MONUMENTS IN MONUMENTS

2019

CONFERENCE PROCEEDINGS

Edited by: Ewan Hyslop, Christa Gerdwilker, Vanesa Gonzalez

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Any enquiries regarding this document should be sent to us at:
Historic Environment Scotland
Longmore House, Salisbury Place
Edinburgh EH9 1SH
+44 (0) 131 668 8600
www.historicenvironment.scot

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FOREWORD

Historic Environment Scotland is delighted to welcome you to the Monuments in Monuments 2019 Conference. This three day event provides a forum for leading experts in the conservation field to come together and discuss the latest research and best practice on the treatment and management of stone artefacts within historic envelopes.

Scotland is known as a nation of stone, and its complex and varied geology is directly reflected in the historic environment across the country. Stone has been the principal material used for building and decorative purposes for thousands of years and the protection and management of this legacy is one of Historic Environment Scotland's core purposes and something that we are passionate about.

Preserving these unique stone assets is becoming more challenging. Climate change is already having a direct impact in a number of ways, including extreme weather and increased rainfall. Dealing with this will require new approaches and technologies, but the key to good stewardship is the availability of a skilled workforce with access to appropriate materials. It also requires interdisciplinarity; today, Scotland's stone heritage is looked after by a range of experts including scientists, conservators, engineers, heritage managers, stonemasons and others working alongside communities and custodians.

In many ways this conference is about the people and the need for a workforce with the knowledge and skills to meet the challenges ahead. Our conference aims to stimulate discussions, enable knowledge exchange on different approaches and methodologies, and to develop professional connections. With a programme filled with leading experts from across the globe, this conference is unique opportunity to forge new collaborations.

The event is taking place at the Engine Shed, Scotland's unique building conservation centre. Run by Historic Environment Scotland, the Engine Shed is a melting pot for all things conservation were a wide range of different audiences can learn about Scotland's rich heritage.

I hope that you find the conference useful in your professional capacity as well as interesting and enjoyable.

Welcome to Scotland and have a great time.

Thanks

Dr David Mitchell
Historic Environment Scotland

PREFACE

We are pleased to present the proceedings of the ‘Monuments in Monuments Conference 2019’. The event was organised by Historic Environment Scotland and hosted at the Engine Shed – Scotland’s building conservation centre in Stirling.

Many excellent papers were submitted from across the globe. In the end not everyone was able to come to Stirling, nor could we fit everyone into our tight programme of talks. Nonetheless, we are grateful for every abstract received and read them with great interest. Following a blind peer-review we selected the 23 papers enclosed in these conference proceedings. The review process has resulted in a high quality publication for authors to be proud of and readers to enjoy. The in-situ conservation of ornament inside traditional buildings commonly presents challenging conservation scenarios and it was the potential complexity of these cases that inspired the conference theme. With such an origin it is not surprising that the received papers are steeped in experience and practice while providing an insight to the latest research, technology and methodologies in stone and building conservation. We hope that the content of the proceedings will be of value to practitioners and researchers in their projects and that the conference and proceedings stimulate future study, ongoing discussions and professional connections amongst colleagues.

We are delighted to have been involved in the organisation of this event and the development of the conference proceedings and hope that you will enjoy reading this publication.

ACKNOWLEDGEMENTS

We would particularly like to thank our key note speakers Dr Christine Bläuer, Audrey Tepper and Sara Crofts for their enlightening contributions. We also thank David Harkin, Tom Parnell and Christa Gerdwilker for their insightful presentations and the poster authors Noemi Giovelli, Marta Pilarska and Ailsa Murray. Thank you also to HES directors Dr David Mitchell and Barbara Cummins for supporting the conference and their opening and closing comments.

Thank you to our field trip hosts for sharing their invaluable site experiences and knowledge: Sara Hamilton and Dr Callum Graham (Fossil Grove), Ian Lambie and John Clark (Glasgow Cathedral), Noemi Giovelli and 'The friends of the Necropolis' (Glasgow Necropolis), Roger Curtis (Leighton library, Dunblane), Jessica Hunnisett (Dunblane Cathedral), Luis Albornoz (British Geological Survey), HES Visitor Operations staff at Dunblane and Glasgow Cathedrals and the HES Conservation team (HES conservation centre).

Historic Environment Scotland would like to thank the programme committee and the editorial team for their work. Special thanks to Christa Gerdwilker, who has been the driving force behind this event and Vanesa Gonzalez for managing the editing and publication process. Additional thanks to Dr Ewan Hyslop, Ailsa Murray, Dr Aurélie Turmel, Colin Muir, Jessica Hunnisett, Dr Katrin Wilhelm and Dr Maureen Young.

Historic Environment Scotland is grateful to the organising team Dorothy Hoskins, Lesley Cadger, Rachel Stewart, Jennifer Farquharson and especially to Sara Armstrong. This complex three day event would have not been possible without Sara's efficiency and attention to detail.

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EVOLVING COLLABORATION BETWEEN ACADEMICS AND CONSERVATORS:

ILLUSTRATION USING NDTS TO MAP AND MONITOR DECAY OF CERAMIC TESSERAE AND EARTHEN FLOORS

Rob Inkpen[1*], **Joy Watts, Eric May, Andy Gibson, Emily Butcher, Paul Simpson, John Stewart** and **Andrew More**

[1] Rob Inkpen, Department of Geography, University of Portsmouth (UoP). robert.inkpen@port.ac.uk
Joy Watts, School of Biological Sciences, UoP.
Eric May, School of Biological Sciences, UoP.
Andy Gibson, Centre for Applied Geosciences, UoP.
Emily Butcher, Centre for Applied Geosciences, UoP.
Paul Simpson, Isle of Wight Council (IoWC).
John Stewart, Historic England.
Andrew More, Historic England.
* corresponding author

ABSTRACT

Collaboration between academics and conservators can be a straightforward process in which the academics supply data to the conservators, who then interpret it in relation to a problem they have previously defined. The techniques (such as non-destructive techniques: NDTs) used to create the data are viewed as unproblematic and easily transferable from each context the conservator works in. Academics, however, develop, test and operate such techniques in laboratory conditions or field experiments where they can control the parameters that influence the data produced. Transferring techniques to the context of conservators involves having to be aware of the operational constraints and solutions needed to ensure the data produced is meaningful. If academics and conservators have the soft skills to evolve a trusting, collaborative relationship then there is a possibility that techniques can be used in more novel ways, even integrating data. This can result in an expansion of and redefinition of the nature of the problem, and a development of solutions beyond the initial experience of the conservator.

Keywords:
NDTs, decay, collaboration, conservators, earthen floors

1. INTRODUCTION

Understanding and conserving degrading heritage materials is an area of both specialist research and practice. The academics involved in this paper have years of experience of researching degradation processes as well as collaboration with conservation organisations. These collaborations and our reflections upon them have provided an opportunity to outline the contours of 'successful' collaborations. We explore our ideas through the case example of collaborative research undertaken using non-destructive techniques (NDTs) at Newport Villa on the Isle of Wight on the earthen and mosaic floors. Our key concern is to highlight that, although it would be helpful to have a fixed blueprint for collaborative success, it is the emergent nature of collaboration that provides the foundation for 'success', however that term is defined by each party.

Conservators seeking an immediate resolution for problems they have identified can look to academic research for novel techniques, both to identify problems more clearly and to resolve them. Academics, at first glance, appear to have a range of such novel techniques, particularly with NDTs, that can be used to combat conservation problems. These techniques require expert knowledge, often with extensive infrastructural support, to operate and interpret the results. To be of use to conservators the knowledge gap between conservators and academics needs to be addressed both in terms of understanding the potential of NDTs and the interpretation of the outcomes. Collaboration would seem to be beneficial to both parties, but effectively bridging the gap between what works in the academic context of the laboratory and field experiments and what works within the context of the conservation sector is not simple. Understanding the constraining nature of both contexts is important in determining the potential of NDTs for collaborative work.

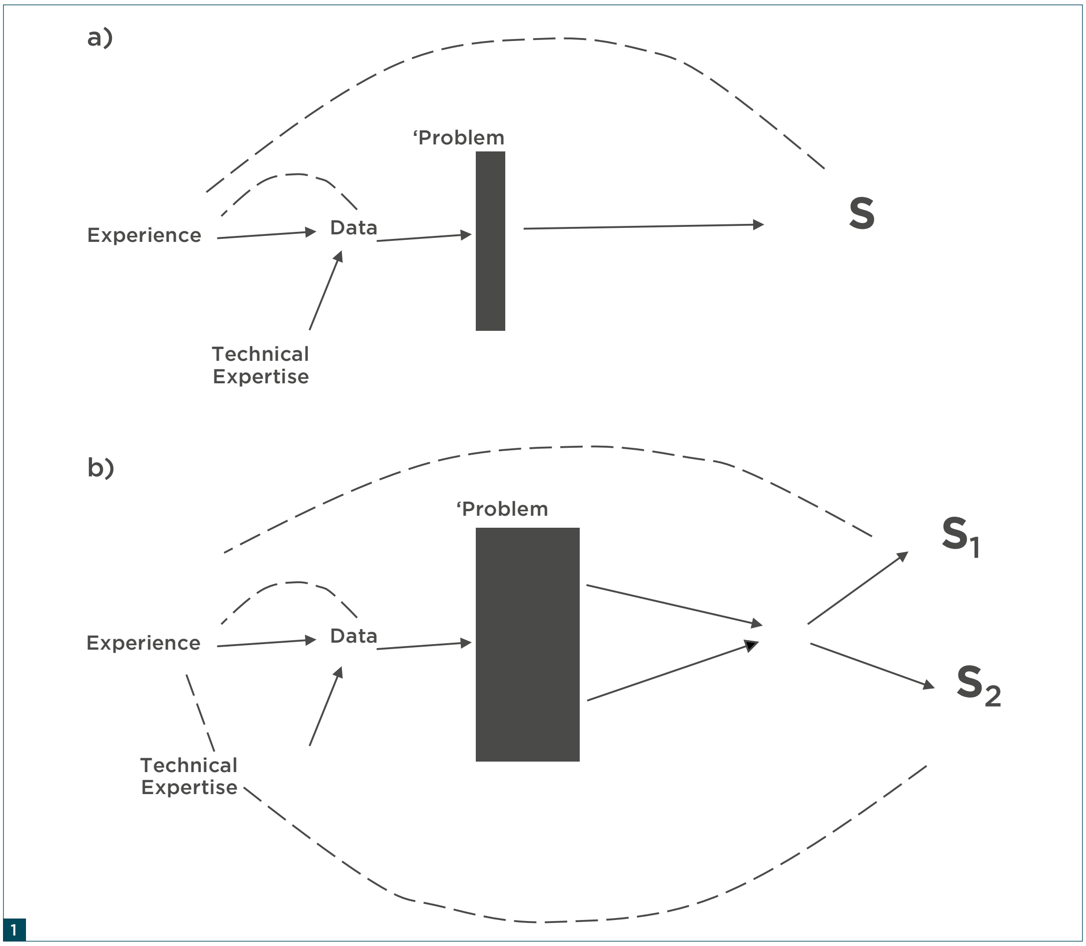

Figure 1:
a) Model of collaboration between academics and conservators where academics provide technical expertise only.
b) Model of collaboration between academics and conservators where there is a collaborative development the problem space and solutions.

2. DIFFERENT CONTEXT, DIFFERENT CONSTRAINTS

NDTs such as laser scanning, moisture monitoring, image analysis, GPR and NIR (e.g. Armesto-Gonzalez et al. 2010, Arayici et al. 2017, Davies et al. 2017 and Saey et al. 2015) for analysing decay of stone and other heritage materials have advanced rapidly over the last couple of decades. In combination they are perceived to potentially be a powerful management tool for conservation (e.g. Moropoulo et al. 2013). However, it is unclear how much these techniques have changed conservation practice, if at all.

Developing, testing and application of these techniques is often undertaken within the controlled confines of laboratories or selected field trials. In these contexts, the researcher is in control both of the conditions of operation and of the nature of the problem being researched (Inkpen and Wilson, 2013). Similarly, the researcher can have an extensive support in data processing and interpretation. The NDTs work within a context tightly defined and controlled by the researcher, where the problem and the potential limitations of the technique itself provide boundary conditions on use.

Transferring NDTs directly to the context of the conservator can be problematic. Figures 1a and 1b provide a simple model of how collaboration between an experienced conservator and a technical researcher could evolve. Figure 1a represents the model case of a conservator relying on experience to define the extent of the problem space that includes the nature of the problem, its physical characteristics, its extent and intensity and the solution (S) traditionally used. A good conservator would be self-critical and monitor and assess the success or failure of the solution in different contexts, providing a feedback loop from solution to inform and expand the experience base of the conservator. The researcher provides data on the problem, with the conservator using the technical data to confirm or reject their experience-based assessment of the problem space and its solution (S). The researcher is a supplier of data and little more.

In Figure 1a, the relationship between the researcher and conservators focuses on the transfer of technical information. Underlying this transfer are the assumptions that the information is in a form that is of use to and easy to understand for the conservator, and that the information addresses the problem identified. Likewise, the technique requires little to no finessing to be applied to another problem in another location; the technique requires no tweaking due to changing contexts of use. The technique is applied in a standard manner across contexts.

In Figure 1b, the technical expertise of the researcher and the experience of the conservator co-produce the expanded problem space, which could result in a reconsideration of the nature of the problem space, potentially resulting in the articulation of different problems and different potential solutions (S1 and S2). Feedback on the effectiveness of solutions is an integral part of the agreed monitoring scheme and a continued dialogue between conservator and researcher ensures that the problems and solutions are constantly under review. In this figure, the technique is still important, but it is the nature of the emerging relationship between the researcher and conservator that becomes an important focus for how the technique is used and for how the outcomes are interpreted.

It is vital that the academic or academic team have an appropriate set of soft skills (Wickens and Norris 2018) so that a trusting working relationship between conservator and researcher can effectively inform conservation practice. Such a working relationship cannot be manufactured artificially: it requires time, effort, listening and understanding on both sides to develop a productive and collaborative relationship. Evolving such a relationship, however, is essential to effectively exploiting the potential NDTs for conservation. As in our case study, this emerging relationship will often mean that academics will often be required to extend and adapt the operation of the NDTs beyond the experience gained in the laboratory. Clear understanding for both parties of the need for operating within the constraints of each technique and the implications of this for problem solving requires an honest and open dialogue between academics and conservators.


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Figure 2:
Photography of the hypocaust used in experiment.

3. WORKING TOGETHER, LEARNING TOGETHER: CONSERVATION OF NEWPORT VILLA, ISLE OF WIGHT

The Isle of Wight Council had a problem managing dense microbiological growth on the mosaics and within the hypocausts of the Roman Villa at Newport (Figure 2). In 2008, English Heritage (now Historic England) proposed a partnership with IoWC to trial the use of UVC irradiation to control microbiological growth at the villa. The problem was well defined, as was the nature of the potential solution. Trials of UVC irradiation, with a box designed and built by English Heritage engineer Andrew More, proved promising. This experienced team of conservators had clear empirical results of an impact; they could see changes on the surfaces (Stewart et al. 2014). These initial trials were about defining the potential of the technology and the parameters of technical issues. This meant that there was uncertainty about the clarity of this technique as a solution. It was at this point that the need for a structured scientific input became clear, and this also provided the opportunity for a more nuanced statement of the problem once dialogue was opened with academics.

The University of Portsmouth did not become involved until the second series of trials, after both problem and potential solution had been identified. Conservator Paul Simpson of IoWC engaged the interest of Eric May of Portsmouth University to advise on the further development of this research. Our involvement was dependent upon soft skills. Eric had worked with Rob Inkpen on a large EU project, BioBrush (May et al. 2008) as well as with Rob Inkpen and Joy Watts on a Commonwealth War Graves project to clean headstones (May et al. 2011). In other words, there was a team of academics who had a range of technical skills and who could, importantly, work happily together on a conservator-defined problem.

Initially, the role of UoP was to identify and quantify the changes in the microbiology under UVC light and to aid in determining the optimal duration for effective treatment. Our initial experiment in 2016 involved exposure of a limited section of the hypocaust to UVC light, taking samples of algae and photographic images taken before and after treatment. Analysis of changes in the hypocaust involved ensuring that all the data was spatially referenced relative to its position within the hypocaust. Initial results were encouraging in that changes in algae cover upon treatment were quantified.

At this point Historic England agreed to fund a Masters by Research studentship at UoP to analyse the impact of UVC light on algae in more detail. This resulted in the problem being articulated in a more complicated manner, as a problem of which microbes were affected, how they were affected, whether they were significant for the colour change observed and whether they were permanently damaged.

Based on the success of the initial experiment, UoP, Historic England and IoWC collaboratively developed an experimental design for assessing the most effective exposure duration for ‘eradicating’ the hypocaust of algae growth. The experimental design provided the conservators with clear information about the practical requirements of the method, and it provided the academics with an experimental design from which they could confidently predict the impact of UVC light. Currently, the research has expanded to include the use of NIR as a potential method for rapid assessment of the extent of the problem of algae growth as well as the effectiveness of UVC treatment (Andy Gibson and Emily Butcher). The long-term aim is to develop this emerging technology as a user-friendly method for conservators to independently assess the extent of the algae growth problem as well as monitoring and managing treatments in the future. The experience gained by both conservator and academics will be disseminated as a technical guidance note to help guide other conservators in the use of UVC to manage microbiological growth.

The initial problem and potential solution were all based on conservation teams’ experience of the villa. The introduction of the academic team was a result of informal networks of expertise that meant the previous work of Eric May was known to the conservators. Rather than an optimal academic solution, a more pragmatic end-user optimal outcome was the focus of the collaboration of the academic team, based on a clear set of operational constraints and associated operational solutions (Table 1). Importantly, the need to have a spatial framework within which to locate each set of data for each NDT was paramount to the monitoring and assessment of UVC light, and was accepted by all involved as an important way to assess the problem and solution.

The initial collaboration in 2016 provided a basis for the collective team discussing the problem and developing trust in the objectives and approach of each group and their methods. The problem itself became differentiated as the UoP team began to redefine the problem space to look directly into what biological components were affected by UVC light. This led them to a research design that permitted the additional use of image analysis to identify a range of outcomes of the UVC treatment based on their impacts upon the colour of the bio-film. Open discussion between the academic and conservation teams meant that each was happy to critically discuss a range of ideas about how to proceed and what to monitor. The mosaic floor, for example, was of interest to the conservators as there was algae growth on it, but the

NDT	Variable measured	Operational constraints	Operational solutions
Image analysis	Visual appearance of surface	Camera variability, lighting variability, operator variability – e.g. angle from which image taken, spatial extent of image – may require stitching images together, processing time, interpretation of errors and classes, specialist software required	Standard lighting, single operator with fixed settings on camera, use of stitching software to geo-correct imagery, reference markers within image to ensure within same spatial reference framework between treatments
Microbial swabs	Nature and magnitude of microbial populations presence	Spatial variability of microbial activity relative to size of swab, preferential survival of microbes on swab, preferential growth of microbes in growth media, specialist laboratory required for identification and counting of microbes	Repeated sampling from nearby points between treatments, points identifiable within images to ensure with common spatial reference framework between treatments, use of sterile plastic bags for storing swabs, use of standard preparation and growth medium
NIR	Wavelength characteristics of surface	Camera variability, lighting variability, operator variability – e.g. angle from which image taken, spatial extent of image – may require stitching images together, processing time, interpretation of errors and classes, specialist software required	Standard lighting, single operator with fixed settings on camera, use of stitching software to geo-correct imagery, reference markers within image to ensure within same spatial reference framework between treatments, interpretation of imagery by single operator using specialist software
GIS	Layering of spatially referenced information	Requires any information to be spatially referenced within common spatial framework, specialist software required to process layers, interpretation of relationships between layers	Use of fixed points at site – stone pillars – to orientate common spatial reference framework

Table 1:
NDTs used in Newport Villa research and operational solutions to operational constraints.

differences between the tile and mortar in the amount and potentially type of algae growth represented an increase in the level of monitoring complexity that went beyond what available academic resources could cover. A compromise of monitoring only the hypocaust was agreed.

The academic team did not just go away and analyse the data. Regular meetings with partners helped to monitor the progress of the project, and to incorporate the thoughts of conservators on the progress as well to ensure the analysis itself was being communicated effectively to conservators. Confidence in the collaboration meant that introducing new techniques such as NIR in 2018 were not viewed as an issue, and enabled further discussions about how to refine and develop monitoring methods with a clear focus on their suitability for conservators. Understanding the operational constraints of NIR also meant that the academic team could use elements of existing practice, such as the markers on site, to incorporate the data from this technique easily into the spatial reference framework. In addition, the similarity between the constraints on NIR and image capture meant that these techniques could use similar operational solutions to ensure they produced reliable measurements. The project as a whole emphasises the key role of soft skills in enabling the collaboration to develop.

4. CONCLUSION

Transferring NDTs for monitoring decay developed by academics to the context of conservators is often problematic. Such techniques have been calibrated and operated under laboratory conditions and in field experiments. In these contexts, the academics can delve into the details of the varying impact of operational parameters and derive the optimal operating conditions. Conservators often look to such techniques as means of providing clear and objective data on an identified problem that they can easily relate to their preferred solution. In this scenario the academic is merely someone who points the equipment in the right direction and provides data to the conservator.

We suggest that a more fruitful view of collaboration is one where both academics and conservators develop an evolving and trusting relationship. In this situation, both parties become involved in developing a research design that incorporates an understanding of the constraints on the techniques used. Likewise, such a collaborative relationship opens up opportunities for reinterpreting the nature of the problem. In this case, the detailed microbial analysis of the biofilm resulted in a more detailed understanding of the dynamics of change under UVC light, and enabled the development of monitoring of change based on image analysis and NIR. Adding these techniques meant that different layers of information could be used to understand the impact of UVC in more depth, and to home in on the most effective duration of exposure for removal of key species. Without the evolution of a dialogue in data interpretation between the academics and the conservators, this type of integrated use of NDTs would not have yielded the understanding it has.

