WANDMALEREIEN IN KRYPTEN, GROTTEN, KATAKOMBEN

Zur Konservierung gefasster Oberflächen in umweltgeschädigten Räumen

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Thomas Danzl, Matthias Exner und Elisabeth Rüber-Schütte (Hrsg.)

Wandmalereien in Krypten, Grotten, Katakomben

Zur Konservierung gefasster Oberflächen in umweltgeschädigten Räumen

Wallpaintings in crypts, grottoes, catacombs

Strategies for the conservation of coated surfaces in damp environments

Internationale Tagung des Deutschen Nationalkomitees von ICOMOS in Zusammenarbeit mit
dem Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt und
der Hochschule für Bildende Künste Dresden

Quedlinburg, Palais Salfeldt
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INHALT

GELEITWORTE

Die wissenschaftliche Tagung »Wandmalereien in Krypten, Grotten, Katakomben. Zur Konservierung gefasster Oberflächen in umweltgeschädigten Räumen«, die vom 3. bis 6. November in Quedlinburg stattfand, stand im Kontext zahlreicher weiterer Initiativen des Landesamtes für Denkmalpflege und Archäologie Sachsen-Anhalt, das vielfältige kulturelle Erbe unseres Landes zu bewahren, für die Wissenschaft zu erschließen und der Öffentlichkeit zu vermitteln.

Das Land sieht sich in der Verantwortung, sein kulturelles Erbe zu bewahren und für die Zukunft zu sichern. Hier reiht sich auch das Interesse für die Wandmalerei in unserem Land ein. Das Landesamt hat als eines der ersten eine systematische Sichtung der mittelalterlichen Bestände vorgenommen und dabei wichtige Kunstwerke neu- oder wiederentdeckt. Eine mehrjährige Förderung durch das Land erfolgte für die dringend notwendige Konservierung der Wandmalereien in der Stiftskirche Quedlinburg in den Jahren 2000–2006. Diese wurde in einer fruchtbaren Kooperation des Landesamtes für Denkmalpflege und Archäologie Sachsen-Anhalt und der Hochschule für Bildende Künste Dresden umgesetzt.

Mit Unterstützung des Kultusministeriums war es möglich, auf der Grundlage umfassender Befunduntersuchungen und Schadensanalysen sowie einzelner Forschungsprojekte eine Konservierungskonzeption zu erstellen, die sich dann in der Praxis bewähren konnte und überdies zu neuen wissenschaftlichen Erkenntnissen sowie zu einer besseren Lesbarkeit der Malereien führte.

Stephan Dorgerloh
Kultusminister des Landes Sachsen-Anhalt

Der Erhalt erdberührter Wandmalereien stellt eine Herausforderung für die denkmalpflegerische Praxis dar. Neben den zyklisch oder dauerfeuchten Bedingungen, die in Höhlen, Krypten oder verschütteten Objekten vorliegen können, spielen auch die Folgen anthropogener Umwelteinflüsse eine negative Rolle für deren Bewahrung. Schadsalze, die etwa über Düngung oder schwefelsaure Niederschläge in nahezu unbegrenzter Menge über das Erdreich eindringen konnten und können, bedrohen die oft bedeutenden Bestände.

Die Deutsche Bundesstiftung Umwelt (DBU) ist als größte Umweltstiftung Europas einem umfassenden Umweltbegriff verpflichtet, der auch das Ergebnis menschlicher Gestaltung umfasst. In ihrem Förderbereich »Umwelt und Kulturgüter« konnte sie daher seit ihrer Gründung im Jahr 1991 bereits in mehr als 700 Projekten über 125 Millionen € für die Entwicklung innovativer Mittel und Methoden zur Bekämpfung anthropogener Schäden an bedeutenden Kulturgütern ausschütten. Auch und gerade der Erhalt wertvoller Wandmalereien, der die praktische Denkmalpflege und die Konservierungswissenschaften in vielen Fällen noch vor unlösbare Aufgaben stellt, ist Gegenstand der Projektförderung durch die DBU – von einer römischen Grabanlage in Nehren an der Mosel bis hin zu den Tiepolofresken der Würzburger Residenz oder dem Musensaal des Augsburger Fuggerschlosses finden sich zahlreiche Beispiele.

Ich freue mich daher, dass die Deutsche Bundesstiftung Umwelt die Durchführung einer ambitionierten und stark praxisorientierten Tagung in Quedlinburg im November 2011 zum internationalen Erfahrungsaustausch zu den jeweils besten Handlungsstrategien für die Bewahrung erdberührter Wandmalereien unterstützen konnte. Die spezifische Rolle schädigender Umwelteinflüsse in Verbindung mit dem kurz- wie langfristigen Effekt von eingebrachten Konservierungsmitteln stand hierbei im Mittelpunkt eines praxisorientierten wissenschaftlichen Austausches. Ein besseres Studienobjekt als die Krypta der Quedlinburger Stiftskirche, Teil des Erbes der Menschheit, hätte sich hierfür kaum ermitteln lassen. Renommierte Fachleute der Konservierungswissenschaften aus aller Welt trugen anhand konkreter Beispiele aus der Praxis vor und konnten die Ergebnisse ihrer Arbeit mit einem engagierten Fachpublikum diskutieren.

Bei der Ausrichtung lag in der Kooperation des Landesamtes für Denkmalpflege und Archäologie Sachsen-Anhalt und der Hochschule für Bildende Künste Dresden, Fachbereich Kunsttechnologie, Konservierung und Restaurierung von Kunst- und Kulturgut, Fachklasse »Wandmalerei und Architekturoberfläche«, mit dem Deutschen Nationalkomitee von ICOMOS eine der Stärken der Veranstaltung, deren Ergebnisse in diesem Band nun ansprechend präsentiert werden. Die DBU erwartet gerne als Resultat der interdisziplinären Diskussion neue, innovative und an praktischen Herausforderungen orientierte Projektanträge.

Ich wünsche eine anregende Lektüre.

Dr.-Ing. E. h. Fritz Brickwedde
Generalsekretär der Deutschen Bundesstiftung Umwelt

Im Namen des Deutschen Nationalkomitees von ICOMOS begrüße ich sehr die Veröffentlichung der Ergebnisse unserer in Zusammenarbeit mit dem Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt und der Hochschule für bildende Künste Dresden veranstalteten internationalen Tagung, die vom 3. bis 6. November 2011 in Quedlinburg stattfand. Das Deutsche Nationalkomitee von ICOMOS war mit seinen internationalen Fachtagungen schon öfter in deutschen Welterbestätten zu Gast. ICOMOS ist im Rahmen der Welterbekonvention Berater der UNESCO und des Welterbekomitees und hat die Aufgabe, die Vorschläge für die Liste des Weltkulturerbes zu beurteilen und »den Erhaltungszustand der zu Welterbe gehörenden Kulturgüter zu überwachen« (§35 OG). Dazu gehört die Arbeit der Monitoring-Gruppe von ICOMOS Deutschland, beratend tätig auch im Rahmen des erfolgreichen Investitionsprogramms Nationale UNESCO-Welterbestätten des Bundesbauministeriums. Dieses vorsorgliche Monitoring (preventive monitoring), bei dem es ICOMOS auch um die Vermeidung von Konflikten im Vorfeld von geplanten Maßnahmen geht, kann bei den internationalen Tagungen durch spezifische fachliche Impulse flankiert werden, um auf der Höhe kunsttechnologischer Forschung aktuelle Antworten auf drängende konservatorische Probleme zu finden.

