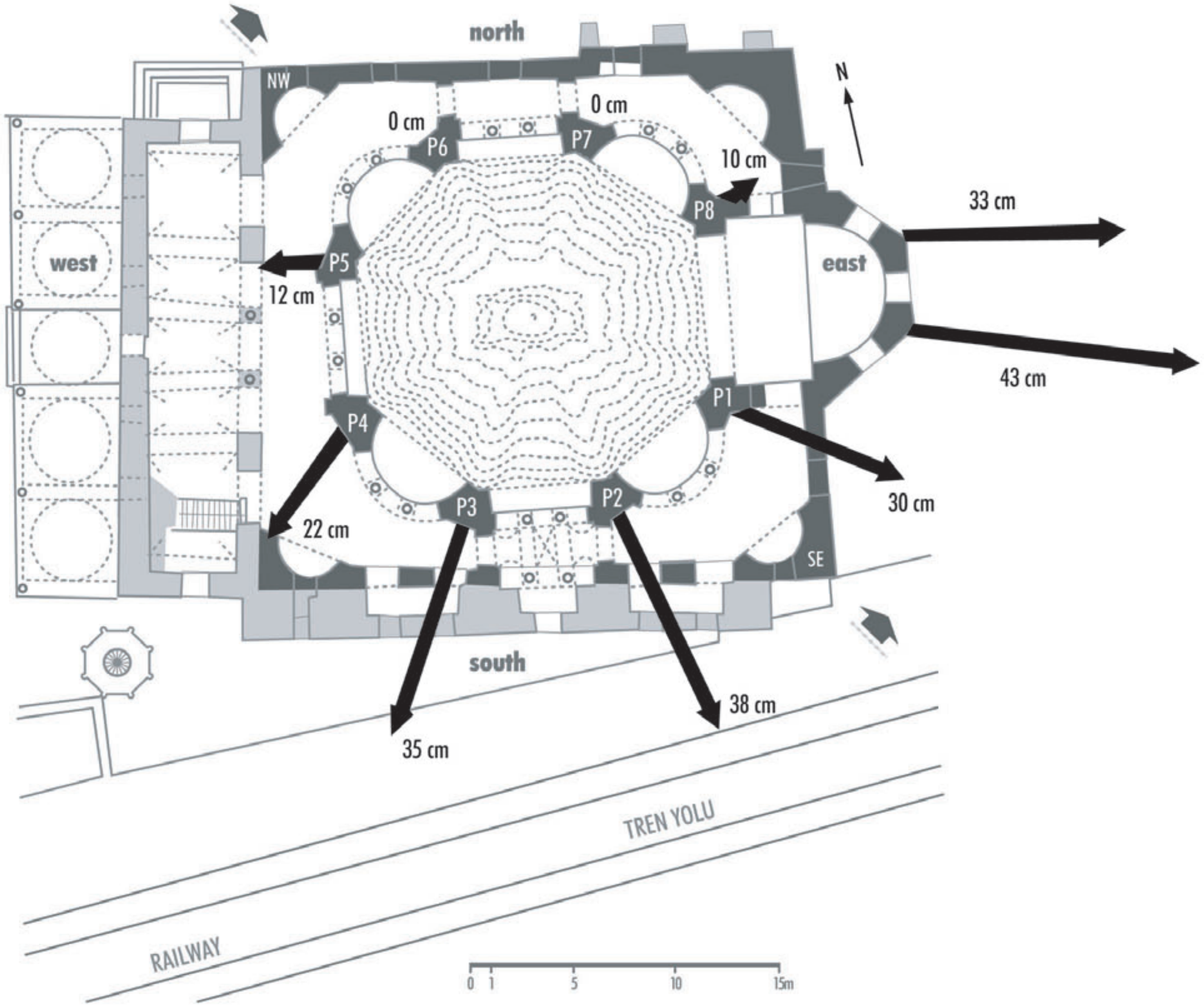


Diagonal section drawing through the dome, developed from photogrammetry. Drawing: © Yildiz Technical University Architecture Department.