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BRINGING THE OUTSIDE INSIDE:
INSPECTING THE CONDITION OF CARVINGS ON FORMERLY EXTERIOR FEATURE WALLS

Brian Johnston[1]*, **Conor Graham**[2] and **Patricia Warke**[3]

[1*] Brian Johnston, Queen's University Belfast.
P.Warke@qub.ac.uk

[2] Conor Graham, Queen's University Belfast.
Conor.Graham@qub.ac.uk

[3] Patricia Warke, Queen's University Belfast.
P.Warke@qub.ac.uk

* corresponding author

ABSTRACT

Climate change's influence has been identified as a major contributing factor to changing rates of stone deterioration in historical building façades. Acknowledging this, attention should be given to wall sections that have transitioned from exterior façades to interior feature walls, following building extensions. In the UK, this usually means that the wall section has been 'moved' from a temperate climate to an artificial one, with conditions akin to a desert or arid environment. Evidence shows that such a move will result in the stonework undergoing an 'adjustment phase' as the material dries out in this artificially heated and rain-free environment. The study site for this work is Fitzroy Presbyterian Church in Belfast, Northern Ireland. The original church was constructed in 1874 from locally quarried sandstone, from which multiple intricate carvings were completed around the windows. During this work, the focus will be on a set of twelve faces flanking the six largest windows, each depicting a saint or biblical character. In 2015, a new extension was added to the building and a section of the eastern façade was transitioned to become an internal feature wall. This included two of the main windows and associated carvings. In this work, a condition assessment of the faces was undertaken. Due to limited accessibility the assessment was carried out using a Mavic Pro Drone to reach the appropriate elevation. Images acquired using the drone were used to generate 3D models of the carvings, by applying structure-from-motion techniques. The six faces on the feature wall were then compared to the six faces that remain part of the exterior façade. This was done to determine the impact that the period of adjustment to the new interior climate has upon these carvings.

Keywords:
structure from motion, photogrammetry, sandstone, drones, condition assessment

1. INTRODUCTION AND BACKGROUND

Repurposing of historical buildings within our city centres has required the renovation of structures. This can include the construction of an extension, as the building's owners seek to increase their space to accommodate the structure's new purpose. The extensions result in parts of the building façade transitioning from the exterior environment into the building's interior. In the case of aesthetically appealing stone work, these façades can be integrated as a feature wall within the new space.

In the UK, these blocks will experience a change from the wet and temperate climate to an artificial one that is both dry and heated. In this way the blocks are experiencing a near instantaneous change in climate. Warke and Smith (2007) identified the occurrence of an initial adjustment phase in blocks that have transitioned from the quarry to the urban environment, resulting in material loss and weight change. Blocks in repurposed buildings will likely undergo a similar process with the loss of sections of the sculpted material.

In the context of this paper, the focus will be a set of twelve carved stone heads. The heads were installed at the same time, but in recent years some have been transitioned to an internal environment following the construction of an extension. This work aims to compare the condition of these heads to observe the impact that this near instantaneous climate change has had upon the carvings. The elevation of the heads requires the use of a drone to image them.

Proper inspection of architectural features situated at high elevations often requires the use of scaffolding or ladders to facilitate access. However, for inspections of building exteriors drones are now being utilised as an important tool in the building surveyor's arsenal (Rakha and Gorodetsky 2018). This tool enables the examination of the condition of stonework from the safety of the ground. There are also possible cost savings, as the use of a drone removes the expense of scaffolding hire and reduces site closure times during inspections. This leads to the question of whether drones can be utilised for the inspection of the interiors of historic structures. In response, a brief review of literature covering the application of drones for historic building inspection will be provided. The author will then propose an operation procedure implemented for the discussed study site that ensured the safety of both the operators and the general public.

Images collected by the drone were used for structure from motion, where the pixels in a series of photographs are matched. This information was then used to generate 3D models which can be annotated and discussed by colleagues following the drone inspection.

2. PAST APPLICATIONS OF DRONES FOR BUILDING INSPECTIONS

In the last ten years, the capability for drones to remotely record data at sites of interest which may otherwise be inaccessible has been highlighted. For example, drones have been used to explore damage to historic sites following natural disasters in L'Aquila, Italy (Lega et al. 2010) and Onagawa Town, Japan (Yamazaki et al. 2015). They have also been used to inspect sections of coastal heritage and remotely situated sites in mountainous regions (Sun and Zhang 2018; Ma et al. 2013).

The use of drones allows the capture of quick and relatively cheap low-altitude photography of the site or structure (Rakha and Gorodetsky 2018). Imagery captured from the drone can be used to generate digital models using 3D photogrammetry, a useful tool in the discussion of heritage conditions with both clients and conservators (Murtiyoso et al. 2017). Thermal sensors and multispectral cameras can also be attached to the drones, facilitating the collection of other data sets to complement the drone footage. For example, drones have been used as a platform for thermal inspections of historic buildings to identify the need for insulation (Entrop and Vasenev 2017).

3. METHODOLOGY

3.1 The study site

The study site is Fitzroy Presbyterian Church, located in South Belfast. The church was constructed in 1874 as part of the rapid expansion of the city. The building was constructed from the local Triassic Scrabo sandstone, part of the Sherwood sandstone group.

The building has a set of six memorial windows, three on the western façade and three on the eastern façade, decorated with intricate carvings of biblical characters or significant iconography. In 2015, the construction of an extension onto the eastern face of the building resulted in the conversion of one of the exterior walls into a feature within a new café space.

During the construction of the extension the stonework was abrasively cleaned, leading to concerns about the condition of the carvings. Discussion with representatives of the church in 2016 revealed that material loss had been observed from parts of the feature walls, including the window carvings. However, in recent years the loss of material has reduced, suggesting that the wall may have stabilised.

The locations of each of the stone carvings are marked in Figure 1.

The set of carvings that remain exterior overlook a small car park that is positioned between the church and a neighbouring hotel. As a result, the wall sections have been sheltered from both direct rainfall and sunshine for most of the year. The interior carvings face onto the road, with no nearby buildings, leaving the façade exposed.

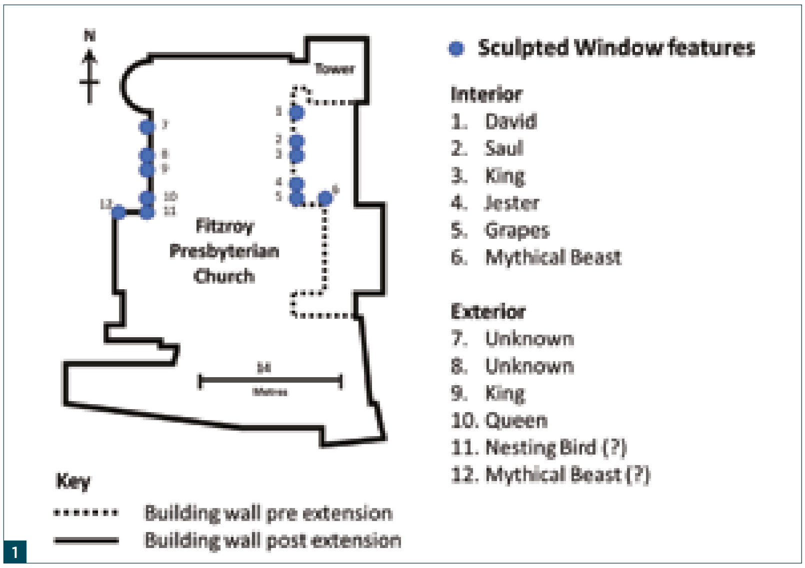

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Figure 1: Positions of the sculpted features.

3.2 Drone operations

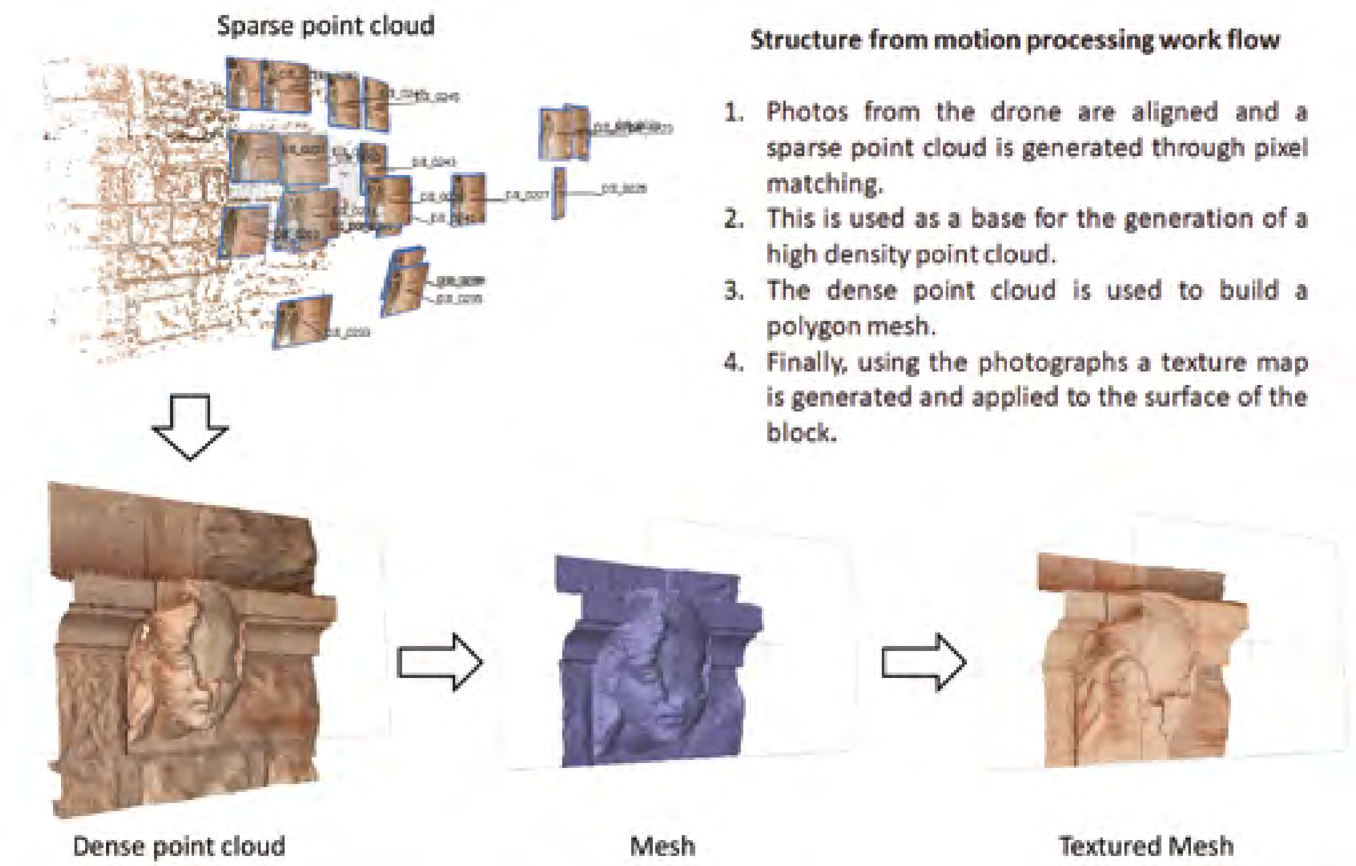
The operation of the drone within an internal space adds additional complications for the system operator while eliminating others. The most obvious issue with the use of drones within an internal space was the presence of obstacles to the operation of a safe flight, such as the surrounding walls and furniture. To reduce this risk, the initial take-off space was cleared of all surrounding furniture. The drone was immediately raised to a height of two metres, above the surrounding furniture.

2

Figure 2: Drone with mounted propeller guards.

To reduce the risk of accidental impact between the propellers and the wall, a set of propeller guards were mounted onto the equipment (Figure 2). The drone's obstacle avoidance sensors were activated for this task, to keep the drone a safe distance away from the structure of interest. This protects both the wall section and the equipment in case of a collision. The propeller guards were also used on the exterior of the building, where near flying was required to obtain suitable images of the carved features.

The drone pilot in this study holds a valid permission for commercial operations certificate, which allows increased flexibility regarding UK drone laws. However, by the UK civil aviation authority legislation, this pilot can still not operate a drone with 50 metres of a person not under the control of the drone pilot. The risk of an unintended impact with a person is reduced indoors, as the operator can seal the room where operations are taking place. A second person must remain in the room, in a location designated as safe by the main operator, in case of an emergency where the operator has been incapacitated.



Structure from motion processing work flow

1. Photos from the drone are aligned and a sparse point cloud is generated through pixel matching.
2. This is used as a base for the generation of a high density point cloud.
3. The dense point cloud is used to build a polygon mesh.
4. Finally, using the photographs a texture map is generated and applied to the surface of the block.

3

Figure 3: Work flow applying structure from motion to the images of the sculpted features.

Foreign object debris (FOD) needs to be considered prior to interior operations, as material uncommon in an exterior environment will be found there. With the restricted nature of the room, the down draft from the drone can cause papers and light ornaments to be blown off countertops if not appropriately weighted. It is therefore necessary to include a sweep of the entire flight area for this material before operations.

3.3 Processing

For each of the sculpted features, between 12 and 20 photographs needed to be taken, ensuring that suitable overlaps were obtained. The images were processed in the office using AgiSoft Metashape, a stand-alone package used for photogrammetric processing and generating 3D models. The photogrammetric workflow is consistent between most software packages (Figure 3).

The first step of the process begins with feature matching and photograph alignment, which will result in the generation of a sparse point cloud of match points. The second step is a longer process of dense pixel matching using the photographs aligned in the previous operation. This will produce the dense point cloud that will be used for generating the desired outputs. The dense point cloud is used to build a polygon mesh which is then coloured using a surface texture generated from the average calculated value from the original photographs.

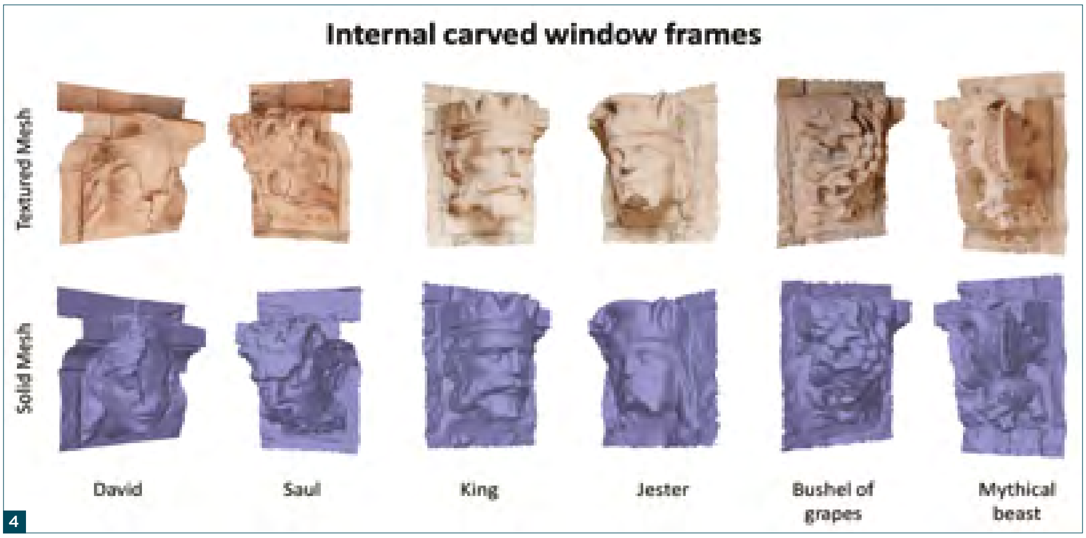


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Figure 4: Output 3D models of the interior carvings.

4. RESULTS

All twelve of the stone carvings were modelled during this project. The obstacle avoidance sensors proved to be too restrictive during the inspection, limiting the drone's movability when attempting to inspect the sides of the carvings. This means that the coverage and availability of overlaps in some locations was reduced.

Most of the sculpted heads were recorded with enough coverage to produce suitable meshes upon which the textured surface could be overlaid.

The internal carvings have very distinctive features (Figure 4); however, the carvings of David and Saul have begun to lose sections of their faces, and the Jester has lost his chin. The exterior carvings (Figure 5) are in very poor condition, with four of the six indistinguishable. Discussion with the church representatives tells us that the nesting bird has recently been lost, and small sections of foliage and a leg can be identified in the mesh. The Queen is in good condition, with most of her features still clear.

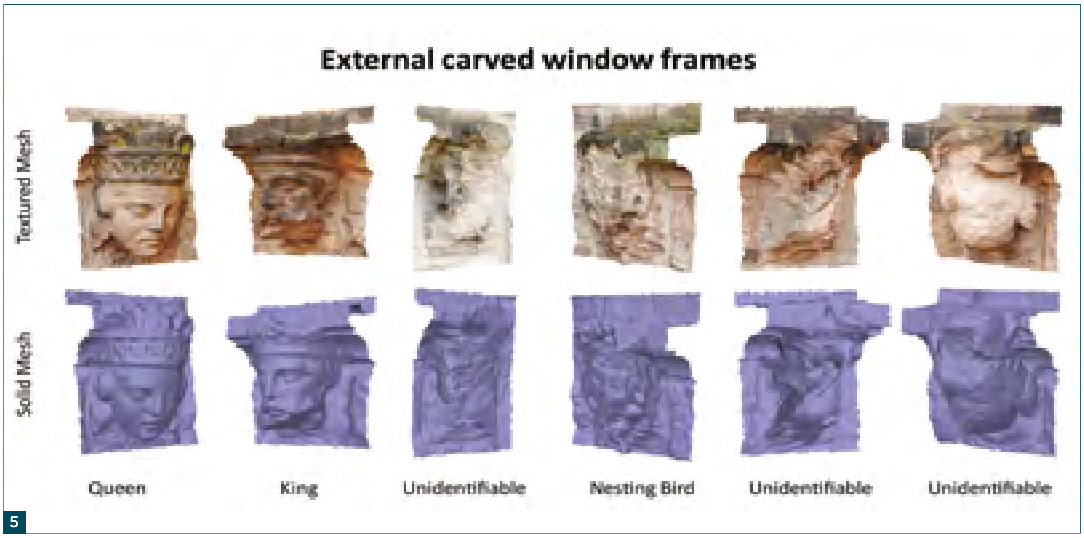

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Figure 5: Output 3D models of the exterior carvings.


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Figure 6: Photos of Saul and David prior to their cleaning in 2015.

5. DISCUSSION

The aim of this work was to compare the conditions of the heads situated on the exterior of the building with those that have undergone rapid 'climate change' following the construction of the extension in 2015. However, upon completion of the work it was found that the exterior carvings have experienced a greater rate of deterioration, predating the construction of the extension. This difference in weathering rates is more likely a result of variance in material properties or environmental factors across the building. As a result, their use as a baseline for comparison with the internal carving would not be appropriate for the study. Instead, examination of a set of photographs taken prior to the conservation work has shown that the carvings have lost detail following the construction of the extension. This is most pronounced in the case of the heads of Saul and David (Figure 6), though damage to these heads can be seen here, corresponding to the sites of subsequent material loss.

Regarding the use of drones for these inspections, the equipment was found to be a quick and effective tool for the internal inspection. Though some limitations were identified, it allows the users to generate 3D models for discussions with colleagues and clients with minimal disruption to the site of interest. Based upon these models, decisions can be made on whether the sculpture requires a closer visual inspection. Future work requires experimentation with multispectral cameras, using drones as a platform to deploy this equipment within the internal space.

6. CONCLUSIONS

Discussion with the congregation has informed the authors that the building has undergone material loss following the construction of the extension in 2015.

Inspection of the windows cannot be used to validate this observation, as the façade that remained external has experienced greater material loss due to either material or climatic variations across the building surface.

The use of drones as part of an internal inspection survey has proven to be successful, through some limitations exist, resulting from restrictions in the platform's mobility due to anti-collision sensors.

The 3D models provide a useful tool for discussion with colleagues regarding the conservation of these important features of the building.

ACKNOWLEDGEMENTS

The authors would like to thank the congregation of Fitzroy Presbyterian Church for unrestricted access to their place of worship while we undertook this work. We also appreciate the permissions provided by the neighbouring property owners who gave us permission to operate in this area.

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USING MULTI-SENSOR MOISTURE MEASUREMENT IN CONSERVATION THROUGH 'BUILDING PATHOLOGY INDICES' AND 3D DIGITAL DOCUMENTATION

Scott Allan Orr[1]***, Maureen Young**[2] and **Adam Frost**[3]

[1*] Scott Allan Orr, UCL Institute for Sustainable Heritage.
School of Geography and the Environment, University of Oxford.
scott.orr.14@ucl.ac.uk

[2] Maureen Young, Conservation Scientist, Historic Environment Scotland.
maureen.young@hes.scot

[3] Adam Frost, Senior Digital Documentation Officer, Historic Environment Scotland.
adam.frost@hes.scot

* corresponding author

ABSTRACT

Several non-destructive techniques are commonly used to measure moisture in stone-built heritage, including electrical properties, infrared thermal imaging, microwave measurement and radar. Each technique, as well as the sensors or devices used to implement it, has advantages and limitations. Two factors of significant importance are substances that can influence readings (such as salts) and the uncertainty of depth of penetration. This paper addresses these factors by developing 'indices of consistency' between devices to: a) amplify between devices with similar properties, and b) remove the influence of factors that make the indication of different moisture levels less clear. These indices are a simple algorithm from a class of data processing techniques known as 'data fusion' that combines information from several inputs (devices); the indices are developed from specific combinations which are selected based on the principles and practical experiences with using the devices. These indices have the benefit of synthesising the data collected from several devices into 'challenge-specific' visualisations that streamline interpretation. This principle is employed for data collected from a multi-sensor survey that was undertaken on a stone barrel vault ceiling in Argyle Tower, Edinburgh Castle, which is suspected to have water ingress due in part to its method of construction, exposed location and evidence of salt-related weathering. These indices are then combined with 3D digital documentation to more closely link them with the distinct geometry of this structure and enable a greater level of interpretation.

Keywords:
surveying, data analysis, laser scanning, handheld moisture meters, building pathology

1. INTRODUCTION

Understanding how and where moisture is entering and impacting the fabric of a structure is an important part of building management. This is especially true for the historic environment, in which the nature of construction techniques varies widely and previous adaptations confound attempts to characterise it.

Building pathology is a holistic approach that seeks to understand buildings in relation to their environment, with particular emphasis on defects and remedial action. In this context, it is not strictly essential to characterise absolute moisture contents. By considering the contrast of moisture between surface and depth, as well as the distribution across a façade, a reasonable conjecture can be made about the source of moisture ingress. This evaluation is usually undertaken qualitatively, but can involve more advanced methods, such as data fusion (Kohl et al. 2006). This is a common approach for studying structural elements of historic buildings (Ramos et al. 2015; Mishra, Bhatia and Maity 2019), but is not commonly employed for moisture detection.