Es ist mir eine Freude mit der heute beginnenden Veranstaltung wieder einmal in Quedlinburg zu sein, das mit seinem reichen historischen Erbe seit vielen Jahren im Fokus denkmalpflegerischer Anstrengungen in Deutschland steht. Ermöglicht wurde die Veranstaltung auch durch das großzügige Entgegenkommen des Landesamts für Denkmalpflege und Archäologie Sachsen-Anhalt unter der Leitung von Prof. Harald Meller, nachdem das Landesamt in engagiertem Einsatz den Löwenanteil der organisatorischen Vorbereitung übernommen hat.

Die Wahl des Tagungsorts fiel um so leichter, als mit den Wandmalereien in der Krypta der Stiftskirche nicht nur ein herausragendes Denkmal romanischer Monumentalmalerei in Mitteldeutschland auf der Tagesordnung steht, sondern zugleich ein ziemlich problematischer langjähriger Patient vorgestellt werden kann, zu dessen Genesung in den vergangenen Jahren weitreichende und vielversprechende Lösungsansätze gefunden wurden. Diese Lösungsansätze sind ganz wesentlich dem Einsatz der Hochschule für Bildende Künste in Dresden zu verdanken, die sich damit als Projektpartner für unsere Tagung empfahl.

In methodischer Hinsicht versteht sich die Tagung durchaus auch als ein Anknüpfen an die ICOMOS-Tagung von 2004, die unter dem Titel »Klimastabiliserung und bauphysikalische Konzepte« in Zusammenarbeit mit dem Landesamt für Denkmalpflege Baden-Württemberg auf der Insel Reichenau stattgefunden hat und 2005 publiziert wurde. Wie damals geht es uns bei der Wahl der vorgestellten Probleme und Lösungen in erster Linie um Wege zur Nachhaltigkeit denkmalpflegerischen Handelns, die wir primär, aber nicht ausschließlich, an Objekten untersuchen, die zum UNESCO-Welterbe der Menschheit gehören und in besonderer Weise dem Engagement von ICOMOS anempfohlen sind. Manche Fragestellung von 2004 kann inzwischen mit neuen Impulsen und Forschungsergebnissen wieder aufgegriffen werden, andere Themen, wie etwa der beängstigende Zustand der Malereien in den Grotten von Lascaux, konnten damals noch nicht öffentlich präsentiert werden.

An vielen Welterbestätten geht es natürlich um wesentlich banalere Anliegen beim präventiven Schutz der Denkmäler, und in den Krisengebieten der Welt sind es ganz andere Sorgen, denen sich ICOMOS stellen muss. Darauf wird u. a. mit unserer Reihe »Heritage at Risk« reagiert, die inzwischen auch durch Präsenz im Internet ein beachtliches Echo findet. Schwerpunkte der letzten Ausgabe von »Heritage at Risk« waren u. a. die katastrophalen Erdbeben in Haiti und Chile sowie Afghanistan (Bamiyan Buddhas, Grabungen in Mes Ainak). An spezifische Forschungen zu drängenden Fragen der Konservierungswissenschaft ist in vielen Ländern angesichts der Fülle der Probleme kaum zu denken. Gerade deshalb erscheint es uns sinnvoll, bei unseren Tagungen den internationalen fachlichen Diskurs und die Weitergabe von Erfahrungen anzubieten. Mit der Verteilung unserer Tagungspublikationen an die circa 100 Nationalkomitees von ICOMOS gibt das Deutsche Nationalkomitee Impulse zum Erfahrungsaustausch und Wissenstransfer. Um den höchst unterschiedlichen Bedürfnissen und dem breiten Kompetenzspektrum unserer Partner gerecht zu werden, wurde der Ansatz auch dieser Tagung bewusst interdisziplinär gewählt: Restauratoren, Denkmalpfleger, Bauphysiker, Materialkundler und Mikrobiologen haben in den letzten Jahren an verschiedensten Objekten und an Beispielen aus unterschiedlichen Gattungen Untersuchungs- und Kontrollmethoden entwickelt, die einen sinnvollen und wirksamen Umgang mit den divergierenden Aspekten der hier diskutierten Probleme versprechen. Dabei kommen sowohl Fallbeispiele aus dem Bereich der Bau- und Kunstdenkmalpflege, wie aus dem archäologischen Arbeitsfeld zur Sprache.

Den zum Teil von weit her angereisten Referenten Konservator Xichen Zao (Xi'An), Konservator Andrew Thorn (Sidney) ist zu danken sowie allen, die zum Gelingen der Tagung beigetragen haben. Das ist natürlich in erster Linie das Team des Landesamts für Denkmalpflege und Archäologie Sachsen-Anhalt, mit dem wir sehr gut zusammengearbeitet haben. Die drei Projektpartner, die hier in Quedlinburg gemeinsam tätig geworden sind, werden durch drei Mitglieder des Deutsche Nationalkomitees von ICOMOS vertreten, auf deren Initiative Idee und Durchführung der Veranstaltung zurückgehen: Frau Dr. Elisabeth Rüber-Schütte vom Denkmalamt in Halle, Herr Prof. Thomas Danzl von der Hochschule für Bildende Künste in Dresden und Dr. Matthias Exner vom Bayerischen Landesamt für Denkmalpflege, der hier für unsere Münchner Geschäftsstelle tätig geworden ist. Ihnen allen mein herzlicher Dank. Vor allem aber habe ich unseren beiden Sponsoren zu danken, dem Beauftragten der Bundesregierung für Kultur und Medien sowie der Deutschen Bundesstiftung Umwelt, ohne deren Förderung die Veranstaltung und die Publikation nicht durchführbar gewesen wäre. Die Ergebnisse der erfolgreich durchgeführten Tagung mit angeregten Diskussionen liegen hiermit als Publikation in der Reihe ICOMOS Hefte des Deutschen Nationalkomitees Band LVI vor.

Prof. Dr. Michael Petzet Ehrenpräsident	Prof. Dr. Jörg Haspel Präsident

Deutsches Nationalkomitee von ICOMOS

Unterirdische oder erdberührte Räume sind besondere Orte, von denen – egal ob sie natürlich entstanden sind oder von Menschenhand geschaffen wurden – eine eigene Faszination ausgeht. Einige dieser verborgenen Orte wurden an ihren Wänden, Decken oder Gewölben künstlerisch gestaltet. Über die Zeiten hinweg haben sich hiervon Zeugnisse in Höhlen, Katakomben, Krypten, Grüften, Grotten und sogar gelegentlich Kellerräumen erhalten. Der Mensch begegnet diesen Räumen auf unterschiedliche Art, als Entdecker, Bewahrer aber auch als Zerstörer.