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.

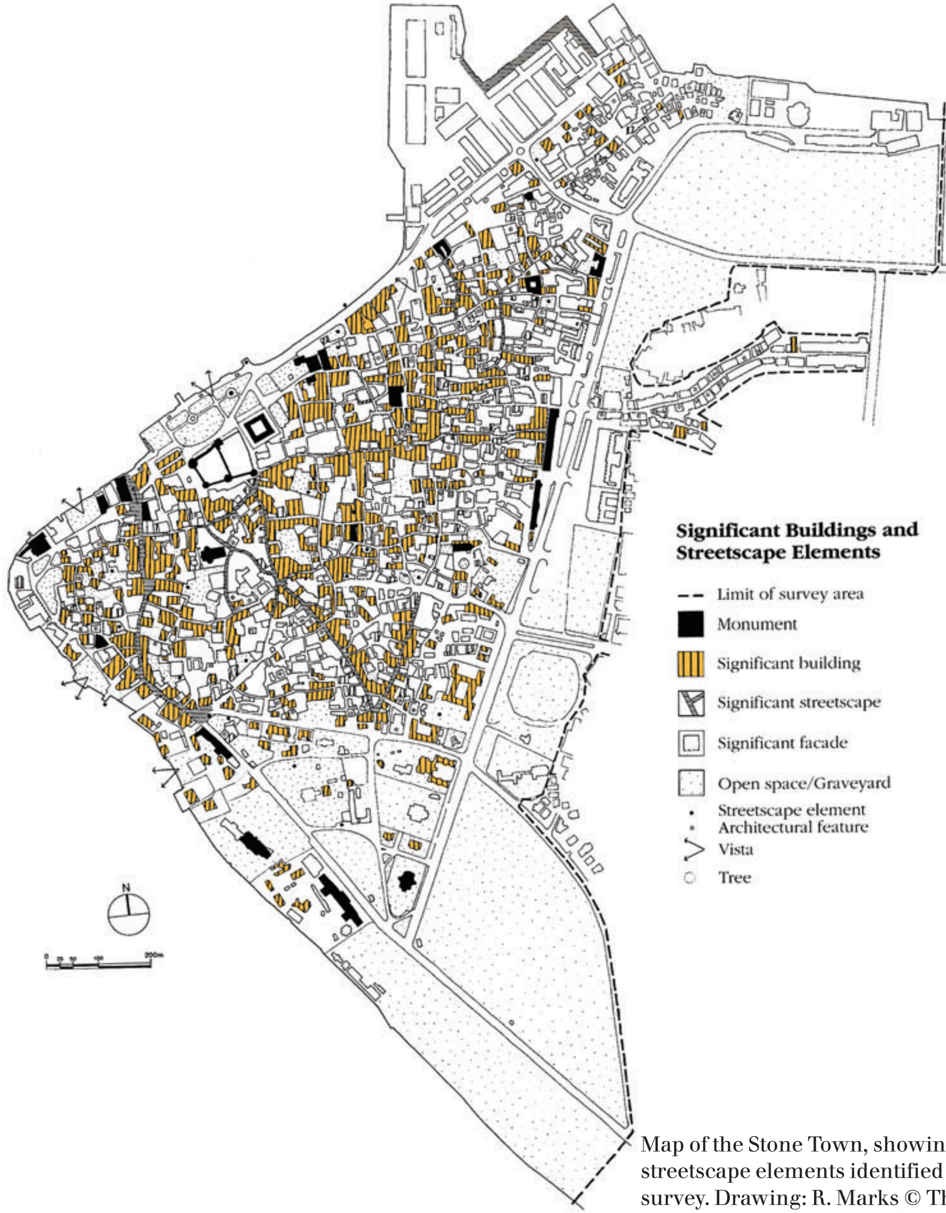
Urban Studies

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

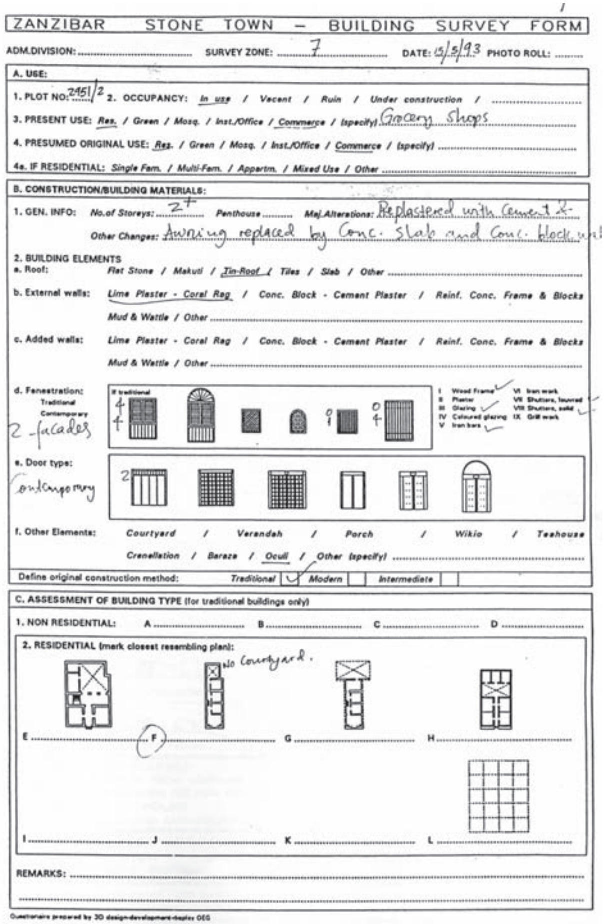
Plan of an urban block in the Kajificheni neighborhood. This typical block contains a mix of building types, including Arab houses, groups of Indian shopfront buildings, and an L-shaped communal tenement structure. Drawings: R. Marks © The Aga Khan Trust for Culture.

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: 13/5/93 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: 4 4 ... 0 1 ... 0 4 — 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 2

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

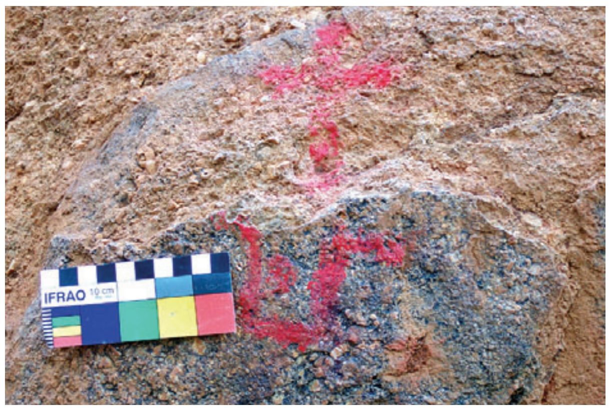
Jutting upward and rising more than 300 feet from the surrounding arid plain, the rock formation known as Uluru is a dominating presence in the Australian landscape. Made of sandstone, it is a unique formation noted for its changing colors as light is reflected throughout the day. Located almost at the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