Scientific investigations can provide invaluable information on the moisture levels within building materials. Non-destructive tools that use proxies for the moisture content are particularly suited to the historic environment, as they do not require any invasive analysis or loss of material, in line with the ethics of preserving cultural heritage (Pinchin 2008). However, the output from these devices is often in arbitrary units and heavily dependent on the properties of materials present in the structure. Additional factors may also influence their output, due to the measurement method. Gravimetric calibration (using the mass of water present in a sample) is a common technique to relate the output of non-destructive moisture measurement devices to an absolute moisture content (Orr 2019). However, this can add additional time requirements into a project, which may not be feasible for an individual building survey. It also requires that sample(s) of appropriate material are available for testing. Thus, it is not feasible to include in all cases.

Digital documentation is a powerful technique to accurately and precisely produce 3D representations of historic structures (Remondino 2011). This is especially useful in combination with moisture measurement, as their integration enables a deeper understanding of how measured moisture levels relate to the geometry and fabric of a building.

In this paper, we present a simple method for combining moisture measurement data from several devices into indices that can be integrated into a building pathology approach. These indices can incorporate measurements from multiple devices to reduce the influence of their measurement principle due to confounding factors. These indices advance current approaches within building pathology by enabling semi-quantitative comparison between measurement locations with respect to relative levels of moisture.

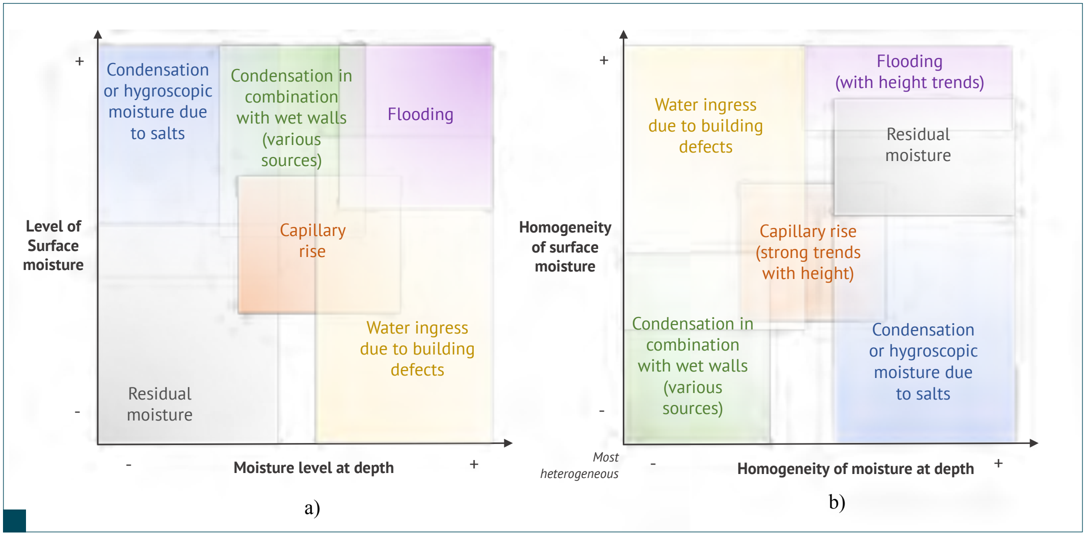


Figure 1:
A two-dimensional visualisation of using comparison between surface moisture and moisture at depth a) and homogeneity of surface moisture and moisture at depth b) to infer potential sources of moisture ingress in buildings. Adapted from Göller (n.d.).

2. BUILDING PATHOLOGY INDICES

A common approach in assessing moisture ingress in building pathology is to compare the relative levels of surface moisture to moisture at depth, and consider how homogeneous (even) the distributions of moisture are across the area of interest. The combination of these two factors can infer potential sources, when considered relative to a suitably ‘dry’ reference area of measurements. A benefit of this approach is that it is not necessary to make a gravimetric calibration. This comparison of moisture at surface and depth within building pathology is usually undertaken qualitatively (Singh, Yu and Kim, 2010) or semi-quantitatively, with moisture ingress estimated but mapped onto numerical skills broadly relating to ‘levels’ (Annila, Hellemaa and Pakkala, 2017).

2.1 Visual representation of the building pathology approach

Although typically assessed qualitatively, a two-dimensional x-y plot can be used to visualise the comparison between surface and depth (Figure 1a) and homogeneity (Figure 1b). It is important to note that the boundaries between different types of ingress are subjective and will have significant overlap. Göller (n.d.) has proposed a system of comparison for surface and depth moisture to infer the source causes, although this has also been presented in more qualitative (Stirling 2011) or ranked (Ismail 2019) formats. As the decay mechanisms for certain types of wood are much more defined, these levels are often defined as specific absolute moisture contents (Singh and White 1997), but this is not appropriate for other building materials such as stone. These indices can be supplemented with visual inspection of the distribution of readings or levels to assess if they are dispersed (several areas that are not interconnected) or primarily concentrated into one region. These nuances are not represented by the homogeneity index.

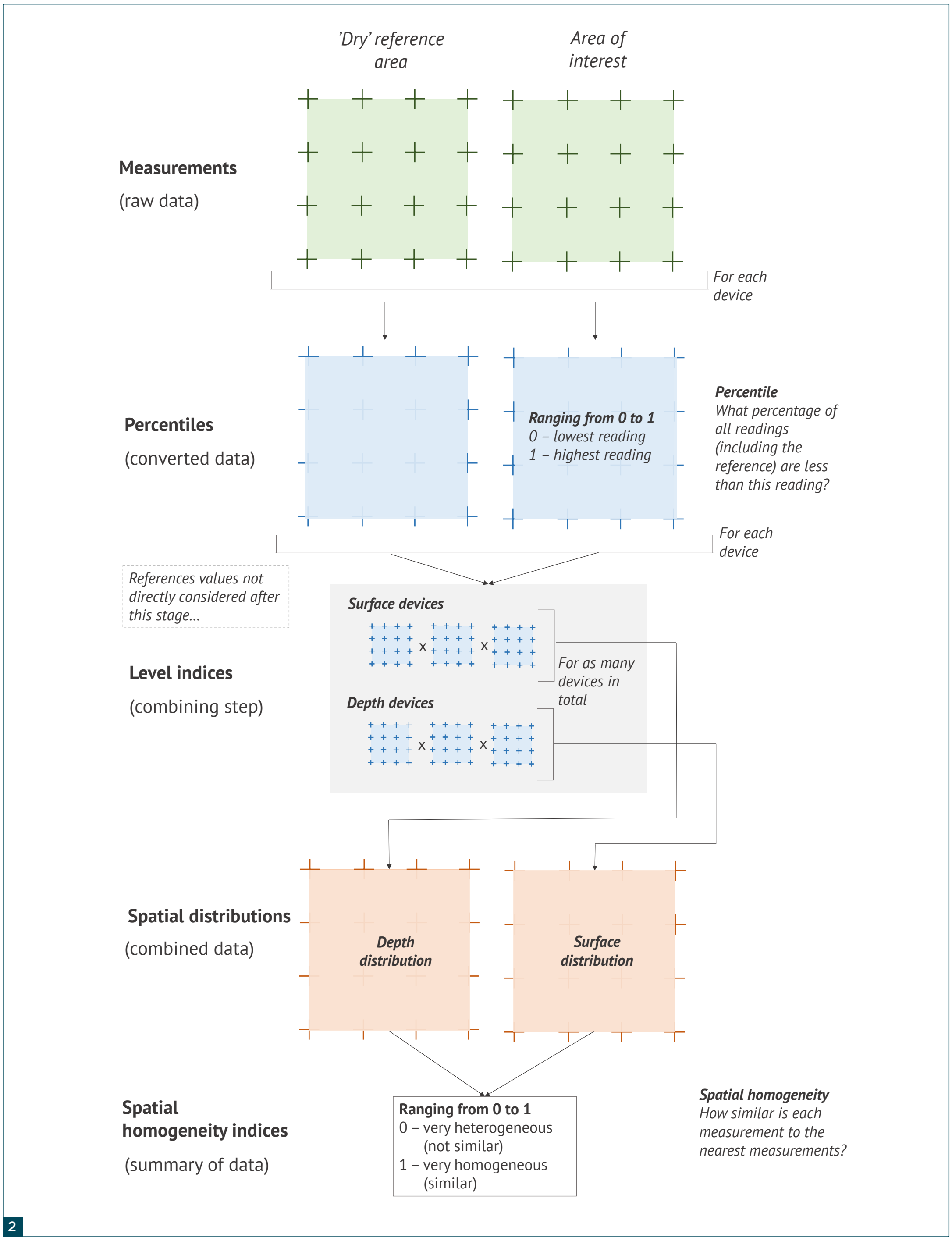


Figure 2:
A visualisation of the calculation procedure for the building pathology indices.

2.2 Calculation procedure

To use the visualisation procedure introduced in Section 2.1 as part of a quantitative evaluation, data fusion can be used (Hall 1997). The indices presented here are mathematical combinations of measurements across conceptual diagrams like those in Figure 1. This enables semi-quantitative comparison between regions of interest. The procedure for determining these indices is summarised in Figure 2. This procedure can be undertaken manually, or automated for ease of repeated use.

2.2.1 Measurement collection

The measurements (typically collected on a grid of points) are taken for the area of interest and a 'dry' reference area. The latter is generally an internal wall, or an area without visible signs of wetness or previous moisture-related deterioration. Measurements can be taken with several devices, which helps to reduce the potential influence of confounding factors due to measurement method.

2.2.2 Conversion to percentiles

The measurements are converted into percentiles: a numeric representation of the percentage of readings each individual reading is greater than. If a reading has a percentile of 90% (0.9 as an equivalent fraction between 0 and 1), its value is greater than 90% of all readings. These percentiles are taken across the area of interest as well as the dry reference. Therefore the percentiles ('relative' readings) of the area of interest increase if they are greater than the reference values, but not if they are similar in magnitude. Converting the measurements to percentiles minimises potential error from unknown types of relationships (e.g. linear, exponential, etc.) between the arbitrary units of moisture measurement devices.

2.2.3 Level indices (spatial distributions)

The level indices represent how much higher moisture levels are relative to the dry reference. They are determined by multiplying the measurements taken with each device on each grid point within each category. The categories are determined by the spatial capture of the device, i.e. whether it is predominantly used to detect moisture at surface or at depth. After the multiplication, the indices are arbitrarily normalised between 0 and 1 for ease of assessment. These can be visualised as two-dimensional distributions of moisture.

2.2.4 Homogeneity indices

The spatial homogeneity indices represent the extent to which adjacent grid points are similar or different in value from one another. It is calculated by finding the average difference between a grid point and each adjacent grid point, and subtracting this from 1. The subtraction is necessary so that a value close to 1 (a higher value) represents a very homogeneous distribution, while a value near to 0 means that a distribution is very heterogeneous.

An overall index for the area (for both surface and depth distributions) can be calculated by determining the average of the spatial homogeneity indices for the respective grids.

2.2.5 Source identification

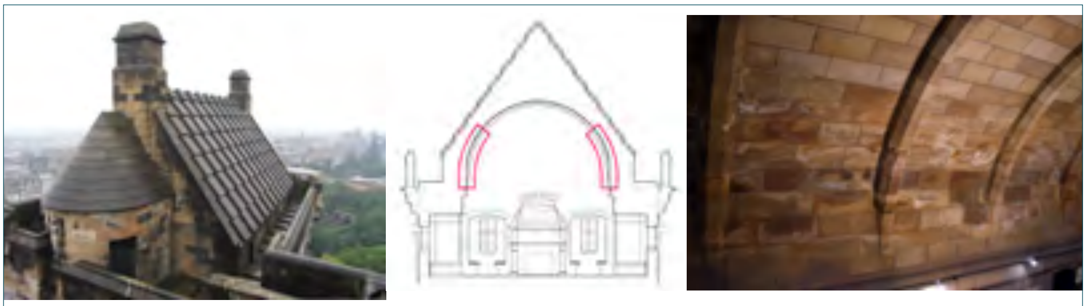
The two types of indices (level and homogeneity) for surface and depth are compared against Figure 1 to determine possible sources of moisture ingress.

2.3 Methods

The details of a case study designed to evaluate this approach are described below.

2.3.1 Case study site: Argyle Tower, Edinburgh Castle

Argyle Tower is a late-19th-century addition to the Portcullis Gate of Edinburgh Castle. The castle's exposed location results in a high exposure to episodes of wind-driven rain (Figure 3a). The tower features a roof formed of interlocked stone 'tiles' on top of a stone barrel vault ceiling interior (Figure 3b). It is unclear from architectural records and drawings what, if anything, is present in this void, nor if there are other architectural elements implemented into the roof structure. The bays near



a) b) c)

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Figure 3:
a) The exterior and context of Argyle Tower, Edinburgh Castle;
b) a cross-section of the construction with the area of interest (location of bays) in red; and
c) an interior view of the deterioration in the bays at the intersection of the vault and the vertical wall.
Image in (a) CC-BY-SA 2.0 Gareth James.

the intersection of the vault and the vertical walls show extensive salt- and moisture-related deterioration (Figure 3c).

Two bays on the north-west aspect were chosen for specific study: Bay A is the central bay, while Bay B is adjacent to the northernmost corner of the tower.

2.4 Moisture measurement

Moisture measurements were taken in two bays of the tower. Measurements were taken on a 10cm grid spacing across an 80cm x 80cm area. Another 80cm x 80cm area was measured at the base of an internal wall to act as the relative 'dry' measurements. Several devices were used to produce the indices (Table 1), each of which has different characteristics such as spatial capture and confounding factors.

Device	Measurement method	Depth(s) of penetration cm	Category	Confounding factors
hf sensor Moisture Measurement System; two models with different calibrations	Microwave	~3, ~30, ~80	Surface, Depth, Depth (respectively)	Metals, voids
Surveymaster Protimeter	Electrical resistance (pin-type)	< 0.2	Surface	Presence of salts
Surveymaster Protimeter	Capacitance	~ 4	Surface	Metals, voids, salts (although minimal)

Table 1:
Moisture measurement devices used in this study.

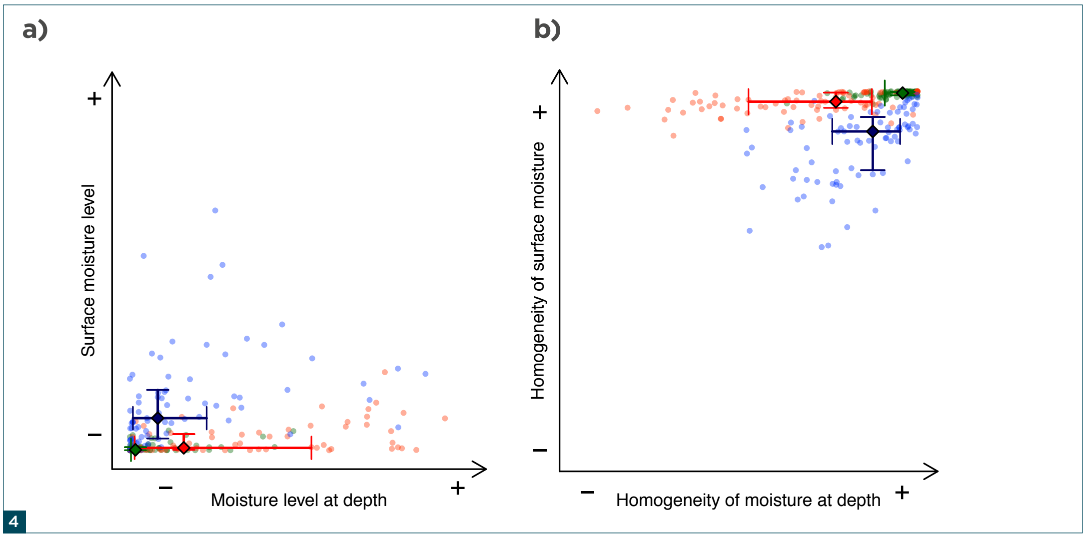

Figure 4:
The level a) and homogeneity b) indices for the bays plotted onto the framework presented in Figure 1: Bay A (red), Bay B (blue), and the reference measurement grid (green). Smaller circles represent individual grid points, while the large squares are the median (the index value which is greater than half of those within the grid) that are presented with the inter-quartile range as whiskers (a range in which 50% of the data centred around the median lie).

2.5 Digital documentation

Argyle Tower was recorded using Terrestrial Laser Scanning as part of Historic Environment Scotland's Rae Project, an ongoing commitment to digitally document all of the organisation's properties in care. The wider 3D dataset for this survey incorporates the entirety of Edinburgh Castle, including interior and exterior spaces. The capture and processing methodology is broadly outlined in *Short Guide 13: Applied Digital Documentation in the Historic Environment* (Historic Environment Scotland 2018). The registration methodology used targets and point-cloud-based feature alignment. In addition, a traverse survey methodology linked the Argyle Tower data to the wider control network of the Castle dataset. The 3D point cloud dataset generated by the laser scanning was then used to create a high-resolution 3D model using CapturingReality's RealityCapture software. For visualisation, the 2D plotted moisture data was subsequently projected onto the subject areas using 3D modelling software Autodesk 3DS Max.

2.6 Results

2.6.1 Evaluation of the indices

Figure 4 shows the level and homogeneity indices on a two-dimensional plot within the building pathology index framework presented in Figure 1. The comparison of these two indices allows for sources of moisture to be inferred.

The median surface level index for Bay A is negligibly greater than the dry reference index (Figure 4a). In contrast, Bay B has a higher median level of surface moisture. Both have higher levels of moisture at depth, but that for Bay B is more significant. Significant spread of individual grid points is apparent. Although several grid points in both bays are clustered around the median reference level index, others are significantly greater than the median values, indicating a wide spread of indices. Bay A primarily has greater depth level indices, while the extreme grid points in Bay B exhibit greater spread in both levels of surface moisture and moisture at depth.

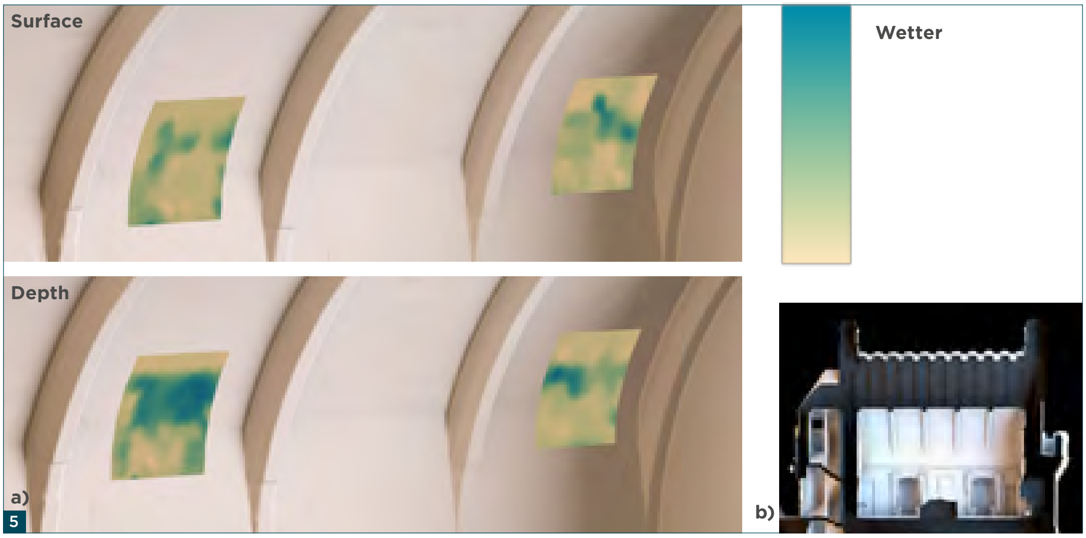

Figure 5:
a) Surface and depth level indices for Bay A (left) and Bay B (right);

b) A 3D cross-section of Argyle Tower, in which the box indicates the measurement locations.

The homogeneity indices (Figure 4b) for both bays are less than those for the reference grid, meaning they are more heterogeneous (less even). Bay A exhibits much more heterogeneity in the depth measurements with regards to the median and extreme values. In contrast, Bay B has more significant heterogeneity in the median and extreme indices for both surface moisture and moisture at depth, but this is less extreme than the spread of Bay A.

2.6.2 Spatial distribution

The distribution of level indices (determined from the device readings summarised in Table 1) for the bays are presented in Figure 5. The distributions have been superimposed onto a 3D model, to better understand how the measurement grid fits into the context of the complex roof construction.

In both bays, a significant decrease in the distribution of level indices is apparent in a band in the upper region. This band is possibly related to a change in wall structure, which represents the point at which the vault separates from the vertical and a cavity is introduced.

The surface of Bay A is characterised by areas of higher indices that are not interconnected. In contrast, the level indices at depth are primarily in one region, just beneath the upper band of lower indices. The surface of Bay B has fewer areas of higher level indices, but they are again disparate and not interconnected. Similarly, the depth indices are only higher in a single area, although a few other groups of moderate indices are present at depth as well.

3. DISCUSSION

A summary of the spatial distributions and median level and homogeneity indices enables potential moisture sources to be inferred (Table 2).

Despite its utility, limitations of the methods must be considered. First, certain ingress pathways are heavily dependent on weather events and environmental conditions. It is difficult to attribute moisture ingress to a building defect if the previous weather (and exposure) is unknown. As well, a suitable 'dry' reference area must be identifiable, to contextualise the readings in the area(s) of interest.

More broadly, the challenge of establishing the accuracy and utility of the indices is dependent on several factors. Principally, it should be assessed in a wide variety of suspected types of moisture ingress. As well, their function and ability to characterise types of ingress may differ depending on the mode of construction and materials used, as well as the information available and discernible about the structure and its use. It is likely that the distribution of values within the level and homogeneity indices will vary depending on these factors, making it difficult to assign prescriptive ranges of values for types of ingress. Future work could explore more advanced fusion algorithms, especially those which incorporate supervised and unsupervised learning techniques.

Table 2:
Summary of moisture levels in the bays.
Low: Less than 0.25; moderate: 0.25 to 0.50, high: greater than 0.75.