Das Thema dieses Tagungsbandes berührt in umfänglichem Maße Zuständigkeiten und Aufgabenbereiche eines Landesamtes für Denkmalpflege und Archäologie. Als Mitveranstalter der vorausgegangenen Tagung in Quedlinburg war uns deshalb wichtig, die Bewahrung dieses besonderen kulturellen Erbes in einen weitgespannten zeitlichen und interdisziplinär angelegten Rahmen zu stellen und einen Wissenstransfer zwischen Archäologie, Baudenkmalpflege, Restaurierungswissenschaft und naturwissenschaftlichen Fachdisziplinen anzuregen. Dieser bewusst breit und international angelegte fachliche Austausch erscheint umso dringlicher, da die Konservierung von Wand- und Deckengestaltungen in feuchter, ja oftmals dauerfeuchter Umgebung mit Recht noch als eine der »last frontiers« der Konservierungswissenschaften angesehen werden muss. Ganz im Sinne angewandter Wissenschaften wurde daher bei der Tagung auch auf konkrete, gleichwohl übertragbare Fallbeispiele gesetzt.

Der entscheidende Impuls zur Ausrichtung dieser Tagung in Quedlinburg ging denn auch von einem vorbildlich geplanten und schließlich durchgeführten Konservierungsvorhaben an den bedeutenden mittelalterlichen Wand- und Gewölbemalereien in der Krypta der dortigen Stiftskirche aus. Mit Unterstützung des Landes Sachsen-Anhalt konnte die Hochschule für Bildende Künste Dresden, damals vertreten durch Prof. Heinz Leitner (†), als Schnittstelle zwischen Praxis, Lehre und Forschung in Zusammenarbeit mit weiteren nationalen wie internationalen Forschungsinstitutionen, amtlich und frei beruflich tätigen Experten wie schließlich mit Studierenden zwischen 2002 und 2006 ein praxistaugliches Verfahren zur Kunststoffreduzierung und Remineralisierung des Putzträgers erarbeiten, das durchaus internationalen Modellcharakter besitzt.

Die vorliegende Publikation möge nicht nur Anreiz zu weiter führenden Diskussionen bieten, sondern auch Initialzündung sein für eine – wie durch verschiedene Beiträge deutlich gemacht – längst überfällige »Hebung« und Verbreitung konservierungswissenschaftlicher Forschung im Rahmen der jahrzehntelangen wie vorbildlichen Förderung des BMFT und der DBU im Bereich der Denkmalpflege. Hochschulen wie Denkmalpflege sind gerade in Zeiten knapper werdender öffentlicher Mittel gut beraten, dieses unbestritten umfangreiche Forschungs- und Erfahrungswissen zu aktualisieren und in weitsichtige und eingriffsarme Konservierungs- und Restaurierungsstrategien zu überführen.

Den Vertretern des Deutschen Nationalkomitees von ICOMOS, der Hochschule für Bildende Künste Dresden, Studiengang Kunsttechnologie, Konservierung und Restaurierung von Kunst- und Kulturgut, der Deutschen Bundesstiftung Umwelt, dem Beauftragten der Bundesregierung für Kultur und Medien, der Deutschen Stiftung Denkmalschutz wie nicht zuletzt den Mitarbeitern des Landesamtes für Denkmalpflege und Archäologie Sachsen-Anhalt sei an dieser Stelle besonders gedankt für die finanzielle Unterstützung, exzellente Vorbereitung und Durchführung einer – so das einhellige Feedback – an guten Gesprächen am Rande und offenen Diskussionen im Plenum so überdurchschnittlich reichen Veranstaltung.

Nicht zuletzt gilt der Dank auch all den renommierten Fachleuten für Ihre Rede- und Schriftbeiträge, die ohne die großzügige Unterstützung der Deutschen Bundesstiftung Umwelt nicht in diesem Themenband hätten zusammengeführt werden können.

Prof. Dr. Harald Meller
Landesarchäologe und Direktor des Landesamtes für Denkmalpflege und Archäologie Sachsen-Anhalt

Sibylla Tringham, Charlotte Martin de Fonjaudran, Cynthia de Giorgio and Sharon Cather

PASSIVE AND REMEDIAL APPROACHES TO SALT DAMAGE AND BIODETERIORATION OF WALL PAINTINGS AND MONUMENTS IN THE CRYPT OF THE GRAND MASTERS, ST JOHN'S CO-CATHEDRAL, VALLETTA

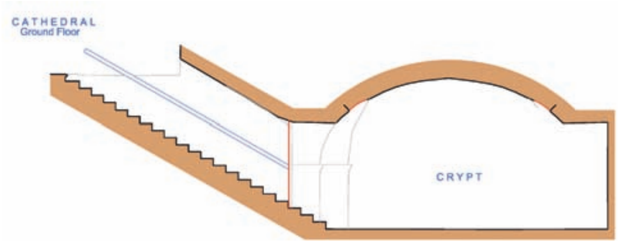
ABSTRACT

Salt activity was causing serious loss to the wall paintings and tomb monuments in the Crypt of the Grand Masters at St John's Co-Cathedral. A series of diagnostic investigations, including condition and environmental monitoring, provided insights into the causes and activation mechanisms of deterioration, and high-lighted the negative influence of the exterior macroclimate on the Crypt's microclimate. Environmentally driven cycles of salt crystallization and deliquescence led to failure of cohesion with loss of material. To address the environmental agents, a passive approach was tested with a programme of incremental climate control trials. While the parameters for a sustainable, long-term solution were identified, the challenges in finding an appropriate solution to environmentally driven deterioration are immense, not least since the Crypt is subterranean, and the parameters for controlling salt deterioration can activate microbial communities. Even though trials prioritised low-tech, minimally invasive control methods, the optimal parameters can only be maintained by a mechanical system. Remedial treatments, including grouting of detached plaster, salt treatments and consolidation of decohesive stone were also undertaken.

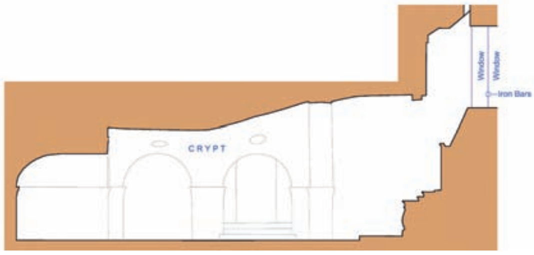
SIGNIFICANCE AND CONSERVATION ISSUES

Salts – commonly found on wall paintings in subterranean environments – were causing serious loss in the Crypt of the Grand Masters by the 1980s, and clearly had been for decades if not centuries. While remedial treat-

[1] The Crypt of the Grand Masters contains the tomb monuments of the first twelve Grand Masters and is decorated with a trompe l'oeil wall painting scheme (after conservation).