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



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

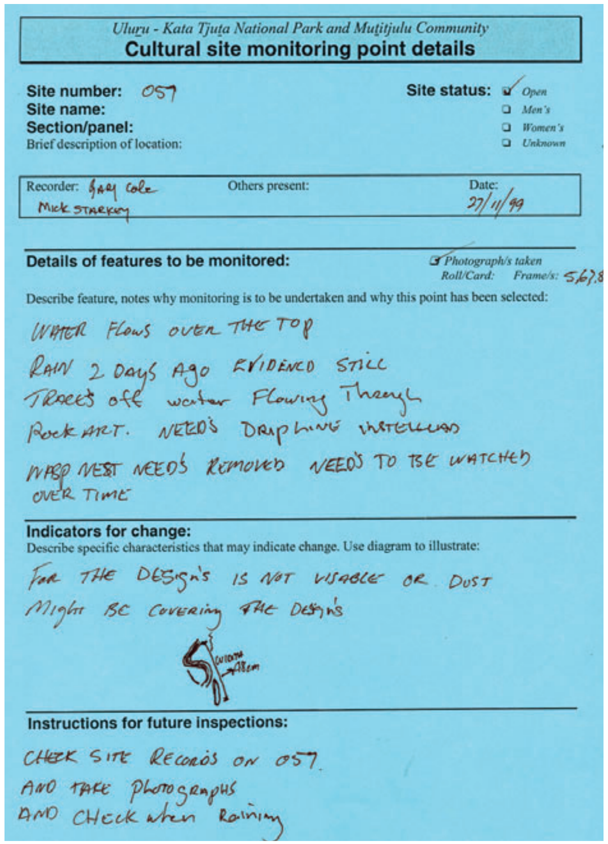
later renamed Uluru–Kata Tjuta National Park. Eight years later, the land around Uluru and Kata Tjuta was ceded back to the Anangu and then leased to the Australian government to be jointly managed with the Anangu. A management plan was undertaken in a collaborative effort between Anangu park rangers, 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.

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 EVIDENCE STILL TRACES OFF WATER FLOWING THROUGH ROCK ART. NEED'S DRIP LINE INSTALLED
WASP NEST NEED'S REMOVED NEED'S TO BE WATCHED OVER TIME

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

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

WIDTH 48cm

Instructions for future inspections:

CHECK SITE RECORD'S 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.

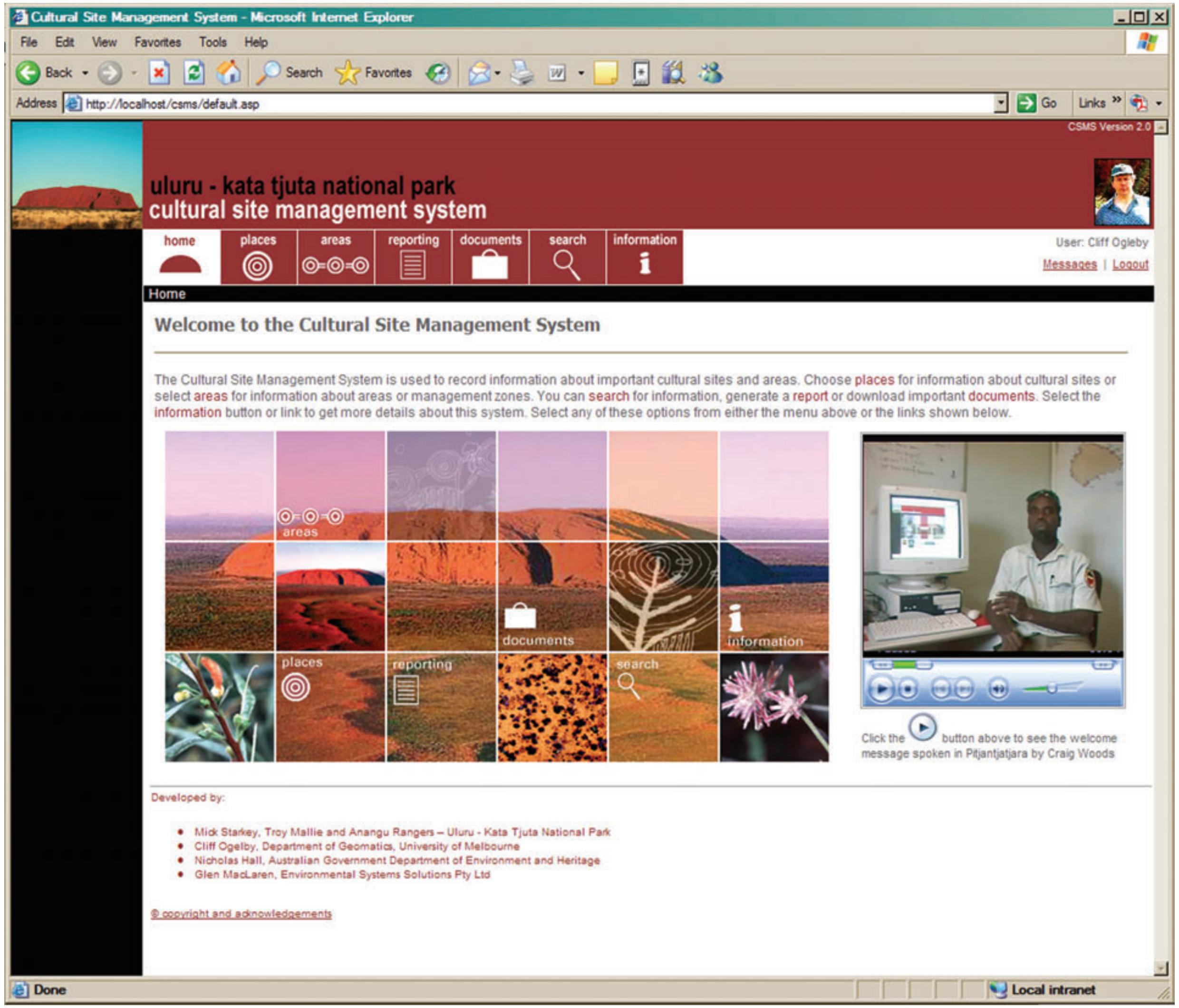
The CSMS was created not only to provide access to the data but also to display interactive maps and short video and audio segments. Often, databases cannot display or play the various types of files required to describe a site, so connections are commonly created to other computer programs. Video and 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		Height Ft In		
Pediment Tomb	Recently restored by Upenn. Red color evident		Lt. Red Evident		7	8