Bay	Surface level index *Median*	Depth level index *Median*	Surface homogeneity index *Median*	Depth homogeneity index *Median*	Spatial features	Potential source(s)
A	Low	Low to moderate	High	Moderate to high	*Surface:* non-interconnected areas; *Depth:* one main region	Residual moisture, water ingress due to building defect(s)
B	Low	Moderate	Moderate	Moderate	*Surface and Depth:* few non-interconnected areas	Residual moisture, condensation or hygroscopic moisture due to salts

4. CONCLUSION

This paper has presented a way of semi-quantifying a building pathology approach to assess moisture sources. The procedure of utility of these was demonstrated with a case study of a complex historic building in a Scottish context. Integrating moisture measurement techniques with 3D digital documentation contextualised the analysis within the complex barrel vault ceiling structure of the building, enabling a greater understanding of the issues. It also allows for results to be presented in a way that is more effectively communicated to a wide range of audiences, in contrast to colour plots presented out of context.

Future work will investigate whether the method can be extended to a wider range of moisture ingress pathways, and streamline the procedure for more efficient integration with moisture surveying and practice. This will require evaluation of a wider range of materials and scenarios, which can be studied both within laboratory and in situ contexts. Data fusion algorithms beyond those evaluated herein may provide further opportunities for advancing methods of building pathology.

The protocol enables a more accurate and in-depth understanding of moisture ingress pathways between areas of interest within the same structure. This is an integral part of building conservation as part of efficient and effective management of the historic built environment.

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USING PORTABLE MOISTURE METERS AND PAPER PULP POULTICE TO INVESTIGATE MOISTURE AND SALT DISTRIBUTION IN ROCK-HEWN BAS-RELIEFS IN BETE GOLGOTHA, LALIBELA, ETHIOPIA

Blen Gemeda[1*], **Heather Viles**[2], **Fassil Giorghis**[3] and **Fkereselasse Sifir**[4]

[1*] Blen Gemeda, DPhil Candidate, School of Geography and the Environment, University of Oxford. blen.gemeda@ouce.ox.ac.uk

[2] Heather Viles, Professor, School of Geography and the Environment, University of Oxford. heather.viles@ouce.ox.ac.uk

[3] Fassil Giorghis, Associate Professor, EiABC, Addis Ababa University. fgconsult2010@gmail.com

[4] Fkereselasse Sifir, Site Architect, World Monuments Fund. hendobi@gmail.com

* corresponding author

ABSTRACT

This study investigates the deterioration of carved bas-reliefs on the interior walls of a medieval rock-hewn church in Lalibela, Ethiopia. Bete Golgotha is one of two churches in the Lalibela church complex that has bas-reliefs of saints on the north and south walls of the church. The bas-reliefs on the north wall are affected by surface material loss due to flaking, while the bas-reliefs on the south wall, conversely, are in very good condition. The aim of this paper is to determine the cause of localised deterioration on stone structures using non-destructive techniques. Surface moisture content and salt distribution were measured along a vertical transect on the bas-relief to determine if moisture ingress and salt weathering were the main causes of the damage that was observed on the north wall. Moisture distribution was assessed using a Protimeter Surveymaster, an Infrared camera and a Moist 350 B microwave moisture meter. Soluble salts were extracted from the bas-reliefs using paper pulp poultice and the concentration of soluble salts absorbed by the poultice was measured using a conductivity meter and an ion chromatographer. The results from the IR camera and Moist 350 B showed a similar distribution of surface moisture on the north and south walls. An overall higher Protimeter reading was measured on the north wall. This was due to the presence of salts, which are known to increase Protimeter readings on stone surfaces. This corresponds with the results of the salt extraction test, which showed a higher concentration of soluble salts on the surface of the north wall. Therefore, we can conclude that the deterioration of the north bas-reliefs may have occurred as a result of salt weathering.

Keywords:
salt weathering, paper pulp poultice, portable moisture meters, non destructive testing

1. INTRODUCTION

In the built heritage environment localised deterioration is a common occurrence. Localised deterioration refers to the phenomenon of patchy ‘hot spots’ of deterioration in materials of the same age exposed to similar environmental conditions. Determining the cause of ‘hot spots’ of deterioration can be challenging because there are complex processes at play. Environmental factors, material properties, human intervention and other factors can contribute to localised deterioration. It is critical to correctly diagnose the causes of localised deterioration in order to carry out effective conservation treatments.

In this paper, two sets of bas-reliefs found on opposite walls inside a rock-cut church are investigated to determine what has caused one set to deteriorate badly when the other set appears to be in good condition. The bas-reliefs are found in Bete Golgotha, a rock-cut church in Lalibela, Ethiopia. The churches were carved into a basaltic scoria hill in medieval times. These groups of churches are an important religious and cultural heritage site and were inscribed on the UNESCO world heritage list in 1978. Bete Golgotha is one of two churches in the Lalibela church complex that has bas-reliefs adorning its southern and northern walls, and some of these bas-reliefs are under threat from rapid deterioration. There are six bas-reliefs, three each on the north and south walls in Bete Golgotha. Four of the bas-reliefs are found in the nave of the church; the rest are in the holy of holies and can only be accessed by priests and deacons of the church. Therefore, only four bas-reliefs could be studied in this research.

Granular disintegration and surface flaking have significantly damaged the surface of the north bas-reliefs (N1 and N2). A lot of surface material has been lost and the reliefs do not appear as sharp and clear as the south bas-reliefs (S1 and S2) (Figure 1). The cause of this damage has not been investigated scientifically before. While art historians have suggested that the north bas-reliefs were the first to be built, with the reliefs on the south being reproduced later


1a
1b

Figure 1: Bas-reliefs in Bete Golgotha: a) N1 and b) S1.

(Gervers 2003), there is no historical or physical evidence to suggest that the north set were built first. Through investigating the condition of the two sets of bas-reliefs it is possible to diagnose the cause of the deterioration and to determine if the difference in appearance between the two sets is a result of rapid weathering.

The basaltic scoria outcrop into which the churches are carved is very porous, contains swelling clays and has weak mechanical properties (Asrat and Ayallew 2011; Renzulli et al. 2011; Schiavon et al. 2013; Gemeda et al. 2018). The north and south set of bas-reliefs are found four metres away from each other in what appears to be the same rock type despite the spatial variability in the vicinity of this church. One of the main differences between the two sets is the thickness of the walls on which they are carved; the north wall has a thickness of 4.5m and the south wall is 0.9m thick. Moreover, the north wall separates the church from a trench that serves as a drainage channel in the rainy season, which could lead to a higher moisture content in the north wall and could aid the transport of soluble salts. Understanding the impact of salt and moisture on the deterioration of the bas-reliefs in Bete Golgotha is highly beneficial to future conservation efforts and studies on the rock-hewn churches at Lalibela. Using multiple non-destructive testing methods, the salinity and moisture content of the bas-reliefs could be determined on site without requiring invasive sampling.

2. METHODS

2.1 Moisture measurement

In this study non-destructive hand-held moisture measuring equipment was used to measure the surface and near-surface moisture content of the bas reliefs on the north (N1 and N2) and south (S1 and S2) walls of Bete Golgotha. Hand-held moisture measurement techniques are useful to scan large areas quickly and map the moisture distribution (Pinchin 2008). The moisture distribution on the surface of the bas-reliefs was assessed by point measurements along a vertical transect. The Protimeter Surveymaster (GE), Moist 350 B microwave moisture system (hf sensor GmbH) and an Infrared camera (FLIR-T460) were used to map the moisture distribution. The Protimeter Surveymaster uses electrical conductance principles to measure the moisture level of the material between two electrodes. Unlike the Moist 350 B, which measures the change in the dielectric constant of a material, Protimeter measurements are sensitive to the presence of salts (Pinchin 2008; Eklund et al. 2013). Because of its response to salts, the Protimeter has been used to define damp/saline zones in buildings (Akiner et al. 1992; Mol 2014).

Moisture measurements on the bas-reliefs were taken along a vertical transect in the middle of the reliefs to avoid measuring moisture content in areas with detailed carvings or protrusions. Measurements were taken three times every 5cm using the Protimeter, and three times every 15cm using the R and P sensors of the Moist 350 B. The R and P sensors can detect moisture up to a depth of 3cm and 30cm respectively. The IR camera was used to detect the source and distribution. Using multiple techniques to measure surface and sub-surface moisture content allows for a more accurate diagnosis of the cause of localised deterioration moisture distribution and building deterioration (Balayssac et al. 2012).

2.2 Salt extraction

The distribution of salts on the surface of the largest bas-reliefs from the north (N1) and south (S1) set was assessed using the paper pulp poultice protocol from Egartner and Sass (2016). Other methods of salt extraction are destructive or invasive, and the resulting concentration of soluble salts cannot be used to determine the spatial distribution of salts because the sampling method is not standardised. Field investigation was done using a commercially available poultice (Arbocell BC1000) and deionised water. For each point of extraction 4g of poultice was soaked in 28ml of water and applied on the surface of the bas-reliefs every 30cm for a period of 60 min. The poultice was then soaked in 100ml of deionised water in the laboratory and filtered to measure the cations and anions in the solution using Ion chromatography. Egartner and Sass (2016) used a 1:20 ratio of poultice to water for their field experiment; in this study a 1:7 ratio was used because using a higher ratio resulted in the poultice not attaching to the surface of the stone. The contact area between the poultice and surface of the stone was roughly 28.27cm^2. The poultice was placed every 30cm on a vertical transect on the centre of the bas-relief; eight spots were sampled roughly in the same area where surface moisture content was measured.

3. RESULTS

3.1 Moisture distribution

The moisture distribution measured using the electrical conductance and microwave technique showed different levels of moisture distribution in the two sets of bas-reliefs. The Protimeter readings showed a higher mean value for N1 and N2 as compared to the values measured in the south set (Table 1). In contrast, the microwave moisture meter measurements using the R and P sensors had comparable values of moisture content between the north and south sets. The R sensor, which measures near-surface moisture distribution up to a depth of 2–3 cm, did not show a significant difference in the mean values of the measurements taken along the vertical transect between the north and south set of bas-reliefs. This contradicts with results obtained using the Protimeter, which also measures near- surface moisture content.

	Protimeter %WME		R sensor MI		P sensor MI	
	N1	**S1**	**N1**	**S1**	**N1**	**S1**
Mean	12.18	6.56	934.65	935.06	1462.71	1419.29
SD	4.32	0.57	62.03	37.23	120.01	71.14
	N2	**S2**	**N2**	**S2**	**N2**	**S2**
Mean	12.61	6.66	951.59	959.8	1502.35	1438.4
SD	3.59	1.05	59.35	34.83	164.57	152.6

Table 1:
Mean and Standard Deviation (SD) of Protimeter, R sensor and P sensor measurements.

Infrared Thermography (IRT) was used in this study to qualitatively assess the surface temperature/moisture distribution. IRT is extensively used for the detection of defects such as thermal bridges, air leaks or abnormally moist spots (Grinzato et al. 1998). The infrared thermography analysis showed a comparable heat distribution in all the bas-reliefs; the temperature range was between 16°C and 20°C and the lower parts of the bas-reliefs were cooler for all the reliefs assessed in this study.

Except for the Protimeter, the results from the other methods used to detect moisture/heat distribution correspond with each other. It is worth noting that the Protimeter readings are affected by the presence of salts. Eklund et al. (2013) observed that the presence of salts may significantly increase the readings taken using a Protimeter. The difference between the measurements taken with the microwave moisture system and the Protimeter could be as a result of the salinity of the bas-reliefs on the north set which is severely damaged by flaking and granular disintegration. It also has what appears to be salt efflorescence on some of the area of the bas reliefs.

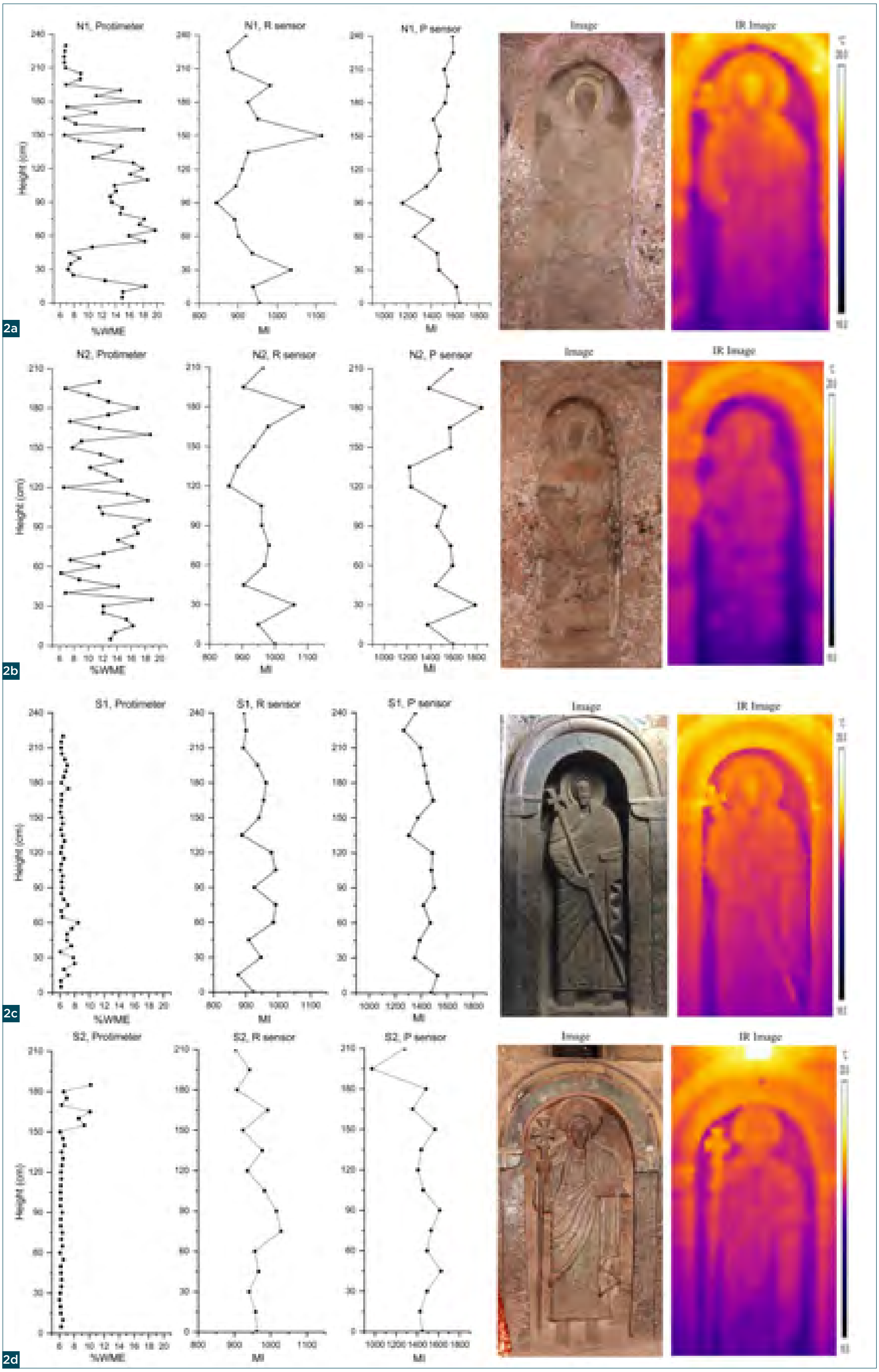

Figure 2: Moisture measurement results of bas-reliefs (from left) Protimeter, R sensor, P sensor, Image and IR images of a) N1; b) N2; c) S1; and d) S2.

3.2 Soluble salts

The soluble salts extracted from the bas-reliefs using paper pulp poultice were soaked in deionised water and filtered. The conductivity (µs/cm) and ion concentration (mg/l) of the filtered solution was then measured. The conductivity of the solution was very low, ranging from 11 to 144µs/cm, with the mean value for N1 samples being 49.62 (standard deviation = 44.55) and S1 samples 29.62µs/cm (standard deviation = 32.39). For the north bas-relief, the highest conductivity was recorded on the lower and upper parts (Figure 3a); this corresponds with areas where salts could be seen on the surface of the reliefs. The Protimeter measurements of the upper and lower parts of N1 correspond with the conductivity and salt concentration values. Similarly, the conductivity of poultice samples from the lower parts of S1 (Figure 3b) was significantly higher than the other areas sampled. Protimeter measurements were also higher on the lower parts of S1 as compared to the rest of the bas-relief; this corresponds with higher ion concentration and conductivity measured. The conductivity of the poultice samples was found to be a good indicator of the salt concentration as the conductivity and salt concentration results correlate very well (R2 = 0.98).

Low levels of soluble salts were detected overall despite the visible efflorescence of salts on the north wall. There were higher concentrations of sulphate, chloride, potassium and sodium ions on N1 samples as compared to S1 (Figure 4). Given the visible salt efflorescence on the bas-reliefs, the low levels of soluble ions measured may have been caused by the salt not diffusing into the poultice. In this church sub-florescence has been observed as the dominant form of salt weathering; therefore, the amount of water that was used (28ml per poultice) may not have been enough to wet the subsurface and to allow the soluble salts to diffuse from the subsurface into the poultice. The dry conditions would have further hampered this during the field experiment, which would have caused the water in the poultice to be evaporated before sufficiently wetting the surface.

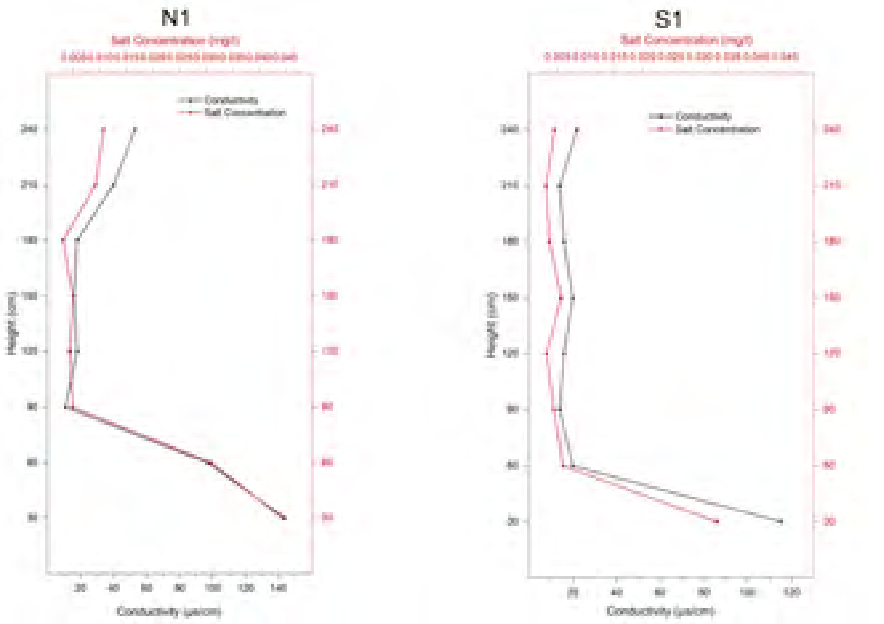

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Figure 3: Correlation of conductivity (µs/cm) and salt concentration (mg/l) of poultice sample solutions of: a) N1 (R2= 0.988) and b) S1 (R2= 0.997).

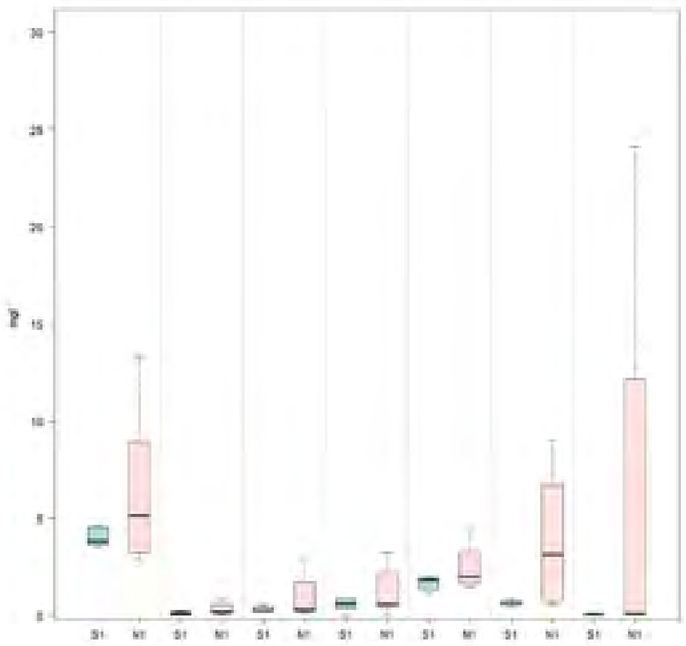

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Figure 4:
Sodium, magnesium, potassium, calcium, chloride, sulphate and nitrate concentration in mg/l for S1 (blue) and N1 (pink) poultice samples.

4. CONCLUSION

Our aim with this study was to demonstrate the use of non-destructive techniques to diagnose localised deterioration of stone. With the use of moisture measuring equipment, an IR camera and the paper pulp poultice technique, we were able to determine that there is a higher concentration of soluble ions on the surface of the north bas-reliefs, which are the most deteriorated bas-reliefs in the church of Bete Golgotha. While we are not able to fully ascertain that the bas-reliefs carved on the north wall have been solely damaged due to salt weathering, our findings and observations suggests that the north wall is more susceptible to salt weathering than the south wall. This is beneficial for current conservation efforts being made in rock-hewn churches in Lalibela, and could serve as a simple methodology to diagnose localised deterioration in settings where destructive sampling or sophisticated laboratory equipment might not be available.

Moreover, we have found that using paper pulp poultice to extract salts can be challenging when the dominant drying front is in the subsurface. The amount of water used to soak the poultice should be increased to speed up the rate of diffusion of the soluble salts to the poultice.

ACKNOWLEDGEMENT

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BELLWEATHERED:
REIGATE STONE DECAY MECHANISMS AT THE BELL TOWER, TOWER OF LONDON

Martin Michette[1*], **Heather Viles**[2], **Constantina Vlachou**[3] and **Ian Angus**[4]

[1*] Martin Michette, Doctoral Researcher, School of Geography and the Environment (SOGE), University of Oxford, UK.
martin.michette@ouce.ox.ac.uk

[2] Heather Viles, Professor, SOGE, University of Oxford, UK.
heather.viles@ouce.ox.ac.uk

[3] Constantina Vlachou, Senior Conservation Scientist, Historic Royal Palaces (HRP), UK.
constantina.vlachou@hrp.org.uk

[4] Ian Angus, Director, Carden and Godfrey Architects, UK.
iana@cardenandgodfrey.co.uk

* corresponding author

ABSTRACT

At the Bell Tower, Tower of London, Reigate Stone decay patterns can be associated with different internal locations. The decay phenomena are surveyed using non-destructive techniques, and the micro-climates of these locations are monitored over an eighteen-month period in order to associate specific environments with patterns of decay. Results are compatible with the hypothesis that distinct environmental mechanisms govern the emergence of powdering and flaking decay phenomena. Powdering is driven by deep wetting of the stone and a steady ambient climate; evaporation and salt crystallisation can take place at or near the stone surface. Flaking is driven by a dynamic moisture profile and ambient temperature cycles; salt crystallisation takes place beneath the stone surface. Identifying these controls with appropriate, low-impact methodologies is crucial to developing preventive conservation strategies.