[2] A transverse section of the Crypt illustrates the staircase leading from the Co-Cathedral and domed vault.



[3] A longitudinal section shows the complex volume of the Crypt and the window at street level

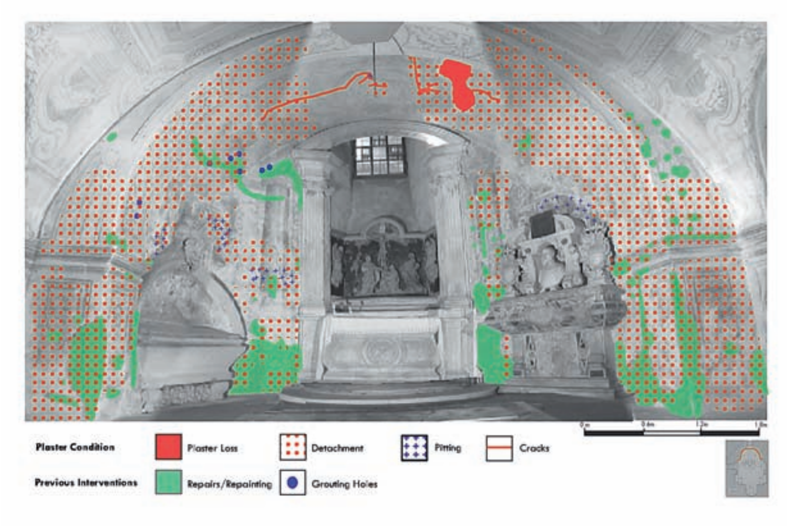
ments typically offer temporary solutions, longer-term approaches require an understanding of the causes and activation mechanisms of the deterioration. Once these are known, action to either avoid or minimise deterioration – preventive or passive intervention – is far more effective.[1] But there are challenges for the conservators who undertake these investigations and design the interventions: causes and effects are intertwined, activation and consequent deterioration cycles may be long (often annual), and resources are always limited. To maximise the benefit, we use an incremental and iterative approach for prioritising and sequencing the investigations.[2] Fundamental to this approach is that results from investigations are interpreted before subsequent investigations are undertaken. The complex conservation issues of the Crypt of the Grand Masters demanded such an approach and relied on the close collaboration between conservators and administrators.

The Cathedral and the Grand Masters' Crypt

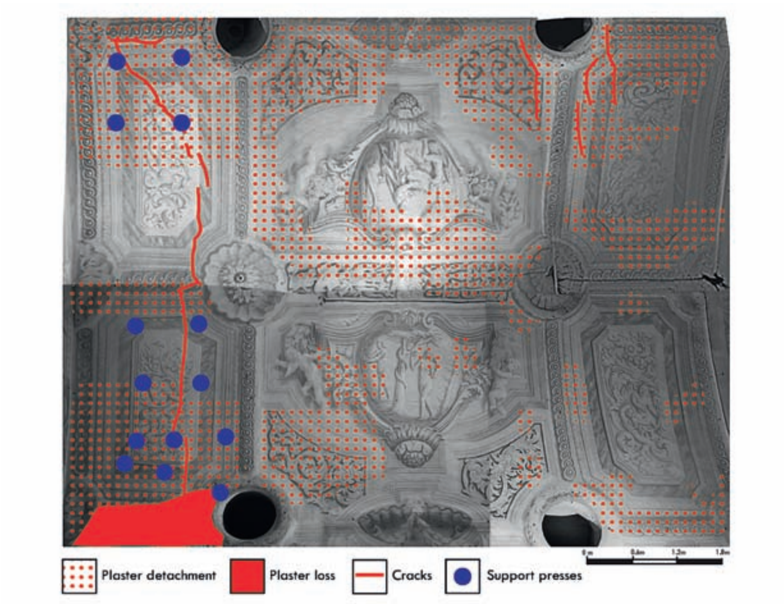
The Knights Hospitaller, formed in the 12^{th} century and later known as the Order of St John, ruled Malta from 1530 to 1798, transforming it into a military fortress and employing accomplished architects and artists to create their monumental legacy. As the urban focus of Valletta, the Co-Cathedral (1572–78) is richly decorated with gilded stucco, inlaid marble tombstones, and a superb wall painting scheme in the vault by Mattia Preti.[3] Among its many treasures is Caravaggio's famous »Beheading of St John the Baptist«.[4]

Knights were buried within the Co-Cathedral, but the Crypt beneath the high altar was reserved for the tombs of the first twelve Grand Masters (Figs. 1–4). Among these are Villiers de l'Isle Adam, who brought the Order to Malta, and Parisot de la Valette, hero of the Great Siege of 1565 when the Knights successfully repelled the Ottoman invaders. Jean de la Cassière, who commissioned the Cathedral in 1572, lies directly beneath the high altar. The Grand Masters' monuments vary in form: free-standing sarcophagi and wall and floor monuments of globigerina limestone or marble. Echoing the exuberance elsewhere in the Co-Cathedral, the walls are decorated with a trompe l'oeil scheme attributed to Niccolò Nasoni, an Italian artist influential in Portugal after his stay in Malta (1723–1725).[5] Its fictive plaques contain Old Testament scenes while decorative details – skulls and trophies – reflect the mortuary function of the Crypt and the military power of the Order.

[4] Several of the tomb monuments are free-standing and constructed of globigerina limestone such as Parisot de la Valette (far right), while others, such as the monument of Martino Garzes, are made of marble and set into the wall (far left).



[5] Graphic representation of the condition shows widespread plaster detachment and an area of loss. Past interventions such as grouting holes and repainting were also recorded.



[6] Temporary press systems were constructed to support plaster at imminent risk of collapse in the vault.

Deterioration and closure

The Crypt was closed to the public in the 1980s following collapse of painted plaster from the vault. Following a further collapse in 2003, the Foundation's concern for the condition of the paintings and monuments increased; as well as the plaster loss, some of the monuments were extremely fragile and a white veil obscured the paintings. To address these problems, in 2003 the Foundation commissioned the Courtauld to undertake a condition assessment to characterise and map the deterioration phenomena. Most alarmingly, in addition to the extensive salt-related deterioration and possible biofilm, the assessment revealed large areas of vault plaster at imminent risk of collapse, while the fine carving of the limestone monuments was at risk of loss due to acute decohesion (Figs. 5–7, 9, 15, 17, 19).[6] An emergency intervention in 2003 to provide temporary support for the painted plaster on the vault allowed time for detailed investigations.

DIAGNOSTIC INVESTIGATIONS

Understanding their sources and activation mechanisms is necessary for successfully intervening against salts, microbiological activity and plaster detachment. Therefore a series of incremental investigations was initiated, prioritising simple, low-tech methods. Data was immediately interpreted to inform choices of further investigations, and the accumulated data fed into the development of a considered conservation approach. The sequence of diagnostic investigations was:

- Physical history including archival research;
- Condition assessment, mapping and monitoring;
- Emergency temporary support of painted plaster;
- Original materials and their susceptibility;
- Salt and ion types and distribution;
- Liquid moisture survey, core sampling and ion analysis;

- Biofilm cultivation and SEM imaging; and
- Environmental monitoring of Crypt and adjacent climates (exterior and nave).