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.

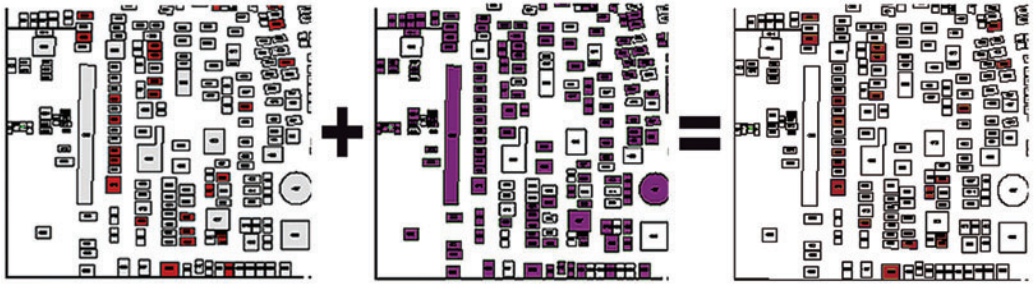
As this project was completed within the structure of a graduate school studio, the actual development of the database, GIS, and finalized survey forms and manuals occurred over the course of a semester. Simple location maps and the most basic structure of the database were created within a two- to three-week 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.

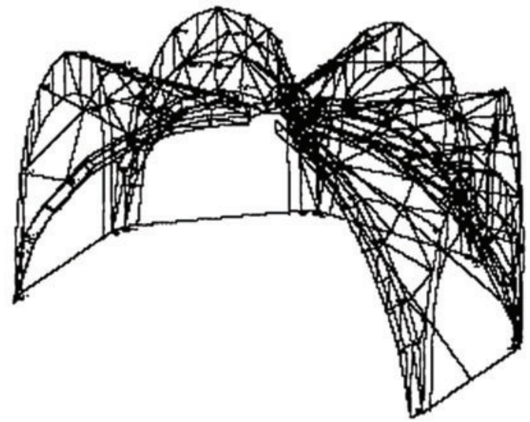
Following the discovery, conservators made small holes in the baroque ceiling to photograph the wall paintings. This attempt to document the frescoes failed because of the steep curvature of the vault, tight space, and general lack of light. However, it was essential to document the extent, beauty, and 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 photo-mosaic 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 photomosaic 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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