Keywords:
historic masonry, non-destructive techniques, environmental monitoring, salt contamination, decay patterns, preventive conservation

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Figure 1: Bell Tower from south-east.

1. INTRODUCTION

Historic masonry is often at risk from severe deterioration. Centuries of weathering, pollution and inappropriate repair can result in lasting salt contamination and advanced stages of decay (Siegesmund and Snethlage 2011). Finely carved stone, usually in softer lithotypes, is both particularly vulnerable and culturally valuable. Reigate Stone was a principal freestone in medieval London (Tatton-Brown 2001). It is highly porous, weakly cemented and prone to rapid decay (Sanderson and Garner 2001). The precise mechanics of decay remain poorly understood. Different patterns and rates are evident in similar environments. Historic treatments and historic pollutants complicate matters further. Understanding the relative importance of material, environmental and historical factors in ongoing decay will be vital to improving the resilience of Reigate Stone masonry in the face of changing climate. The Bell Tower (Figure 1), one of the oldest parts of the Tower of London, dates to the 12th century and still contains a large amount of primary masonry, including Reigate Stone exposed to a range of environments and treatments and displaying distinctive decay patterns. As such it can be a useful bellwether and case study for understanding the decay of vulnerable historic masonry.

This paper presents results from an eighteen-month monitoring programme and a non-destructive testing (NDT) protocol designed to characterise decay and investigate internal environmental conditions at different locations within the Bell Tower. The objective is to associate specific mechanisms with observable patterns of decay. Flaking and powdering have been identified as two common Reigate Stone decay patterns (Sanderson and Garner 2001). While there have been suggestions that these correspond to sheltered and exposed locations respectively, many cases do not obviously fit this trend. There has been no investigation into the mechanisms which drive the emergence and propagation of these distinct patterns; however, salts have been identified as a major cause of Reigate Stone decay in several studies at the Tower of London. Severe degradation in the Salt Tower is attributed to historical storage of saltpetre (KNO_3). The masonry was treated with a poultice in the 1970s (Bowley 1975). Decay is ongoing. Parts of the Wakefield Tower were found to be heavily salt-contaminated in a study which proposed relative humidity (RH) regimes as a preventive conservation strategy (Price 1993). In a later study based on thermodynamic modelling, Price (2007) found that the proposed regimes would have been potentially damaging and suggested alternative regimes. This highlights the challenges of conserving salt-contaminated masonry, demonstrating that even preventive strategies could prove detrimental if it has not been possible to model all potential decay mechanisms and their dynamic interactions; when salts are involved, this can be practically impossible (Menendez and Petranova 2016). An increased understanding of the mechanisms driving decay at the microclimatic scale could be a first step towards developing more effective preventive conservation strategies.

2. METHODOLOGY

Repeat surveys were made of different locations within the Bell Tower in order to assess active decay. Flaking and powdering were assigned to individual stones and areas and recorded with photographs and micrographs (ICOMOS 2008). Dust trays were placed at the base of selected masonry to provide a measure for ongoing decay rates. A T660 capacitance moisture meter and a T610 microwave moisture meter (Trotec) were used to perform a rapid assessment of relative moisture content (MC), with multiple point readings ($n \approx 20$) taken across different locations. The T660 measures to a depth of approximately 2–4cm, whilst the T610 measures to approximately 20–30cm (Trotec 2019). Water uptake tests were performed on a representative example of each decay pattern using Karsten tubes sealed against the stone surface with putty and filled with distilled water. The NDT was designed to provide a rapid assessment of material qualities associated with observable decay patterns, in order to inform a more in-depth characterisation in ongoing studies.

A network of sensors was installed in the Bell Tower to record a range of environmental parameters over an eighteen-month period. Hygrochrons (iButton) were used to record localised internal temperature and RH variations. Surface-wetness (Campbell Scientific) and surface-temperature (Gemini) sensors were attached to selected Reigate masonry, so that the sensor was pressed and sealed against the stone surface. Surface sensors were used in areas proximate to the monitored micro-environments and connected to dataloggers (Gemini). A weather station (Vaisala) placed on the roof of the Bell Tower recorded temperature, RH, precipitation, solar radiation and wind speed and direction. Recording intervals were set to between 10 and 180 minutes, depending on sensor location and expected rates of change determined in trials. Sensors were calibrated at the start of the monitoring period and on several further occasions as and when they were repositioned.

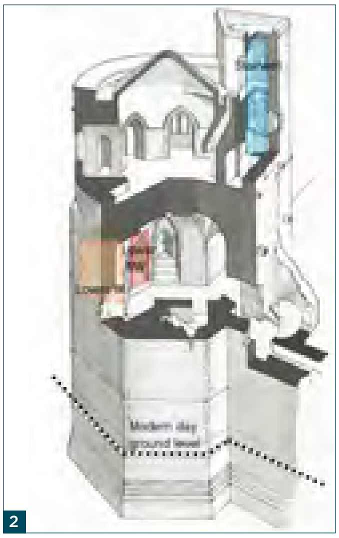

Figure 2:
Axonometric of Bell Tower from south, showing locations in this study (modified from a drawing by Terry Bell).

Figure 3:
Reigate masonry in lower chamber.
Top left: NW alcove;
Top right: W alcove;
Bottom left: typical powdering decay;
Bottom right: severe efflorescence.

3. RESULTS AND DISCUSSION

3.1 Decay patterns

Decay patterns on internal masonry can be grouped in to categories distinguished by location (Figure 2):

- Powdering dominates the lower chamber, ranging from gentle to severe. Differential erosion is noticeable in the west alcove. Decay is particularly severe in the north-west alcove. Some stones display efflorescence (Figure 3).

- Flaking dominates the spiral stairwell leading to the Bell Tower roof. Severely flaking stones are concentrated in but not limited to the upper west flank, particularly near the treads. Many stones on the east flank are in a sound condition (Figure 4).

  Micrographs of detached material found in the stairwell show a laminar propagation of flaking decay occurring irrespective of faintly visible bedding planes, with parallel fissures visible in the exposed sub-surface (Figure 5). Salt crystals can be seen embedded in the stone, including some which lie directly along the grain of a fissure. Micrographs of powdering stones show signs of efflorescence and a grainy, unconsolidated surface. Visual observations strongly suggest that salt contamination is driving the decay of Reigate masonry.

Figure 4:
Reigate masonry in stairwell.
Top left: flaking decay on west flank (Jan. 2018);
Top right: west flank following detachment episode (Aug. 2018);
Bottom left: east flank;
Bottom right: typical detached material and fresh subsurface.

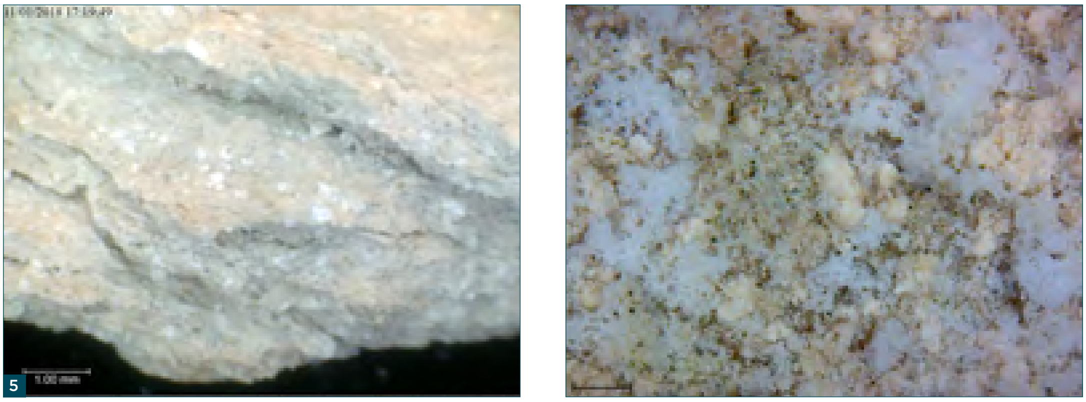

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Figure 5: Micrographs of detached flake (left) and powdering surface (right) showing salt contamination (scale bars 1mm).

Dust trays placed in the lower chamber recorded gradual granular disintegration of the surface across the entire monitoring period (Figure 6). Whilst there was very little material loss in some areas, parts of the west and north-west alcoves were decaying rapidly. In areas of rapid decay, there were noticeable increases in the rate of material detachment in spring and summer months, and slight decreases in the rate of detachment in winter months. Detached material was very fine and damp. There was some evidence of gradual granular disintegration on the flaking stones of the stairwell, but their decay was dominated by the episodic disaggregation of large amounts of surface material. This occurred as a series of laminar flakes became unstable and collapsed, rather than the detachment of single flakes. Newly exposed surfaces show signs of powdering. Stairwell dust trays were removed in June 2018. Further evidence of flaking was found throughout the year (e.g. Figure 4).

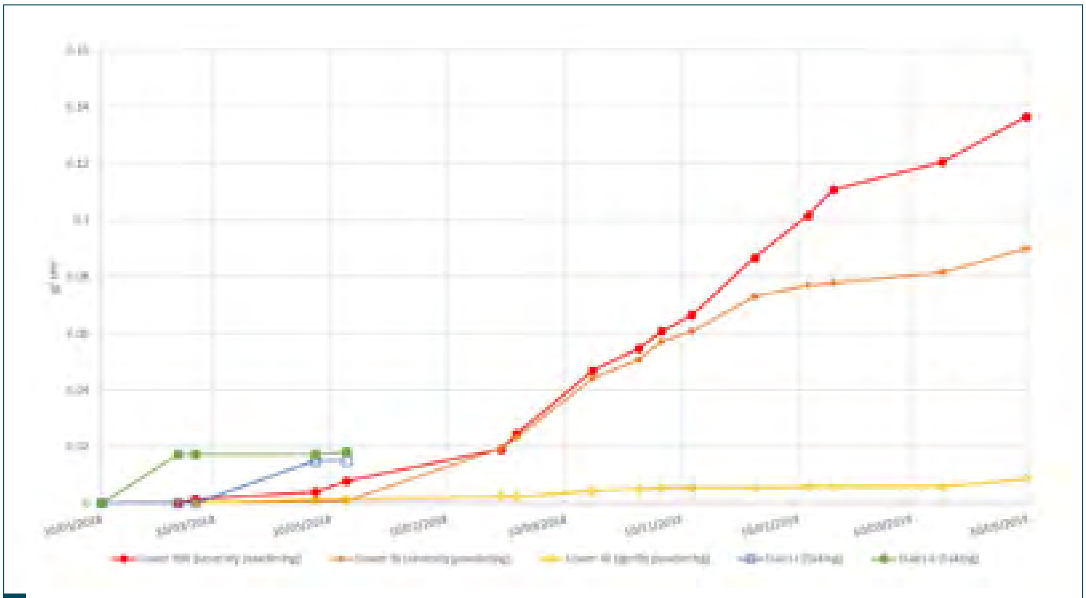

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Figure 6: Cumulative mass of material collected in trays at base of decaying masonry.

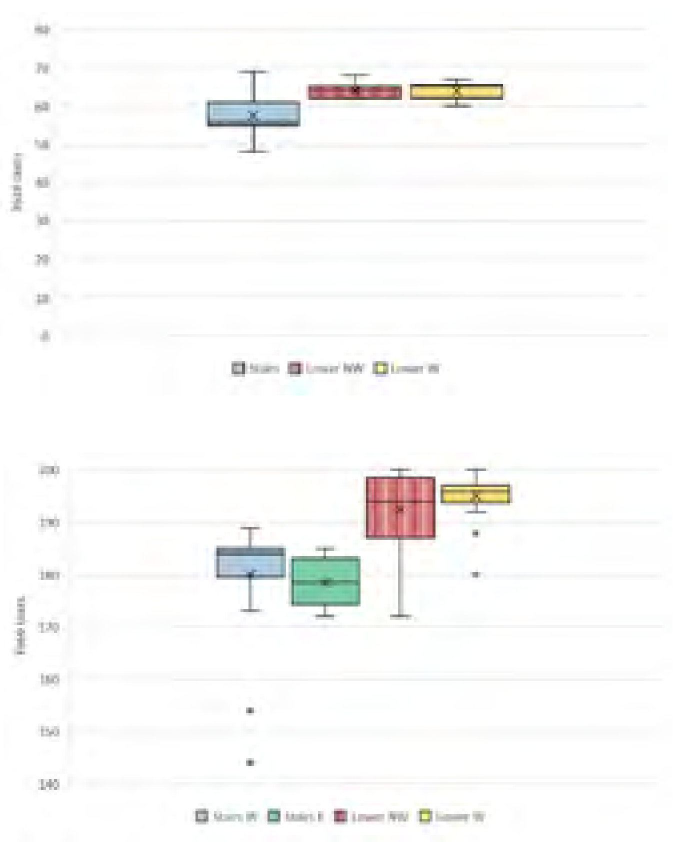

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Figure 7:
Boxplots of readings taken with moisture meters, showing mean (x), median (middle line), interquartile range (box), range (whiskers) and outliers (i.e. datapoints over 1.5 times above or below IQR). Results for T660 near surface readings above, results for T610 sub-surface readings below.

Figure 8:
Karsten tubes attached to flaking surface in stairwell (top) and powdering surface in lower chamber (bottom) with water level after 3.5 minutes marked by dashed line.

MC as measured with both moisture meters was higher in the lower chamber than in the stairwell (Figure 7). There was no significant difference between the average MC of different areas within the two locations. MC at depth was more variable in the stairwell. Visually apparent state of decay on individual stones was not necessarily reflected in higher MC, particularly on flaking stones. It is possible that cavities within flaking stones interfere with the readings. It may also reflect that near-surface moisture fluctuation, not moisture content itself, is driving decay. The powdering stone absorbed significantly less water during the water uptake test than the flaking stone (Figure 8). When the tests were ended after 3.5 minutes, moisture could be seen seeping from the surface of the flaking stone. This could indicate the powdering stone is close to saturation. It could also indicate a more fractured and open near-surface pore network on the flaking stone. Considered alongside the visual survey, the general indication is that differing proximity of an internal moisture profile to the stone surface may be resulting in salts crystallising at depth to drive flaking, and near the surface to drive powdering.

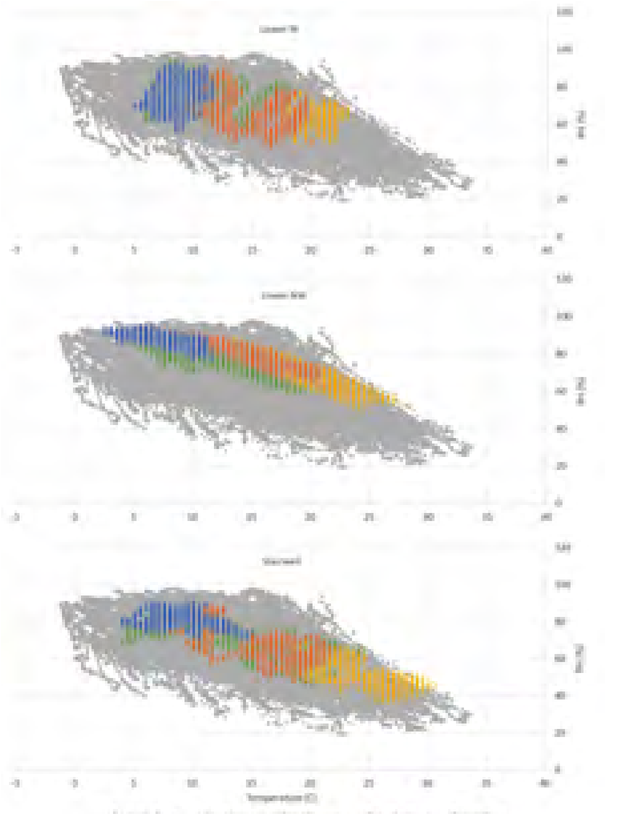

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Figure 9:
Scatterplots showing seasonal distribution of temperature and RH at surveyed locations (March 2018 – February 2019).

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Figure 10:
Four-week period in winter 2018/19 showing microclimatic temperature (dashed) and RH (solid) variations in lower chamber.

3.2 Microenvironments

3.2.1 Lower chamber

Noticeably different micro-environmental conditions were recorded within the lower chamber (Figure 9). RH is more consistently high in the north-west alcove. This can be explained by the open arrow-loop in the west alcove; conditions are affected by constant air exchange with the outside. The arrow loop of the north-west alcove is by contrast sealed. Sensors for monitoring the alcoves were placed within the recess of each arrow loop. This resulted in high daily temperature cycles

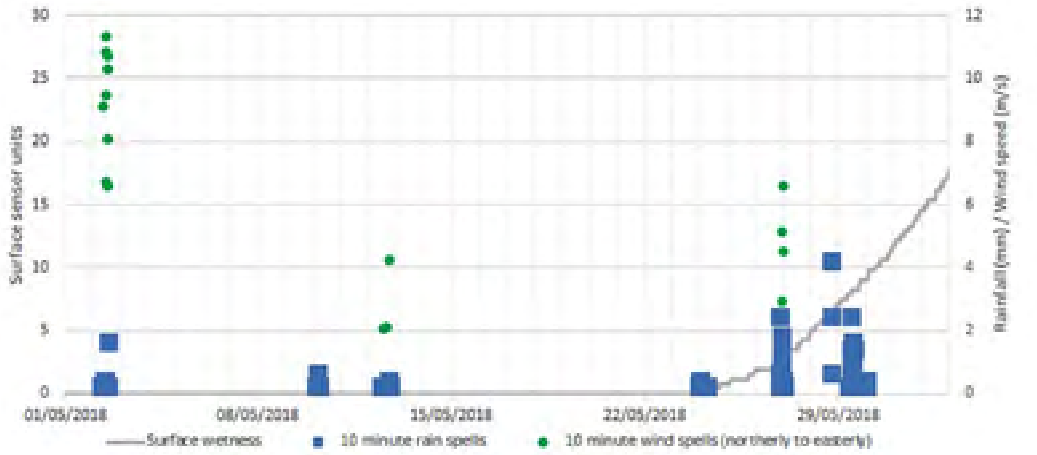

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Figure 11: Five-week period showing correlation between surface-wetness sensor sealed against Reigate Stone in north-west alcove and wind-driven rainfall.

in the north-west alcove during summer, as direct sunlight from the setting sun hit the external north-west elevation. During winter, decreases in temperature around the dew point correspond with decreasing RH in the west alcove and increasing RH in the north-west alcove, suggesting condensation is forming on masonry in the north-west alcove (Figure 10). As condensation does not generally form on Reigate Stone due to its high sorptivity, this could be a further indication that the masonry in the north-west alcove is saturated. A surface-wetness sensor attached to Reigate masonry in the north-west alcove responded to a period of heavy rainfall in May 2018 with a sharp increase in activity (Figure 11). These findings suggest moisture infiltration in response to a deep wetting of the masonry. The correlation between increased activity on the surface-wetness sensor and increased detaching material captured in the proximate dust tray in late spring 2018 is notable. The indication is that increased wetting from external sources combines with increased drying at the internal stone surface to accelerate decay.

3.2.2 Stairwell

Conditions at the top of the stairwell display a broader temperature and RH range and more distinct seasonal shifts than the lower chamber (Figure 9). Winters in which RH rarely drops below 75% and hot, dry summers are interspersed with highly changeable conditions in spring and autumn. Key to these differences is the exposed location of the upper stairwell at the roof of the Bell Tower. Diurnal and prolonged solar radiation correspond to incremental changes in internal surface temperature and ambient RH; prolonged or heavy rainfall corresponds with increases in RH (Figure 12). In this environment the masonry is likely to be in dynamic equilibrium with atmospheric humidity (Franzen and Mirwald 2004). Extended periods of high humidity will result in moisture adsorption, capillary condensation and deliquescence of salts. Interruptions will form an unevenly distributed solution. Intense dry spells will drive rapid evaporation and salt crystallisation within the porous network. During re-wetting the moisture front will retreat from fissures formed in the previous evaporation zone and the sequence repeats. Whilst the growth of flakes is likely to be controlled by environmental factors, a major cause of collapse during the monitoring period appeared to be abrasion caused by passing people. The area of advanced decay near the treads suggests vibrations may be an additional factor.

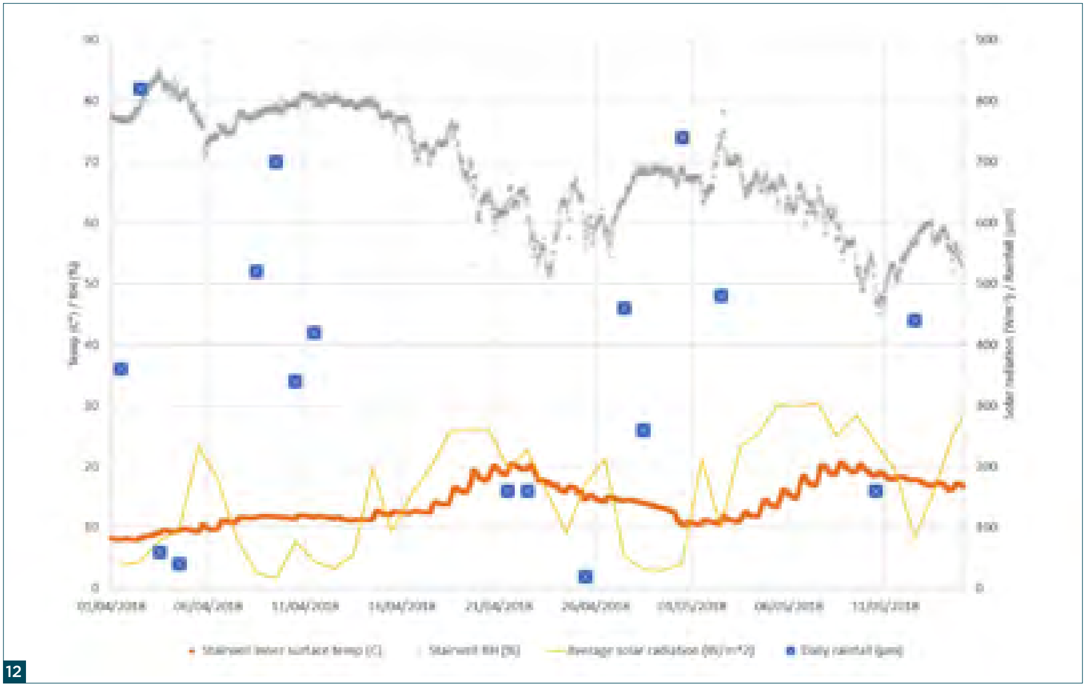

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Figure 12: Six-week period in spring 2018, showing correlation of solar radiation and rainfall with RH and Reigate surface temperature in stairwell.