Physical history

Initial archival research shed considerable light on the Crypt's physical history, and especially its rate of deterioration. Already in the late 19th century there were calls for its restoration to address the »effects of time and humid air«.[7] Reports of previous restorations remain to be found, but photographs from the 1950s compared to others from 1999 show that the deterioration accelerated considerably over those years. In 2003 the condition had not changed significantly since 1999. Photographic monitoring was initiated in 2003 to assess the rate of ongoing deterioration.

Large gaps in the physical history hamper efforts to identify factors that may have triggered the deterioration after the 1950s. Some past interventions have left physical evidence (such as drilled holes for grouting, and repainting) but piecing together a chronology is difficult. For example, glass panels were removed from the only window, presumably to »ventilate« the space, but when this occurred is unknown. Similarly, as a subterranean structure it is not possible to know the impact of events affecting the building fabric such as changes in street drainage.

Original technology

Investigations of the technology of the 18th-century wall painting were limited to specific questions related to causes of deterioration and their activation mechanisms. The Crypt is excavated from the globigerina limestone bedrock and lined with ashlar. From losses in the painted plaster, it appears that it remained unpainted until the 18th century. A lime-based plaster containing sand and crushed globigerina was then applied in two layers (each ~10 mm thick) over the stone in large patches. Deep keying of the stone indicates adhesion concerns. Other painted plaster schemes in Malta exhibit similar problems, suggesting that the original technology may be inherently susceptible to adhesion failure and detachment. Giornate, indirect incisions and nails embedded in the plaster indicate a fresco technique; analysis confirmed the dominance of earth pigments and smalt. However, an organic binder was certainly used for selected details in the vault; these were powdering, though unaffected by salts.

While fresco painting flourished in southern Europe, it is highly unusual in Malta. More typically, wall paintings were executed in oil, such as the vault of Our Lady of Victory (c. 1715).[8] This may well relate to the shortage of suitable aggregates, particularly sand. No other schemes attributed to Nasoni in Malta have evidence of fresco technique, making the Crypt technology yet more interesting.

[7] Salt-related deterioration led to acute decohesion of the limestone monuments.

[8] Once the environment was stabilised, the stone monuments were consolidated.

[9] Most of the paintings were covered in a heterogeneous white veil of salt efflorescences and biofilm. The salt activity disrupted the paint layer and the biofilm obscured much of the painting.

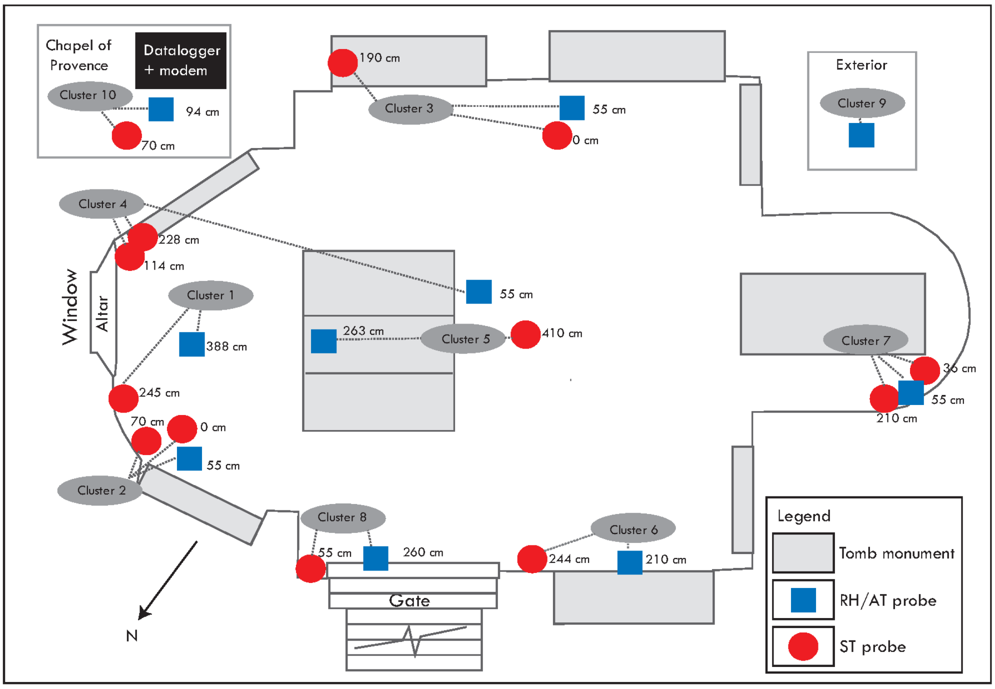
[10] When these non-original materials were removed, the painting was found to be in good condition and much of the original painting was re-vealed.

Globigerina limestone, the ubiquitous stone of Malta, was often selected for monuments since it is soft and easily carved. Globigerina is extremely heterogeneous,[9] as reflected in the varying conditions of the monuments in the Crypt. Their deterioration also varies relative to their exposure to the single window in the Crypt: the sides facing the window exhibited more severe decohe-sion than the opposite sides.

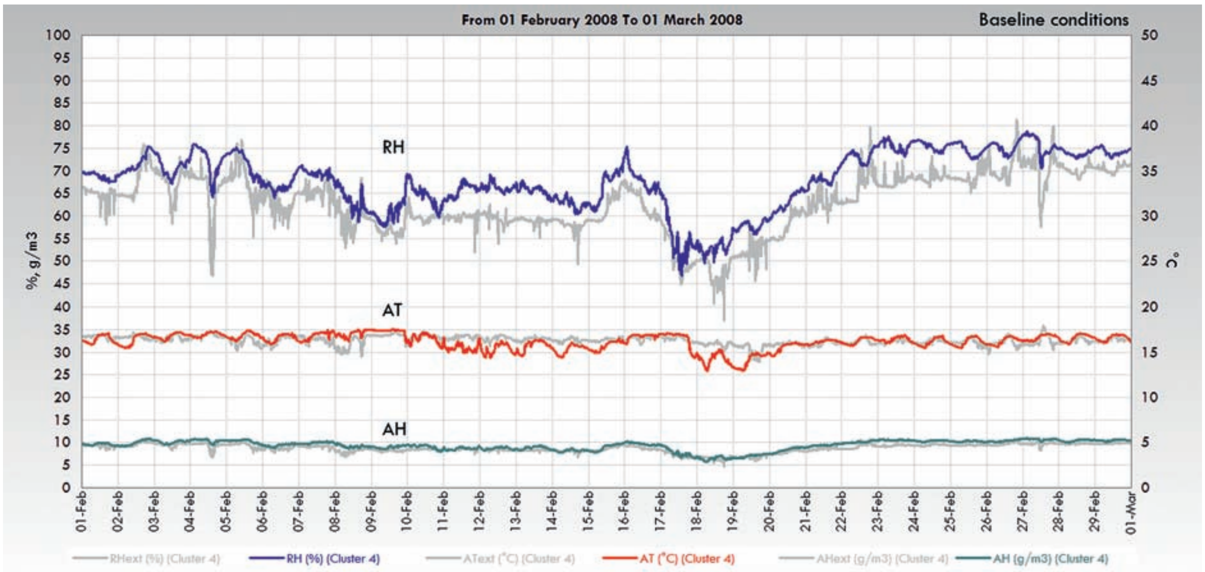
Salts and biofilm

Salts were clearly the major cause of deterioration of both paintings and monuments. Investigations therefore ai-med to identify the dominant salt species and their distribution, potential sources, pathways, and the environ-mental contribution to their phase changes. Ion chroma-tography, optical microscopy and microchemical tests were carried out on salt efflorescences, and aqueous extracts from core-samples and powdered stone material.[10, 11]

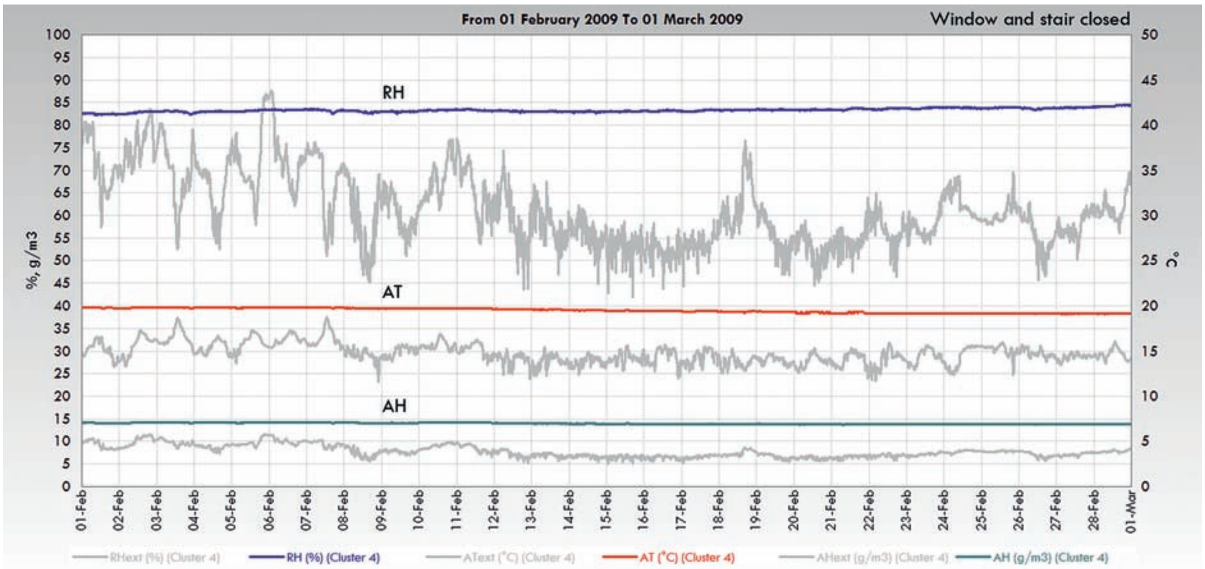
The predominant salt efflorescence on the painting is calcium sulfate,[12] with greater abundance in the upper plaster layer decreasing to trace amounts in the stone support.[13] Considering its widespread superficial distri-bution, together with the open window and urban con-text, this points to an airborne source of sulfur dioxide (SO_2) deposits followed by a sulfation processes. SO_2 is fixed on the calcium carbonate support – either wet (as



[11] Sketch plan of the Crypt with environmental monitoring sensor locations

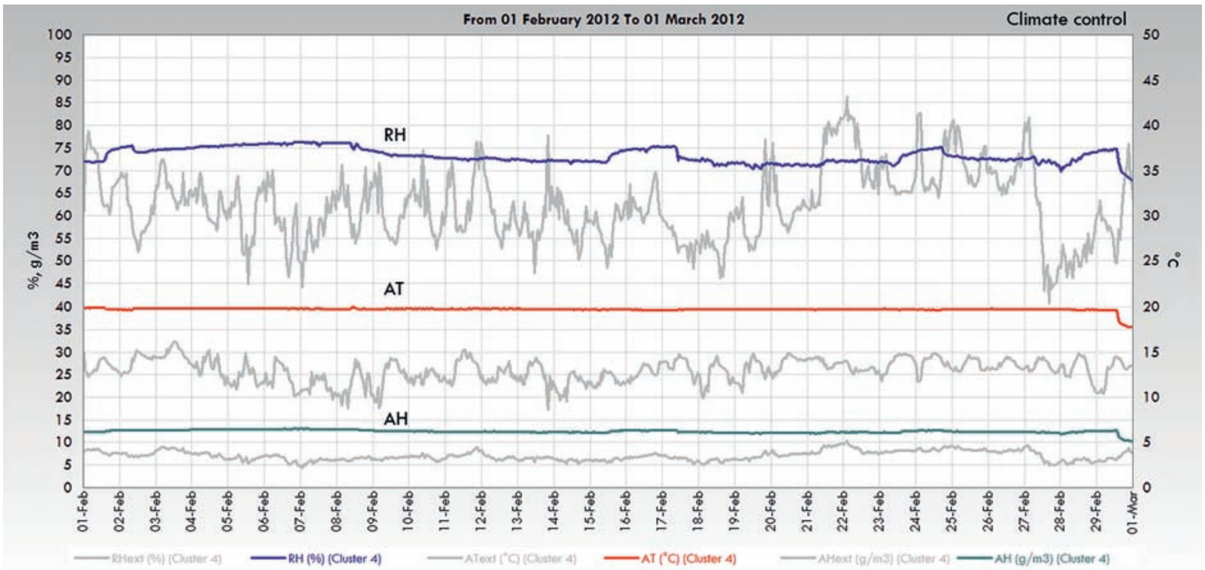


[12] Environmental data of prevailing (baseline) conditions in the Crypt, showing that the absolute humidity of the Crypt closely follows that of the exterior with slight moderation of the resulting RH due to the good thermal buffering.



[13] Exclusion of the external environments (exterior and Co-Cathedral) led to stabilisation of the Crypt microclimate.

[14] A temporary climate control system maintains the Crypt microclimate at levels that avoid salt phase changes and microbiological activity.



[15] Detail of salt efflorescences on painting, photograph taken during prevailing (baseline) environmental conditions (June 2003).