3.2 Outlook

Linking measurable environmental conditions to observable patterns of decay is a first step to developing preventive conservation strategies (Michette et al. 2018). These can be designed to control specific mechanisms in order to mitigate ongoing decay. The mechanisms identified here will be further modelled and investigated in order to determine realistic strategies of control.

Besides the variations in active environmental mechanisms identified here, the nature of any salt contamination is certain to play an important part in Reigate Stone decay. Significant differences in the type and concentration of salts have been recorded in masonry within the same building elsewhere at the Tower of London (Price 1993). Sampling masonry in the surveyed areas of the Bell Tower will be vital to building accurate models of the overall processes of decay. Reigate Stone was sourced from numerous quarries along a varied band of rock (Sowan 1975). Different colourations of Reigate Stone were observed in the stairwell, indicative of several mineralogical variations used in construction. These inherent variations are also likely to play a part in the emergence of decay patterns. Ongoing work will consider the composition of native Reigate Stone in physio-chemical interaction with contaminates as part of a larger project in order to develop appropriate conservation strategies.

Photos of the lower chamber taken in 1945 and 1958 highlight the significance of contingency when considering the emergence of decay patterns (Figure 13). Rubble can be seen blocking the western alcove, the line of which closely matches the differential erosion visible today. The photos also show changes to the dressed masonry; what appears to be a thick limewash or plaster coat applied to

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Figure 13:
Lower chamber in 1945 (top) and 1958 (bottom). North-west alcove on far right of image; west alcove immediately to left.

the main arch and the emergence of the present-day discolouration in the north-west alcove, thought to be the result of a fire. Exceptional or episodic interruptions, such as fire or building works, introduce systemic shock which can outweigh or abruptly alter stable long-term processes. Whilst constructing an accurate timeline for historic buildings often proves impossible, ongoing work will integrate documentary analysis.

4. CONCLUSION

The objective of this research was to investigate patterns and controls of internal Reigate Stone decay. The results of NDT in combination with a high-resolution environmental monitoring program are compatible with the hypothesis that specific environmental mechanisms are responsible for driving observable patterns of salt-driven decay. These can be associated with distinct microclimates found in the Bell Tower, Tower of London. Gradual granular disintegration was observed in the lower chamber. This powdering phenomenon can be associated with highly saturated stones and a relatively steady ambient climate. Whilst temperature changes affect drying and subsequent decay rates, deep wetting and consistently high ambient RH maintain a fixed zone of evaporation. Salt crystallisation takes place at or near the stone surface. Episodic collapse of larger amounts of material was observed in the stairwell leading to the roof. This flaking phenomenon can be associated with a fluctuating ambient climate and dynamic moisture distribution within the stone. Extended periods of high RH followed by dry, hot spells result in a cyclic redistribution of solution and a shifting zone of evaporation. Salt crystallisation progressively results in the formation of sub-surface fissures. Once the build-up of fissures has reached a critical point, further disturbance results in the detachment of loosened material. Whilst the multiple analytical techniques presented here provide initial evidence that these factors are key controls in the ongoing development of distinct decay patterns, the nature of salt contamination, inherent stone properties and historic contingency must be considered in their emergence. Identifying these controlling mechanisms can inform preventive conservation strategies of vulnerable historic masonry.

ACKNOWLEDGEMENTS

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3D DOCUMENTATION OF MURAL PAINTINGS AND 3D MAPPING

Dipl.-Ing. Gunnar Siedler, Dipl.-Inf. (FH) Sebastian Vetter

fokus GmbH Leipzig, Lauchstädter Str. 20, 04229 Leipzig, Germany.
home@fokus-gmbh-leipzig.de

ABSTRACT

The authors' experience in the fields of heritage conservation documentation and software development has led them to acquire the background knowledge necessary to develop methods for image processing and digital mapping. fokus GmbH Leipzig was involved in several projects for documentation and investigation of medieval mural paintings, especially in Germany, Sweden and Switzerland.

3D laser scanning or digital photogrammetry (Structure from Motion – SfM) is used to record curved surfaces (vaults, apses) and structured or deformed surfaces (walls, ceilings, floors). The resultant photogrammetric surface model (SfM) is automatically textured with the images used.

Photographic documentation is simultaneously created with a digital medium-format camera, to ensure sufficient image resolution. Frequently, UV fluorescence images are also taken.

With the help of a surface model and the orientated images, unwrapped textures and ortho projections of vaults, cross vaults or walls can be calculated. 2D multi-layered TIFF files can then be merged into a single image. Additional historic images or UV fluorescence images can be processed in the same way (using the same coordinate system), to produce congruent image plans (Siedler and Vetter 2013). Depending on the image size and the required image resolution, 2D image files of several hundreds of MB are created. These can only be evaluated efficiently in 2D at present.

The PROQUATO R&D project (2016–18) was initiated by the Institute for Photogrammetry and Remote Sensing of TU Dresden and Scan 3D GmbH, Berlin to counteract current problems in processing 3D documentation. The main project aim was the display of different image contents on one multi-textured surface model and the development of tools for efficient 3D mapping in close cooperation with conservators.

Keywords:
3D object documentation, textured surface model, ortho projections, 3D mapping

Figure 1:
Detail resolution depending on image scale 1:20, 1:50, 1:100 for 400dpi image resolution.

1. DEFINITION OF QUALITY PARAMETERS

1.1 Image scale/image resolution

The required detail resolution (pixel size at the object) dependent on the image scale/resolution as well as the metric accuracy have to be specified depending on the task on the object. So the subsequent user (architect, planner conservator, executing company...) can process their own graphical/metrical evaluation and content interpretion in CAD or mapping software.

The required detail resolution is traditionally defined by image scale and resolution. For an image resolution of 400dpi (400 points per inch = 25.4mm) the point size is 0.06mm. Multiplying the point size by the image scale provides the metric size of the pixel at the object, which means 0.06mm for scale 1:1, 1.3mm for scale 1:20, and 3.2mm for scale 1:50 (Figure 1).

The following table (Figure 2) displays evaluation scales, two quality levels (200 and 400dpi) and the requirements for evaluation accuracy resulting from the image scale for different application examples. In general mural wall paintings are processed for a scale 1:10 and 400dpi (0.6mm point size). For objects with higher levels of detail a scale of 1:5 and 400dpi (0.3mm point size) is used.

Sector **Pixel size 400dpi** **Pixel size 200dpi** **Accuracy**	**1:1** **0.06mm** **0.12mm** **0.5mm**	**1:2** **0.13mm** **0.25mm** **1.0mm**	**1:5** **0.32mm** **0.64mm** **2.5mm**	**1:10** **0.64mm** **1.3mm** **5.0mm**	**1:20** **1.3mm** **2.6mm** **1.0mm**	**1:50** **3.2mm** **6.4mm** **2.5mm**	**1:100** **6.4mm** **12.7mm** **5.0mm**
Architects/ consultant				X	X	X	X
Building archaeology			detail	stone by stone detail	stone by stone	general overviews	
Field archaeology			graves, other details	sections, elevations, graves	plans		
Conservation	**1:1**	**1:2**	**1:5**	**1:10**	**1:20**	**1:50**	**1:100**
Stone				X	X	X	
Wall painting/ stucco			X	X	X		
Wood/objects archaeology		X	X	X			
Wall painting/ textile/paper	X	X	X	X			

Figure 2: Overview for required detail resolution depending on application examples; Detail resolution (pixel size at the object) for 400dpi and 200dpi; Evaluation accuracy depending on image scale (0.5mm x image scale); mural painting highlighted in red boxes (Siedler and Vetter 2018).

1.2 Camera sensor

A DSLR camera with full frame sensor (24 x 36mm) is a minimum requirement.

The use of high-resolution sensors only leads to the desired results if new calculated lenses with appropriate optical resolution capacity are used. In addition to this, object lighting is required to allow image recording with low ISO sensitivity.

For documentation of high-quality objects in the field of historic interiors/mural painting, a camera with medium-frame sensor is more useful. Currently we use medium-frame camera PhaseOne 645D-P65 with 65 megapixel and PhaseOneXF IQ4 with 150 megapixel for our projects.

These camera systems are advantageous for interior conditions due to the high dynamic range of the medium-frame sensor and the lower noise of on-site contrasts. One image by medium-frame camera with 150 megapixel replaces four to six images by a DSLR camera. The resulting lower number of images reduces the amount of work and the risk of errors during colour adaptation of images.

2. EVALUATION METHODS

Not every evaluation method is suitable for every project. Depending on the object surface (flat walls, vaults, stucco ornaments), the appropriate method must be chosen (Luhmann 1978; Pietschner et al. 2003).

2D image rectification allows mathematical transformation of 2D plane within the bundle of rays of one camera (central projection). The result is a true-to-scale image plan that allows measuring on one object plane.

The 3D orthogonal projection always assumes the 3D recording of the object surface. The 3D data (point-cloud, textured surface model) are projected orthogonally onto a reference geometry (plane, cylinder, cone) (Vetter and Siedler 2011). The creation of 3D data can be done by digital photogrammetry (SfM) or terrestrial laser scanning (TLS). The result is a true-to-scale image plan (orthophoto), which allows measuring on all planes that are PARALLEL regarding the reference geometry (Brumana and Galeazzo 1992; Stephani 1992).

3D object documentation is based on 3D recording of the object surface by point-cloud using TLS or SfM. In a second step, the points are connected by triangulation to create a digital surface model (DSM). If necessary, the DSM is textured using orientated images. The result is a true-to-scale textured DSM that allows three-dimensional measurements, creation of section and deformation analyses as well as creation of orthogonal projection onto several geometries.

For all these methods the following applies: without good photographic images, a good result cannot be created. In the opinion of the service company the 2D-rectification is the cheapest method, which also provides the highest image quality. 3D orthogonal projection is the most time-consuming method, because images need to be orientated photogrammetrically and DSM need to be scanned or created by matching (SfM).

2.1 3D-object documentation as textured surface model

An advantage of SfM is the creation of a textured surface model in addition to the point cloud.

This process is automated, though the user can control texture resolution, image selection and the regions of an image to be textured. However, the colour adaptation of the images and the assignment of the texture to selected regions of the surface model are all automated processes (Figure 3).

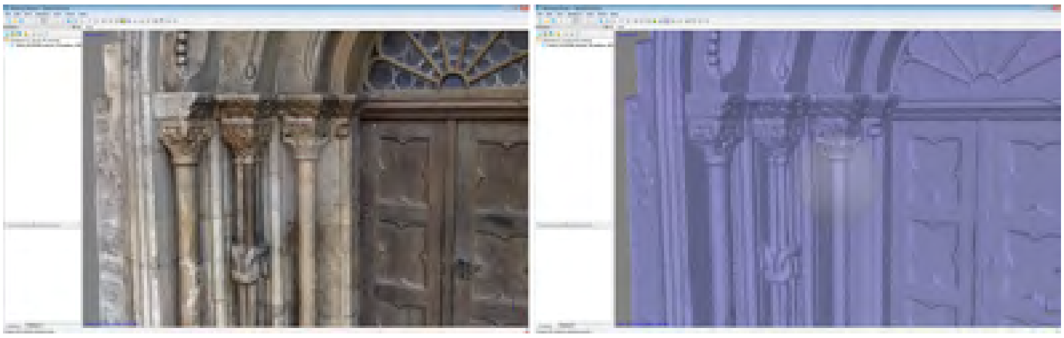

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Figure 3:
Left: textured surface model (SfM) – point distance 2–3mm, texture resolution for scale 1:20; Right: surface model without image texture (SfM).

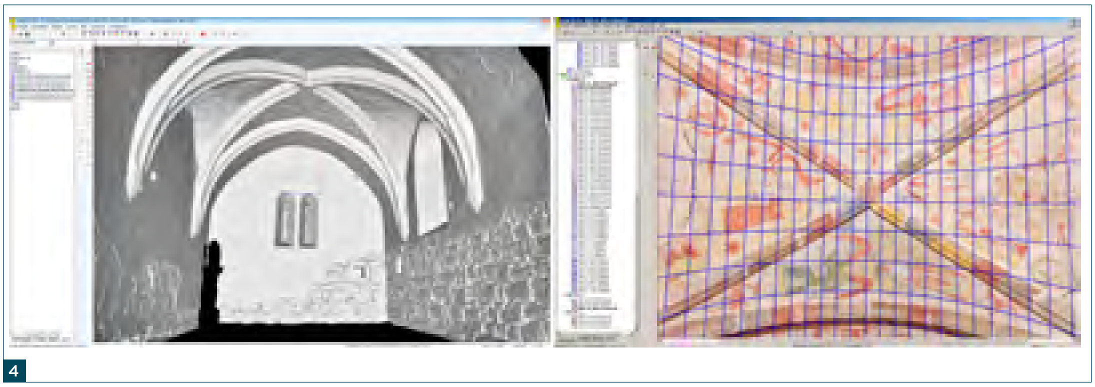
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Figure 4: Left: surface model (TLS), Right: projection of unwrapping geometry within the orientated image.

2.2 3D ortho projection of additional orientated images

In this method, photogrammetrically orientated images with resolution of 0.3–0.6mm are projected orthogonally onto an object plane or cylinder as 2D image plan by using a DSM (2–3mm point distance). This procedure is generally used in the recording of mural wall paintings. Currently, the amount of image data cannot be displayed sufficiently on a surface model because of required detail resolution of 1:5/1:10.

Additionally, professional single images with appropriate lighting cannot be replaced by a large number of small images that can be used for SfM. The automated colour adaptation and texturing during SfM is inaccurate, so the colour adaptation and image montage in Adobe Photoshop are hard to replace.

3. PROJECT EXAMPLE FOR HIGH-RESOLUTION TRUE-TO-SCALE DOCUMENTATION

3.1 Church of St Christopherus in Haufeld

Inside the Church of St Christopherus in Haufeld (Thüringen), the photogrammetrical documentation of mural painting (14th century) was processed in 2014 by unwrapping with orthogonal projection in the scale 1:5 for resolution of 300dpi.

On site, nearly 200 reference coordinates were measured by tacheometer and thirty-nine images of the current condition were taken by a PhaseOne 645D-P65.

In addition to this the room was recorded by a terrestrial laser scanner as a point cloud within the same coordinate system. This was the basis for the creation of a digital surface model (Figure 4, left).

With the help of the reference coordinates the images were photogrammetrically orientated and orthogonally projected onto a cylinder (unwrapping geometry) using the surface model.

Twenty-four historical colour slides from 1944 at the Zentralinstitut für Kunstgeschichte (ZIKG) in Munich were scanned with 4000dpi (5500 x 3700) and 16-bit colour depth (Siedler and Sacher 2006). These images were photogrammetrically orientated and orthogonally projected using the same unwrapping geometry. This allowed congruent image plans of both different conditions (1944 and 2014) of the vault (Figure 5).

3.2 Isny Chapel St Joseph

The Gottesackerkapelle St Josef is a rotunda from the 18th century that contains a vault with illusionistic painting on an area of c. 13 x 18m^2 and has required an evaluation scale 1:5 for 300dpi.

Automated recording of the geometry by SfM and simultaneous automated high-quality texturing was undertaken. A total of 150 images were taken by digital medium-format camera (PhaseOne 645D-P65) with sufficient overlap of 60% to 80% for recording of the geometry. An additional sixty images were taken using the same camera in a higher image scale with the help of a flash system including 4 x 600-watt reflectors for recording the texture (Figure 6).

Due to the higher effort required for lighting and camera placement, these additional images were made with only 20% overlap. All images were developed and colour adapted with Capture One (of company Phase One).

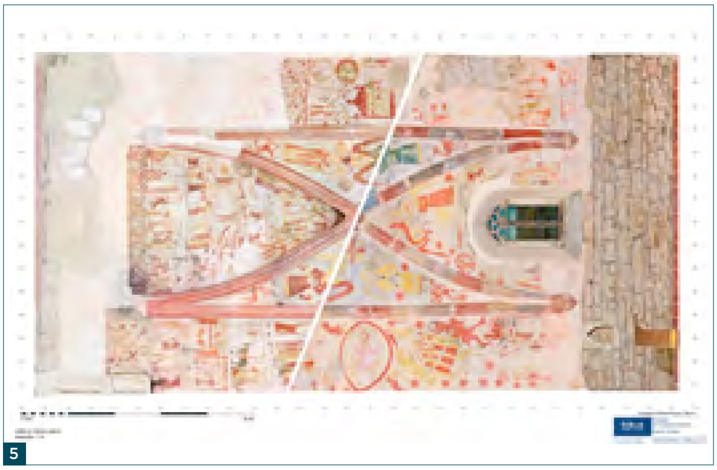

Figure 5:
Haufeld, Church of St Christopherus, digital unwrapping with ortho projection in scale 1:10; Left: historical colour slide of ZIKG, Right: documentation (2014).

Figure 6:
Image from PhaseOne 645D-P65 for surface model creation by SfM (left) and texturing (right, higher resolution).

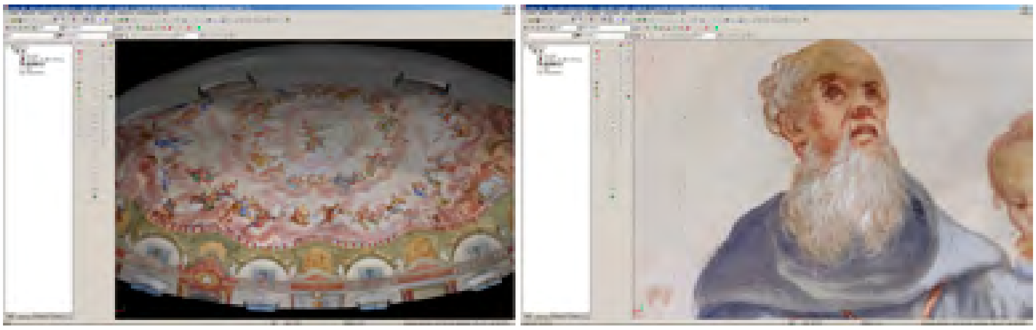

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Figure 7:
Display of textured surface model within metigo® 3D;
Left: total view;
Right: detail showing the texture quality.

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Figure 8:
True-to-scale image plans original processed in the scale 1:5 for 300dpi;
Left: orthogonal projection of the ceiling,
Right: unwrapping combined with orthogonal projection.

Thirty control points were measured by tacheometer for using as reference for photogrammetric image orientation. Both image groups were processed in AgiSoft Photoscan for the simultaneous calculation of image orientation and the creation of a dense point-cloud (Figure 7).

The surface model (triangulation) was calculated with 5.2 million points (point distance ca. 4–5mm). For the export of the textured surface model, the texture was created for the scale of 1:5 and 300dpi.

The export of true-to-scale vertical ortho projection (Figure 8, TIFF) and the unwrapping with orthogonal projection for eight sections through the vault are calculated to enable documentation work by conservators (mapping of condition, planning and documentation of conservation work).

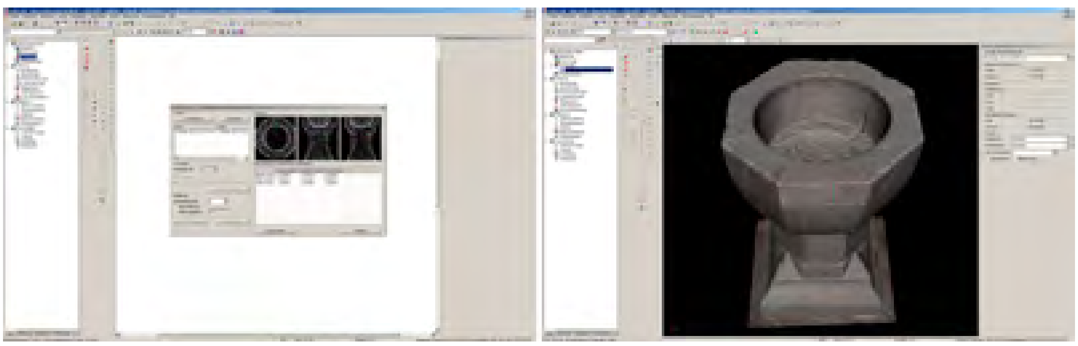

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Figure 9:
Left: Import window for surface model in STL-, VRML- and OBJ-files with insertion of scaling factor and unit; Right: 3D display of textured surface model.

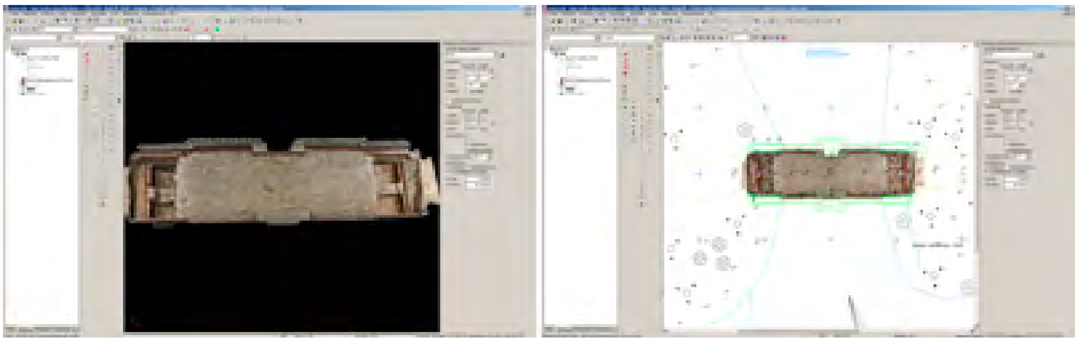

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Figure 10:
Left: 3D display of textured surface model of an exposed bridge construction; Right: combination of CAD-drawing with othogonal projection.