[16] Same detail as Fig. 15, photograph taken when external environments were excluded and the Crypt microclimate stabilised (June 2009).

calcium sulfite) or dry – and converts to calcium sulfate.[14] Halite (sodium chloride) was identified on the wall paintings,[15] and chloride and nitrate ions were found in significant amounts up to a depth of 220 mm,[16] suggesting either that they are autochthonous or that liquid moisture may also be a source of salt-forming ions. In the stone monuments, sodium chloride is the dominant salt and high nitrate levels suggest the presence of sodium nitrate.[17]

High amounts of nitrate and ammonia on the painted surface indicate biological activity, but not whether this activity is current.[18] Samples of the white, fibrous biofilm were tested with a fluorometric method,[19] with no positive results; laboratory cultivation was also problematic.[20] The appearance of the film did not change over several years and regrowth did not occur following trial removal. The original painting beneath the biofilm was stable, though repainting was usually deteriorated. The issue of microbial communities in salt-laden environments is an important, though under-studied subject.[21]

Liquid moisture

As moisture is intrinsic to salt deterioration, understanding its sources and distribution within the Crypt is required to determine its role in the deterioration. Data on liquid moisture distribution can point to failures of the building envelope which are more easily remedied than adverse microclimates. It is also a necessary precursor to environmental monitoring to allow interpretation of environmental data in relation to the moisture-loading of the structure. Since liquid moisture occurs in depth and electrical resistance and capacitance meters are at best superficial and at worst unreliable,[22] drilled core samples were taken.[23] Moisture content was calculated, hygroscopic absorption measured, and ion analysis undertaken.

In the Crypt, moisture is generally greater in depth than at the painted surface, indicating an internal source rather than condensation events.[24] Wet and dry conditions occur both near the floor and at high locations. It is not possible to determine the source – or sources – of this subterranean water due to the heterogeneity of its distribution. Although the Crypt is cut into bedrock, the Co-Cathedral's position is high on the rocky spine that is Valletta and is ringed by streets and drains hundreds of years old. This prevents firm conclusions about sources of liquid moisture as well as effective exclusion of its evaporation into the Crypt.

The environment and its influence

Based on these investigations, environmental monitoring was designed to test the hypothesis that the Crypt's microclimate was strongly influenced by exchange with the exterior, and that frequent fluctuations in relative humidity were causing cycles of salt phase changes. The two sources of air exchange are the window in the Crypt opening onto the street, and the stair leading up to the nave level of the Co-Cathedral (Figs. 2–3). The environmental monitoring strategy was designed to determine how the Crypt functions as a hygral and thermal buffer within these multiple climates.

It was critical to test the hypothesis before changing the microclimate. The measurements of prevailing conditions provide essential information. They establish the external macroclimate and Crypt microclimate and their relationship; highlight the environmental parameters contributing to the activation of deterioration; and, finally, provide a baseline against which to test subsequent mitigation trials.

Data on relative (RH) and absolute humidity (AH), ambient (AT), surface (ST) and dewpoint (DPT) temperatures were recorded throughout a year to illustrate the

[17] In some areas, such as near the altar and the apse, the white veil was extremely thick and opaque obscuring details such as this owl.

[18] The same area as Fig. 17, after removal of non-original materials.

impact of external environments on the microclimate of the Crypt.[25] The exterior and the intermediary Co-Cathedral environment as well as multiple locations in the Crypt were measured (Fig. 11). During this monitoring, material loss from monuments was recorded to correlate loss with microclimate conditions.

The environmental data confirmed the hypothesis that there is rapid and recurring air exchange between the Crypt and the exterior. Broadly, the absolute humidity of the Crypt closely follows that of the exterior with slight moderation of the resulting RH due to the good thermal buffering (Fig. 12). ST remains well above DPT in all locations, showing that condensation does not occur, and supporting the findings of the liquid moisture survey.

Calcium sulfate, the dominant salt on the wall paintings, is sparingly soluble but in the presence of sodium chloride, its solubility is increased and can undergo cycles of crystallisation and dissolution at relative humidity levels lower than 99%.[26] Sodium chloride and (presumably) sodium nitrate – which contaminate the monuments – each has an equilibrium relative humidity (RH_{eq}) of ~75% at 20°C. But salt mixtures – present in the walls and monuments – greatly increase the range of RH conditions for phase changes. Therefore the rapid and frequent changes in RH that occur in the Crypt likely cause repeated deliquescence and crystallisation and consequent failure of cohesion with loss of material.[27] Such fluctuations are also liable to promote moisture movement and accumulation of salt-forming ions near the surface of the paintings and monuments.

PASSIVE INTERVENTION

Given these conditions – a subterranean chamber heavily salt-contaminated, with microbial communities, and unknown liquid moisture sources – the options for interventions were severely limited. Treatment of the salts by aqueous extraction was inadvisable given their type, distribution and the likely unintended consequences of the treatment.[28] Therefore a course of passive intervention in which the activation mechanisms of the ongoing deterioration are targeted was chosen. These included:

- Phased exclusion of exterior and then Co-Cathedral environments;
- Air circulation and controlled air exchange;
- Dehumidification and air cooling; and
- Removal of microorganisms and nutrient substrate from the floor.

Only after these activation mechanisms were brought under control could a remedial approach be considered; any intervention carried out prematurely would be short-lived as the deterioration agents would continue to be active.

Successful passive intervention requires accurate identification of activation mechanisms and convincing correlation with ongoing deterioration.[29] Moreover, prediction of the effects is critical but not easy. Assessment requires ongoing monitoring of the actual impact of the intervention. None of this is straightforward due to the complexity of the interrelated effects that result from altering conditions in an open system; and above all, it takes considerable time. Additional problems stem from the administrative side. Administrative structures and funding are normally project-based rather than long-term investments, and the preference for interventions with a visual improvement means that remedial interventions are often prioritised. The implementation of the passive intervention approach for the Crypt is due to the administrative and financial support from the Co-Cathedral Foundation. Critical to this was effective communication between the Foundation and conservators regarding options and potential results. Agreeing to an approach that was theoretically sound, but costly, time-consuming and with few precedents is a testimony to the vision and commitment of the Foundation's Curator and Trustees.

Microclimate control

Beginning with simple, non-mechanical measures, a series of incremental trials was designed to determine the impact of phased exclusion of the external climates. Additional goals were the identification of optimal RH and AT values to slow down the deterioration processes, and assessment of the need for mechanical control measures. Environmental data was compared to baseline data and correlated with the condition of the objects (monitored and measured).[30]

Three, year-long phases of environmental control trials involved sequentially reducing air exchange first through the window and then from the stair. Sealing the window led to a remarkably stable microclimate. This lasted until late autumn when the air in the Co-Cathedral cooled below that of the Crypt, creating a convection current increasing air exchange between the two. The stair was then sealed. Yet again, the Crypt microclimate stabilised and the stone powdering reduced considerably (Fig. 13). The RH then stabilised at 90%. This is higher than one would expect for a closed environment of lime plaster and limestone, since the sorption isotherms for both are about 80%.[31] This suggested a steady source of liquid water within the structural fabric. Possible sources were again investigated and repaired as far as possible, but these interventions were severely limited in this historic subterranean environment.

With the encouraging cessation of powdering due to the sealed environment, these new conditions were maintained to determine whether the stable climate could be sustained without mechanical control and without other negative impacts. As anticipated, the salt-related deterioration was brought to a standstill: with the environmental fluctuations eliminated, the damaging salt phase-changes did not occur. It is also likely that the high ambient RH (85–90%) kept most salt ions in solution within the porous materials (Figs. 15–16). The AT also remained higher than in previous years, as a result of thermal inertia and lighting during conservation work.

Although the salt-related deterioration was minimised, a longer period of high RH and AT triggered growth of microbial colonies on the stone floor. This »longer period« was a year, underscoring the need for extended periods of monitoring to assess the consequences of these interventions. The colonies, a mix of fungi and bacteria typical of damp environments,[32] were most dense in areas beneath the tomb monuments. Identification of species – time-consuming and fraught with difficulties in terms of sampling and cultivation methodologies – was not considered a priority. Instead of a remedial approach with biocides, which can itself be problematic,[33, 34] a remedial and preventive approach was adopted by removing both the growth and potential nutrient sources (compacted dirt) from the floor, and establishing less favourable environmental conditions.[35] The next challenge was to identify and create an environment which minimised both salt-related activity (where a higher, stable RH is preferred) and microbiological growth (where a lower RH and AT are preferable, ideally with air movement[36]). This was extremely difficult since the conditions which minimise one type of deterioration trigger the other. Simple exclusion of external influences was already shown to be unsuccessful, so mechanical means were then investigated.

Trials of air circulation within the Crypt and of limited air exchange with the exterior (by means of fans) were carried out.[37] The resulting negative impact on both salt activity and microbiological growth was due to inadequate control of air exchange and consequent RH fluctuations. These trials provided empirical evidence as to the extent to which the environmental parameters could be safely altered. Since a high (>72–73%) RH needs to be maintained to avoid activating the salt-related deterioration, AT becomes the only factor that can be manipulated to control biodeterioration, though a careful balance is essential to prevent condensation. Next, an air cooler was used to bring the AT down to ~20°C, with the RH ~73%, thus halting both biological growth and salt-related deterioration (Fig. 14).

Interpretation of the impact of the environmental trials was possible due to the rapid rate at which both types of deterioration occurred. If the RH dropped below 67%, damage to the stone was observed within 24 hours. In conditions of high RH and high AT, new microbiological colonies were present within a week. Therefore it was possible to correlate environmental changes directly with changes in condition and to identify optimal conditions for minimising environmentally driven deterioration. In the Crypt, these optimal conditions were found to be 71–73% RH and 18–20°C. Conservation work began

[19] Stone monument with acute decohesion and deposited dirt before treatment.

[20] Same monument as Fig. 19, after consolidation and cleaning.

after a long period of stability (10 months) when the Crypt was sealed, but the impact of the team's presence can be identified in the data with periods of daily fluctuations in temperature. Working in the Crypt and affecting the climate meant that the conditions – both physical and environmental – could be monitored more closely and the working parameters investigated more fully.

These conditions have been maintained for 12 months with a temporary system. A custom-made environmental control system has been specified, though resolving compromises between technical and aesthetic requirements is challenging. The system should maintain RH and AT at optimum values while also accommodating possible increasing fluctuation, and more extreme external weather events, as well as possible alteration of moisture behaviour of the fabric in the future. Dependence on a mechanical system for environmental control is not ideal and introduces risks. Therefore alarm systems and full redundancy in the case of failure are critical. Long-term condition and environmental monitoring must be in place to ensure that adverse changes are quickly and effectively addressed. Fortunately, the infrastructure at the Co-Cathedral enables the implementation of such a programme.

REMEDIAL INTERVENTIONS

The remedial interventions were begun once the deterioration activation mechanisms were brought under control. They included:

- Addressing cohesion failure of tomb monuments and wall paintings;
- Stabilisation of detached plaster (injection grouting);
- Removal of non-original materials (salts and biofilm) from wall paintings; and
- Filling of plaster losses and uncovering of areas of wall painting from beneath limewash.

Cohesion failure of the limestone was the most alarming condition; therefore the monuments were prioritised for treatment. Given the risk of biodeterioration, an inorganic consolidant was preferred and an alcohol dispersion of colloidal calcium hydroxide was selected.[38, 39] An alcohol dispersant was preferred to water due to its inferior affinity to salts. Since the reaction product is calcium carbonate, it is also compatible with the original stone.

The consolidated stone surface has a low mechanical strength, discouraging the formation of damaging subflorescences or failure in-depth should environmental parameters drastically change in the future. Other users report problems with the formation of a white haze on the consolidated surface, but this did not occur on the Crypt monuments (Figs. 7, 8, 19, 20). This may be due to the application conditions: the ambient conditions of high RH and the thickness of the layer of powdered material.

The second priority was to address the detachment of the painted plaster (provided with temporary support in 2003). In most cases, the void was 2–5 mm deep, and, in deformed areas, up to 30 mm deep. Building on previous Courtauld research on the development of tailor-made grouts,[40] the performance criteria for the intervention were based on the specifics of the Crypt, including detachment of both horizontal and vertical surfaces. The conditions required a grout with low viscosity, good tack, good adhesion and flexibility after setting, while also being low density, but with bulking properties.

Following in-situ and lab testing of physical properties, a lime-based grout was developed containing both a lightweight inert filler and pozzolana. To minimise additional weight and allow for retreatment in the future, the grout was injected as anchor points between the stone and plaster, avoiding filling the voids.

The white veil obscured the painting details and dramatically reduced the trompe l'oeil effect. In its various forms, this veil was either salt efflorescence, biofilm or a mixture of both. Cleaning trials undertaken seven years earlier did not show any changes or new colonies. Removing the white veil revealed a wealth of details, and delicate shading (Figs. 9, 10, 17, 18); cleaning the floor also made a considerable impact on the aesthetics, the light-yellow stone complementing the painted scheme (Figs. 1, 4). Below cornice level, overpainting of the original scheme was widespread and compromised by salts and biofilms. Its removal also revealed the extent and the quality of the surviving scheme.

CONCLUSIONS

The complex and interrelated conservation issues in the Crypt required an incremental approach to understanding the causes and the activation mechanisms of deterioration. Only by undertaking carefully sequenced investigations and trials could clear relationships between causes, activation and condition be convincingly determined. All this fed into the design of a passive approach.

Simple, minimally intrusive, free-standing, low-cost options for environmental control were preferred and investigated first. They did not work. So we were reluctantly forced to move to specifying an engineered environmental control system. Although the paintings and monuments have been conserved, their long-term stability depends absolutely on environmental stability. Monitoring their condition and the environment is critical to identifying and remedying problems when they occur. The effectiveness of a passive approach has been demonstrated over the short term, but the long-term effects on the building fabric are less predictable. While reliance on environmental control is not ideal, it is hoped that sufficient measures are in place to avoid failure. The administrative and financial implications of this project have been significant and depend utterly on St John's Co-Cathedral Foundation's commitment.

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