4. CURRENT RESULTS FROM THE R&D PROJECT PROQUATO

The mapping software metigo® MAP has been developed since the year 2000 to create digital, vector-based mappings including mass calculation. The software is used in various fields of conservation. Small projects can be processed as a single mapping project, while complex projects such as a cathedral can be organised as a hierarchical project, with several mapping projects for each wall.

In the field of the R & D project PROQUATO = process optimisation, quality enlargement and evaluation tools for multi-textured surface models (2016–2018) requirements for 3D mapping were analysed and developed in close cooperation with the clients.

4.1 Data import

Metigo® MAP allows the import of textured surface models in VRML- and OBJ-format or without texture (STL). For mapping modes a mesh made of triangles is always required.

The import window (Figure 9, left) allows the insertion of a scaling factor for true-to-scale import of surface models. Scaling inside the mapping project is not possible later on.

Free navigation is possible within the 3D display. Within 2D display of model views (orthogonal projections) the image data is reduced to the set project scale and resolution.

If the textured surface model was created within a defined coordinate system, the congruent combination of orthogonal projection with existing CAD plans is possible (Figure 10).

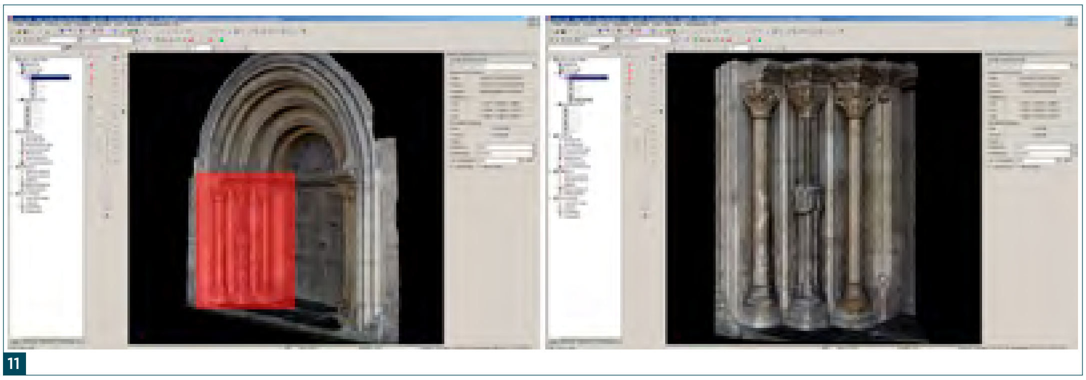

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Figure 11:
Left: 3D display with selection of a new segment;
Right: 3D display of the new segment.

4.2 Evaluation of complex surface models by model segmentation

In general, the 3D data is displayed through OpenGL via the graphics card. That means the performance of the 3D display predominantly relies on the characteristics of the graphics card.

If the surface model is too big for the hardware used, it is possible to do evaluation only on parts of the whole surface model. Segmentation allows partial loading of the surface model (Figure 11, Figure 12). At the beginning the user can load the surface model in reduced resolution as a whole point cloud to define segments, e.g. single parts of a façade. Later, only the wanted segments need to be loaded for mapping.

For complex objects such as figures it is useful to create individual segments (e.g. for arms, legs, hands), because it is easier for navigation and makes evaluating hidden places (e.g. inside of an arm) much easier.

4.3 Drawing modes for 3D mapping

Using the 3D polygon mode, 3D lines (cracks, gaps, etc.) can be mapped as well as 3D areas. Therefore the drawn polygon is intersected with the surface model and its result stored as individual 3D object (Figure 13).

Cutting tools for area mapping are available in the same way as in 2D mapping. They allow a later extension or reduction of mapped areas as well as the custom-fit cutting of adjoining areas. Additionally, vector symbols or text elements can be used.

The length and area of the 3D polygons are always calculated for quantity survey (Figure 14).

Border lines and transparent area filling can be shown in the 3D display. Hatching is only shown in 2D model views (Figure 15).

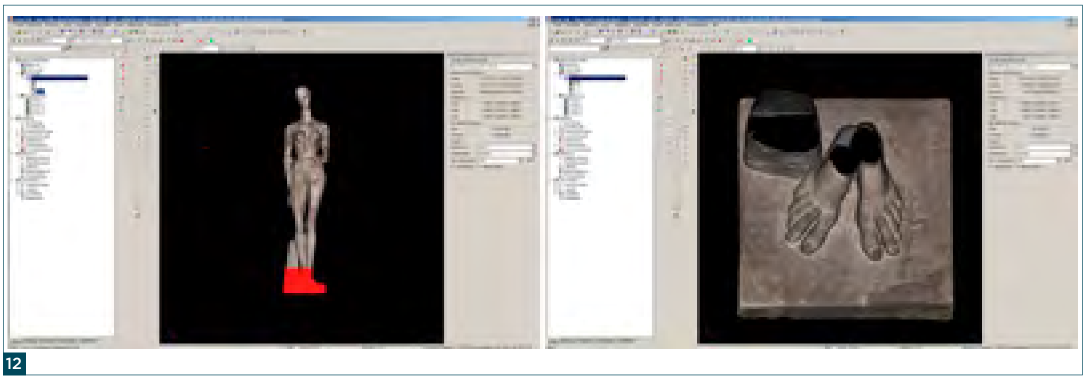

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Figure 12:
Left: 3D display with selection for a new segment;
Right: 3D display of the new segment.

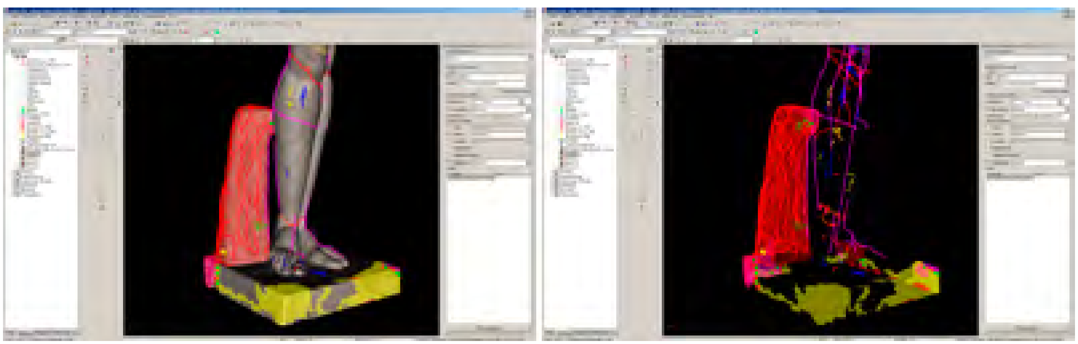

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Figure 13:
Left: 3D display with textured surface model and mapped elements;
Right: 3D display of 3D mapped elements without surface model.

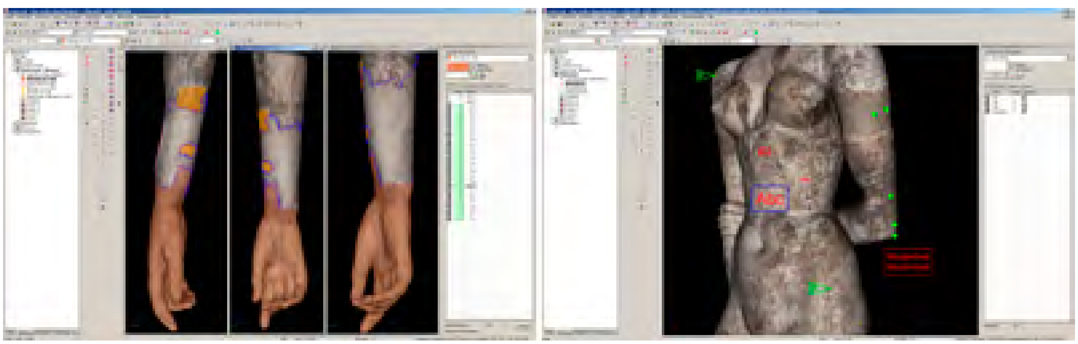

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Figure 14:
Left: 3D display shows custom-fit cutting of adjoining areas;
Right: 3D display shows vector symbols and texts for mapping.

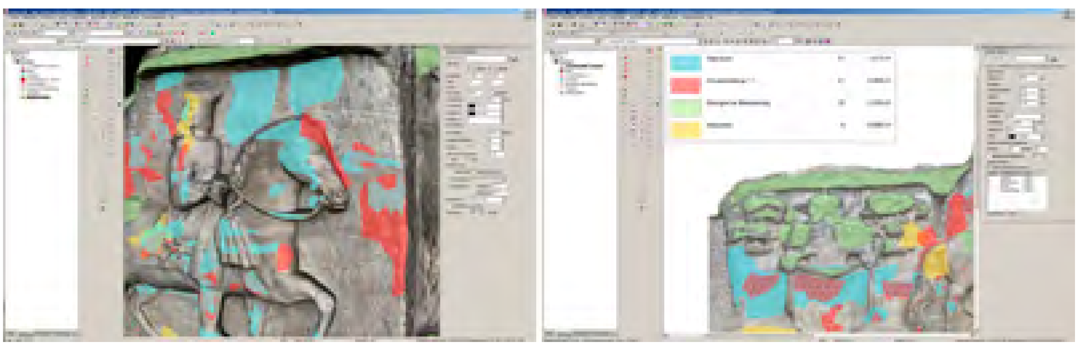

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Figure 15:
Left: 3D display of area mapping with transparent filling;
Right: hatching on 2D model view with orthogonal projection and legend.

4.4 Printing with the help of 2D model views

A true-to-scale 2D model view of the chosen 3D display can be created, to be used for 2D printing output (Figure 16). Display options like texture quality, shading, scale, position as well as projection mode (orthogonal/perspective) can be set up.

Automated creation of ‘model view unwrapping’ (inside/outside; 4/6 views) allows complete display of the object (Figure 16, Figure 17).

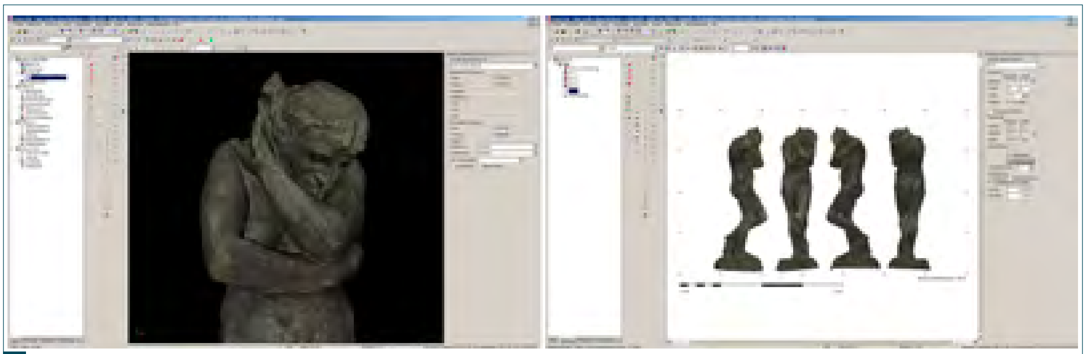

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Figure 16:
Left: 3D display of textured surface model; Right: true-to-scale outside unwrapping of 4 model views with orthogonal projection.

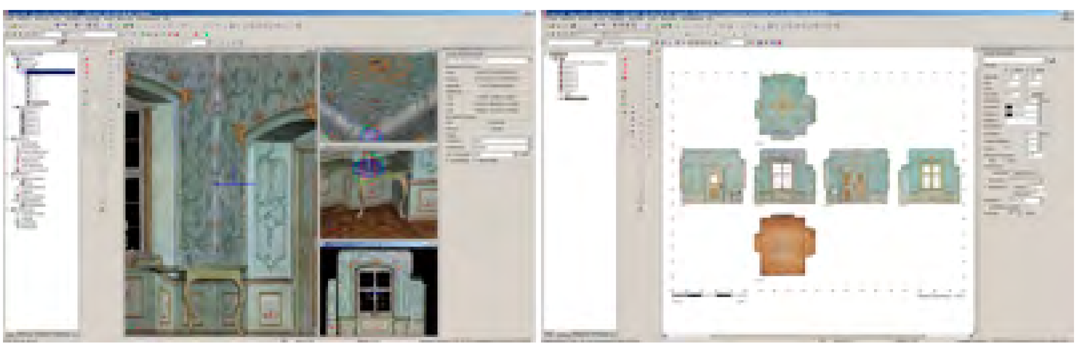

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Figure 17:
Left: 3D display of textured surface model of the room; Right: true-to-scale inside unwrapping of 6 model views with orthogonal projection.

The plan can be completed through the insertion of grid crosses, scale bar and title block.

The 3D display can be controlled like the 2D model views, using mapping groups and group legend (Figure 18).

The true-to-scale printing or image output is carried out in the same way as 2D mapping. Currently the 3D mapping can only be passed as complete mapping project with free viewer.

Quantity measurement is determined automatically on the basis of the true-to-scale surface model. So the amount, length and areas of mapped elements are calculated immediately and the sum can be shown within the legend for each class. If the total amount of the object is mapped, the mass fraction for each area mapping class can be shown within the legend too (Figure 19).

4.5 Current development tasks

While 2D plans can be combined congruently for simultaneous evaluation, suitable tools for this workflow on a 3D surface are presently missing. At the moment there are developments that allow new texturing of a surface model, as well as the management of several textures on one surface model. As a result the evaluation of a multi-textured surface model (Figure 20) should be possible.

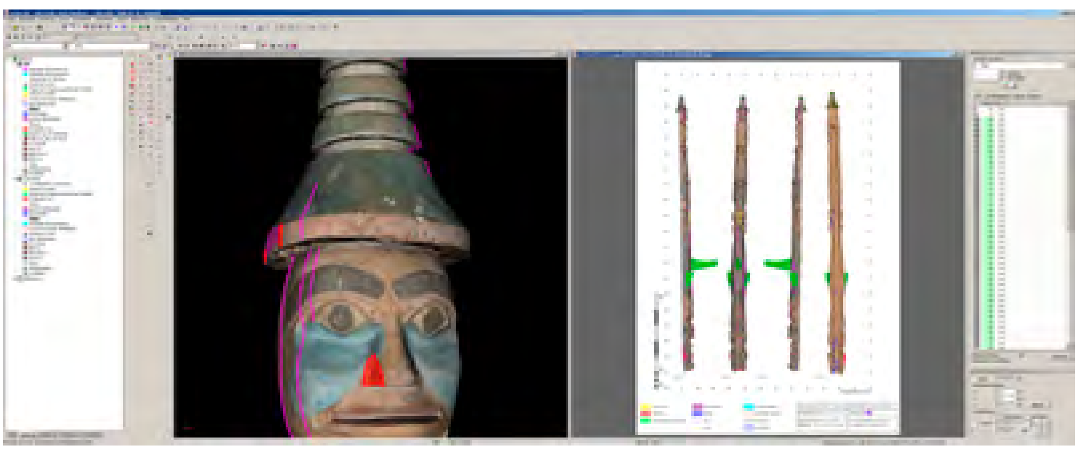

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Figure 18:
Left: 3D display of textured surface model of the totem pole with mapping; Right: true-to-scale outside unwrapping of 4 model views with orthogonal projection, mapping and group legend.

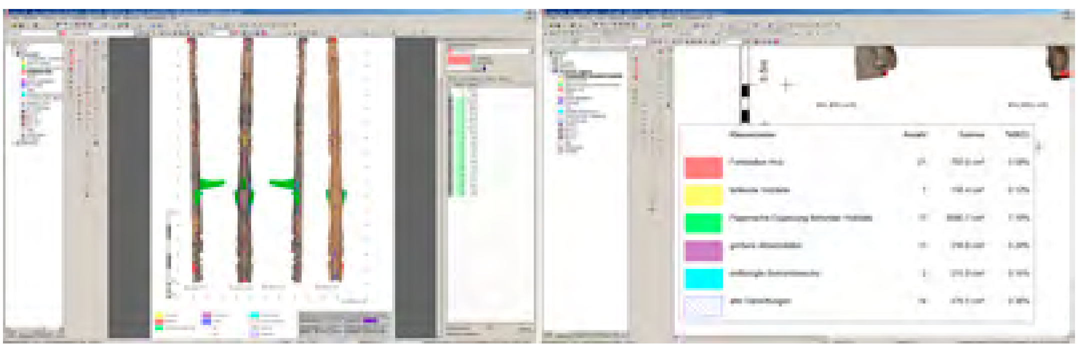

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Figure 19:
Left: 3D display of textured surface model of the totem pole with mapping; Right: legend of the mapping including the quantity survey.

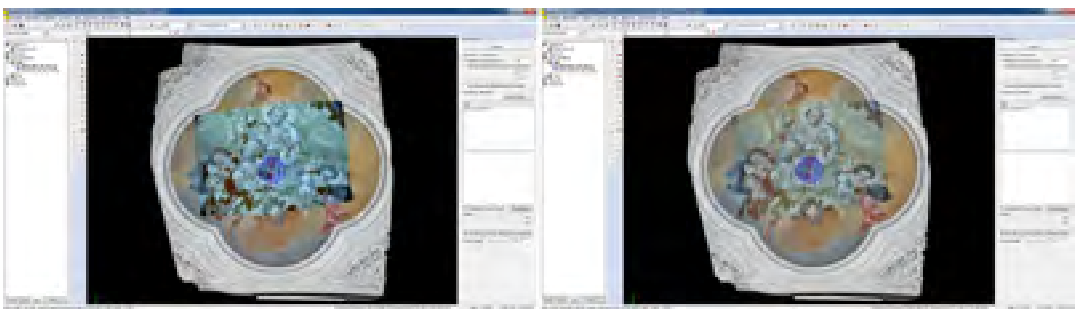

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Figure 20:
Multi-textured surface model with day light image and one UV-light image; Left: UV-light image with 100% opacity; Right: 3D UV-light image with 50%.

5. SUMMARY

The procedures described allow the true-to-scale documentation of objects in high textural quality. The aim is to meet the requirements of a restoration-based mapping basis, or photographic quality in the field of mural painting, even with a textured surface model.

The costs for the necessary hardware will be significantly reduced within the next few years. So the step from two-dimensional to three-dimensional evaluation is now possible, depending on the requirements of the project.

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LIFTING THE LID ON THE MONUMENT TO JOHN, DUKE OF MONTAGU BY LOUIS-FRANÇOIS ROUBILIAC

Paul Wooles, ACR

Paul Wooles ACR, Freelance Stone and Plaster
Conservator, East Midlands, England.
paulf.wooles01@hotmail.com

ABSTRACT

Investigation and consideration of the effects of moisture and current conservation practice in respect of the 18th century Roubiliac monument to John, Duke of Montagu (d. 1749). The marble monument is regarded as one of Roubiliac's finest works, and one of four internationally culturally significant monuments within the chancel of St Edmund's Church, Warkton, Northamptonshire. The monument had developed disturbing structural problems relating to corroding ferrous fixings, which had triggered stresses in both the structure's architecture and its two full life sculptures of Mary, 'Duchess', and 'Charity', both intrinsically and elegantly linked with the monument's architecture in a naturalistic illusion. Concerns were first voiced in 1978 by John Larson, followed by a string of conservation professionals and institutions in the ensuing thirty years, when conditions became critical. Indicative of that time, a well-intentioned proposal to install a membrane is puzzling, as the structure is isolated from traditional damp sources. Why was this monument alone suffering from corroding ironwork while the remaining three were not – even though, counterintuitively, they were exposed to traditional sources of liquid and ambient moisture? If anything, the opposite would normally be expected. The result of the investigation has led the author to question and rethink some of the current practices and procedures commonly undertaken by monument conservators.

Keywords:
Roubiliac, internationally culturally significant, corroding ironwork, stresses, marble sculpture, liquid moisture

Figure 1:
Image by kind permission of Buccleuch Living Heritage Trust: Photography by Tom Arber.

1. INTRODUCTION

The 18th century chancel at Warkton Church was specifically designed to house four monuments in individual niches; but this was not the original intention. Recent research by Professor Phillip Lindley tells us that the monuments by Roubiliac to Duke John and Duchess Mary were originally planned to stand in new recesses built into the church's earlier medieval chancel. However, during these alterations the chancel was deemed to be structurally unsafe and subsequently demolished (Lindley 2014).

Roubiliac himself appears to have been responsible for the design of the new chancel; initially with two niches, but later altered to four. It was also designed with a cupola to illuminate the monuments from above, although due to a breakdown in communication following the death of the principal overseer for the works during building, the cupola was excluded (Lindley 2014). To compensate for this oversight, the disproportionately large east window was built to maximise natural illumination (Lindley 2014) and has previously been held responsible by some for creating an imbalance within the internal environment that was detrimental to the monuments. The monument to Duchess Mary by Van Gelder (Figure 1) was identified as being at most risk (Larson 1980).

During the ensuing thirty years a string of conservators paid visits to the church as well as the Council for the Care of Churches, the British Museum and latterly English Heritage, who carried out a twelve-month monitoring programme. However, no report or recommendations were ever presented.

In 2008 Skillington Workshop was appointed to undertake an investigation of the monuments, commissioning environmental monitoring and pXRF analysis. Delving into the historical events of the church and its environment, the author made an important connection between the physical nature of the monument and past events, providing an altogether different hypothesis for the monuments' deterioration.

2. ST EDMUND'S CHURCH

2.1 Environment

High concentrations of sulphur were recorded with pXRF on sculpture surfaces within the church (Jefferson 2013). These may be attributed to the early forms of heating, which used fossil fuels.

The earliest record of coal being delivered to the church was in 1840; '2 cwts of coal' was recorded in the churchwarden's accounts of that year. However, coal was used domestically in Warkton from 1808. The church accounts of 1818 state: 'Paid Mr Illif for repairing stow [sic]' (Jones and Toseland 2006: 81) – making it apparent that fuel was being burnt at the church before 1840. Fossil fuels generated heat in both the vestry and the nave. It is not clear when heating was first installed, but given that there were repairs in 1818, it seems reasonable to conclude that it had been in place for some years.

The two stoves were of different sizes. One was placed in the north-east corner of the vestry and the other below the central aisle of the nave, with the flue routed towards the south respond of the chancel arch. Two rodding points, for the chimney and flue, are in the chancel arch area.

The church archives illustrate frequent repairs, including substantial repairs to stoves and flues from 1898 to 1904 (Bills, shoeing and jobbing smith). It is not possible to identify which stove(s) the accounts refer to, but some of the problems encountered are still in living memory. Local historian Alan Toseland recalls his father and grandfather bemoaning the problems with the nave stove, when backdraught from prevailing winds filled the church with smoke.

Evidentially the historical environment contrasts greatly with that of today. Not only were airborne internal furnace pollutants a problem, but there are indications that the church was damp. Accounts of October 1866 contain the statement: 'Repairing ceiling . . . 4/–' (Church Wardens Book 1818), and also around this time, a trench was dug around the church (Alan Toseland, pers. comm., June 2019).

The boilers were decommissioned in the 1950s and storage heaters were installed in the 1970s. Environmental monitoring concludes that the church is reasonably well thermally buffered from the external environment; however, buffering in the chancel is slightly lower than in the nave, especially near the east window, meaning humidity conditions here are less stable. From monitoring, we know that the 1970s heating system was by far the biggest destabiliser of the environment, causing condensation to form on monuments following cooling after heating events (Curteis 2013).

Figure 2:
Plan of church.

2.2 The monument to John, Duke of Montagu

Why this monument alone suffered from destructive iron corrosion is unclear. It should, if anything, have been the least likely of the four to suffer in this way, owing to its disconnection from traditional sources of liquid moisture (Figure 2).

Between 2008 and 2013, the author discovered a critical development in the deterioration of Duke John which required emergency measures. A clean vertical fracture had appeared in the angle of the moulding on the shelf directly under the figure of Charity, putting it under significant stress (Figure 3). The stress was magnified by opposing forces resulting from the resistance of a large iron fixing starting at a shoulder socket, and terminating in the core at the rear of the figure (Figure 4). The function of the fixing is to counteract the imbalance in the figure.

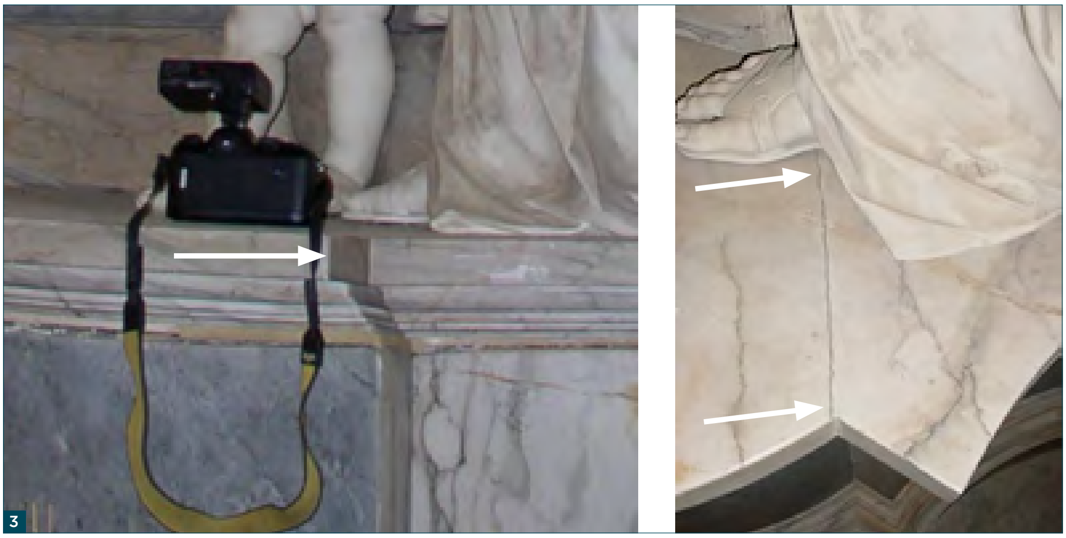

Figure 3:
Images from 2008 and 2013. The fracture in the shelf radiating from the angle of the moulding and terminating below Charity. Images courtesy of Skillington Workshop Ltd.

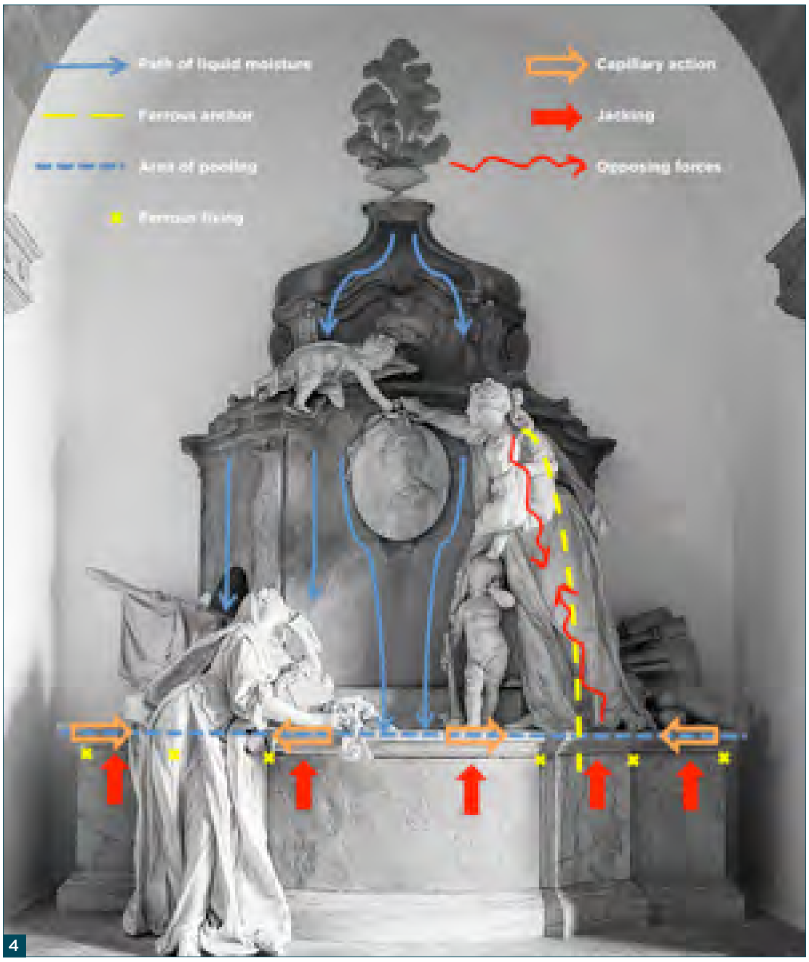

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Figure 4: Image by kind permission of Buccleuch Living Heritage Trust: Photography by Tom Arber.

So where has liquid moisture previously come from, and why is this monument alone affected by problematic iron corrosion? Condensation has historically been a problem, but clues to the puzzle lie in a combination of previous cleaning campaigns and the configuration of architectural elements.

A 1948 article in the *Kettering Evening Telegraph* was accompanied by an image of Mr Sinnett, agent to the Duke of Buccleuch, with the monument of Mary, Duchess of Montagu, illustrating severe soiling to its upper surfaces (Figure 5).

The beautiful and well-known statuary at Warkton's ancient church of St Edmunds is having a wash and brush up for the first time in twenty years.

Every week, Mrs Polly Mutton sees that the rest of the building is as spic and span as a new pin. But she wasn't allowed to touch the white marble figures [. . .]

In the 1920s an outside firm from London – maybe even from Italy [. . .] came to Warkton's little church [. . .] and washed and polished the statues.

After some correspondence with the British Museum, Mr Sinnett [. . .] learned that all that was necessary to restore the marble to something approaching its virginal whiteness was plenty of warm water, soap that would not harm a baby's delicate skin, and gentle handling.

The article is not strictly accurate, as records show that estate worker Gerald Worthington and his colleague Frank

Taffs cleaned the monuments in late 1942/early 1943. The task was one of the first Gerald undertook on the Boughton Estate, aged fourteen. John Gair, then Clerk of Works for the Estate, instructed Gerald to purchase Lux soap flakes for cleaning the monuments. They were equipped with a small burner to heat water, and cleaned all monuments within a week (Alan Toseland, pers. comm., March 2013).

The fact that the monuments were cleaned three times within twenty-eight years during the 20th century demonstrates how polluting the boilers were. It is also likely that there were cleaning campaigns during the 19th century when the boilers were frequently repaired. It is not unrealistic, therefore, to assume that the frequency of cleaning campaigns could run into double figures. What are the effects of injudicious cleaning?

3. THE REPERCUSSIONS OF HISTORICAL CLEANING CAMPAIGNS

Duke John's monument is unique at Warkton in that the configuration of its architecture appears to be the main driver for hastening the expansion of ferrous fixings, whereby the structural integrity is compromised and the sculptural elements are put at risk of irreversible damage (Figure 4).

The figures of the Duchess, leaning, and Charity, standing, disguise butted vertical joints in the marble shelf of the base, which comprises three elements. The pooling of liquid moisture settling on the shelf – caused by either condensation or mismanaged cleaning – is channelled by capillarity between the figures and the shelf elements to the hidden joints below the figures. When the moisture reaches the hidden joint lines, it is again channelled vertically down through the joint, where it comes into direct contact with the ferrous fixings that tie together the main blocks of the monument's base. The resulting corrosion and expansion lifts the shelf at the front edge, pushing it out of level. The earliest photographic evidence of this is dated 1948 (HPV Nunn (A) National Monuments Record). The resulting incline in the shelf by its very nature subsequently drains any liquid moisture collecting on its surface into the joints of the monuments' architecture, creating cycles which accelerate the corrosion and


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Figure 5: Mr Sinnett, agent to the Duke of Buccleuch before the monument of Mary, Duchess of Montagu. Note the soiling to upper surfaces. From the Kettering Evening Telegraph, 1948.

consequent expansion. In addition to the above, the flanking niches provide many moisture-entrapping voids in which water pools, leading directly to the core if left unattended.

The consequences of the above had put both figures under exceptional stress, especially Charity, which is rigidly anchored to the monument core. The outstretched dexter arm of the Duchess is fortunately jointed at the junction with its drapery; therefore, the joint was able to 'give' following movement in the shelf upon which it rested. However, point loading upon the figure's drapery had developed.

Given the above, the author concludes that the historical cause for iron corrosion was more associated with anthropogenic intervention as opposed to environmental and building envelope factors. Conservators will always investigate the impact of rainwater in an external environment or via absorption into the internal building fabric; however, perhaps more thought should be given to the configuration of a monument's architecture in an internal setting, and how it may interact with its environment. The monument to Duke John illustrates clearly that not only is the relationship with the building envelope a consideration when investigating an internal monument, but also historical anthropogenic intervention, and the way its architecture performs in its given environment can be significant contributors to deterioration.

4. 'AN INVESTMENT IN KNOWLEDGE PAYS THE BEST INTEREST'

The investigation and works at Warkton reconfirmed in the author's mind not only the significance of a thorough historical investigation, but the belief that in addition a more thorough archaeological investigation of a monument should be undertaken during the dismantling phase. For example, fragments of stone mullions from the dismantled medieval chancel windows were found in the core of Duke John's monument. Consequently, the core itself was recorded with both a digital point-cloud scanner by Leicester De Montfort University, and an archaeological appraisal by Ian Soden. A comprehensive form of recording embracing new technology should at least be considered, or at best adopted for a conservation proposal, given that we now have at our disposal accurate ways of replicating or recording materials which could be lost forever if the technology is ignored due to competitive tendering.

Monuments invariably harbour interesting features that are only ever revealed by those involved in their conservation. Ferrous fixings are vital components of a monument's construction that hold, restrain and support; manifestly of various shapes and sizes, and sometimes primed with resin of one form or another (Figure 6). Often they are simple yet beautifully crafted pieces of archaeology in themselves; however, they are generally recorded on a whim of the conservator, as there are no set guidelines for recording. Historical references regarding specific grades of iron (or copper alloy) used for monument construction appear non-existent. Is the use of better graded iron reflected in the significance of the monument itself; or are different grades used for different functions?


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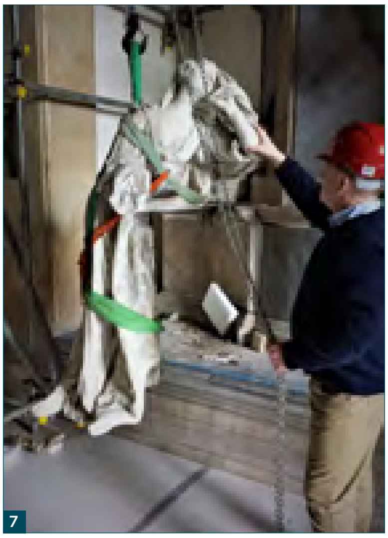
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Figure 6:
An original ferrous cramp to the inscription block and its stainless steel replacement. Image courtesy of Skillington Workshop Ltd.

Figure 7:
Image courtesy of Skillington Workshop Ltd.

The recording of fixings utilising XRF should be a prerequisite of a conservation proposal, at least where culturally significant monuments are concerned.

Anatomical sculpture worked partly in the round, sitting elegantly upon a monument's architecture and creating an artificial yet lifelike illusion, is a fascinating facet of a sculptor's skill, but is rarely seen except by those involved in monument conservation. The dismantling stage is a great opportunity for 3D laser scanning to record this aspect of the sculptor's work, providing an invaluable resource to students and academia alike and furthering understanding of this discipline (Figure 7).

5. Rebuilding

The logical practice of substituting ferrous fixings for the stability of BS:316 stainless steel robs us of an innate warning system regarding excessive levels of liquid moisture. Historically and today, both professionals and lay people alike can be alerted to problems arising from moisture by the expansion of iron fixings performing as tell-tales. Is contentedly walking away, thinking we have solved the problem, good enough? Should post-conservation monitoring be more carefully considered? Greater emphasis on the design of the internal structure of monuments, so that they are able to deal more efficiently with defects/ changes in the building fabric/ environment and breaches/failure in membranes arising from climate change or change in building use, should be considered.

The topic of isolating membranes is beyond the scope of this paper, and in the author's view should be the last measure, following all other attempts to eliminate or reduce liquid moisture sources to a minimum. Noting from above how architectural configuration or anthropological intervention might influence decay triggers, this must be a consideration, especially where membranes are concerned. If the building is at risk of flooding, what impact will a membrane have? Will the structure be able to drain itself, or will floodwater stagnate within it? Could the congregation of contaminants at the membrane leach into the monument core? Stand-alone structures are not necessarily risk-free following isolation at ground level.

The re-dressing of an original core to form a cavity between it and the monument architecture helps reduce migration of liquid moisture and salts. However, in order to be truly effective, it must be vented to prevent stagnation. Venting through air bricks in adjacent walls or floors, or hidden yet accessible voids on a monument, may provide an opportunity to install vents without any visible change.

The profession is not currently taking advantage of the opportunities a dismantled state gives regarding future monitoring. Wet internal conditions following the installation of stainless steel will no longer be obvious given the removal of tell-tale ferrous fixings. A responsible and possible way forward would be to install discreet conduits into various points of a monument core where sensors can be inserted at future dates to monitor performance.

6. CONCLUSION

Identifying all decay triggers is key to the success of an investigation, as interpretation of the results with influencing facet(s) of the decay process(es) missing can invariably lead to wrong conclusions and treatments. The investigation of the monument to Duke John, and the influences of its architecture reacting negatively upon itself, illustrates a facet of the investigation process that historically may have been overlooked. Have previous investigations and resulting interventions led to misguided conservation campaigns?

The early signs of climate change are a warning to monument conservators; considerations and/or preparations should be made for its possible impact. The more we understand about our monuments, the better prepared we can be for potential changes.

Numerous facets of monument archaeology are not routinely recorded. Identifying rates of internal contaminants, material analysis, fixings, mortar types, aids to construction such as oyster shells, wedges or spacers, lifting sockets, all provide useful and interesting information. Needless to say, financial constraints can deter conservators from including these additional investigation costs, especially in a competitive scenario. However, a commitment by stakeholders such as the Church Buildings Council to insist on the above as an integral part of a project plan would allay this aspect of the tendering process.

At least, a call to develop a template for standardising the recording of these precious works of art – one that not only ensures good practice, but provokes discussion and provides those who come after us with a clearly defined record of their archaeology – should be considered.

ACKNOWLEDGEMENTS

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INSIDE THE WASHINGTON MONUMENT:
PRESENTING AND PROTECTING A HIDDEN GALLERY OF 193 CARVED STONE BLOCKS

Judith M. Jacob[1]* and **Audrey Tepper**[2]

[1]* J. Jacob, Senior Conservator; National Park Service; Northeast Region;
Historic Architecture, Conservation, and Engineering Center.
judy_jacob@nps.gov

[2] A. Tepper, Historical Architect, National Park Service, National Mall and Memorial Parks.
audrey_tepper@nps.gov

* corresponding author

ABSTRACT

The Washington Monument, standing on the National Mall in the United States capital, contains a collection of 193 unique commemorative stones set into the interior walls. The 'stones', as they are colloquially called, date from 1849 to 1989, and are from every state in the country, civic organisations, cities and towns, foreign countries, and individuals, all donated in tribute to President George Washington. Each stone is different in material, embellishment, and condition. In celebration of the new millennium, the Washington Monument was the subject of an extensive preservation campaign, funded by a ten-million-dollar public-private partnership. As part of the campaign, the stones were cleaned and made ready for presentation; in some cases, material and structural stabilisation of a condition was also necessary. This paper describes the guidelines created for presentation treatments and gives examples of treatments. It also describes ongoing environmental challenges of water infiltration, annual condensation and drying events, salt blooms, a pipe leak, and the 2011 earthquake. Plans for the next phase of interventions will focus on these environmental challenges, beginning with the design of an environmental monitoring program and the simultaneous development of protection treatments. Treatments being considered include: installation of sheet-metal flashing and/or a gutter system above stones, replacement of cement bedding and pointing mortar with lime mortar, application of wax to stone faces, and removal of iron elements. Cycles of wetting and drying will never be eliminated entirely, but interventions can be made to lessen their impact on the commemorative stones.

Keywords:
stone, tablet, monument, water, condensation, salts


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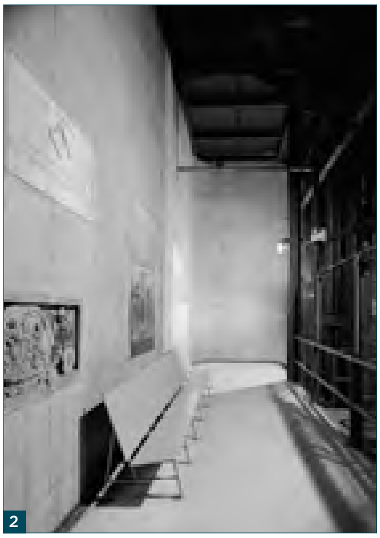
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Figure 1: Washington Monument. All photos courtesy of the NPS unless otherwise noted.

Figure 2: Commemorative stones, 160ft level (elevator enclosure on right). Photo: Jack Boucher, Historic American Buildings Survey, 1994, Collection: Library of Congress.

1. INTRODUCTION

In preparation for the new millennium, the Washington Monument was the subject of a four-year preservation campaign, funded by a ten-million-dollar public-private partnership. On the exterior, cracks were filled, joints were pointed, and the lightning-protection system was upgraded. On the interior, new heating and cooling systems were installed in the top visitor levels, the levels themselves were remodelled, and the elevator cab and controls were replaced. As part of the campaign, 193 unique stone blocks, set into the interior walls of the monument, were subject to presentation and stabilisation treatments with work executed by the National Park Service, Northeast Cultural Resources Center (now the Historic Architecture, Conservation, and Engineering Center). This paper gives an introduction to the history of these blocks, describes the guidelines established for presentation treatments, summarises the presentation treatments, and documents observations regarding conditions in the years since. Plans for the next phase of interventions, focusing on protective measures not fully anticipated as necessary twenty years ago, will also be described.

2. DESCRIPTION OF THE WASHINGTON MONUMENT AND THE COMMEMORATIVE STONES

The Washington Monument, standing at 555’ 5 1/8” (169.294175m), is the tallest freestanding load-bearing masonry structure in the world (Figure 1). The monument is an open shaft, containing an elevator surrounded by a steel staircase with 898 steps and fifty landings (Figure 2).

The 193 stone blocks are formally called the ‘commemorative stones’ and colloquially called the ‘stones’. One hundred and sixty-four of these were donated between 1849 and 1857, and twenty-nine were donated between 1860 and 1989. Stones represent states, cities and towns, civic organisations, foreign countries, and individuals. They range in size from 1½ by 2 feet to 6 by 8 feet and are placed at heights from 3 feet to 16 feet above stair landings. Stone types are numerous and include granite, marble, limestone, sandstone, and jade. Some stones have nothing more than a simple inscription, while others have relief carvings or are fitted with bronze and silver plaques and letters.

3. HISTORY OF THE WASHINGTON MONUMENT AND INSTALLATION OF THE COMMEMORATIVE STONES

In 1833, the Washington National Monument Society was formed to fund and construct a monument to the memory of the nation's first president, George Washington. In 1836, the renowned architect Robert Mills won a design competition for a 500-foot tall obelisk, surrounded by a circular colonnade surmounted by equestrian statuary.

The monument was constructed over the course of four decades and during two distinct periods. The first period commenced with the laying of the cornerstone in 1848. Walls were faced with Maryland marble on the exterior, local gneiss on the interior, and filled with rubble stone and mortar. Construction was supervised by the Washington National Monument Society. In 1858, with a depleted bank account and internal dissent, the Society was forced to abandon work, leaving an open shaft just over 150 feet high. The second period of construction commenced in 1878, under the direction of Lieutenant Colonel Thomas Lincoln Casey with the United States Army Corps of Engineers. Casey enlarged the foundation and redesigned the walls to eliminate the rubble core. He used Maryland marble on the exterior (from a different quarry than that used earlier) and New England granite on the interior. The capstone was set in 1884 and four years later, the monument was officially opened to the public. The grand colonnade envisioned by Mills was never built.

Once the monument had opened to the public, it was placed under the jurisdiction of the United States Office of Public Buildings and Grounds. In 1933, jurisdiction was transferred to the National Park Service.

For this paper, the 'lower part' of the monument is that constructed between 1848 and 1858: ground level to the 140ft level (fourteenth landing). The 'upper part' is that constructed between 1879 (after the foundation had been enlarged) and 1884: the 150ft to the 500ft levels. The twenty-year period of construction inactivity will be called the 'break in construction'.

During the first period of construction, eighty-four stones were set into place as integral components of the masonry. From 1885–1889, after the shaft had been completed, ninety-five stones that had been stored in the Lapidarium, a wooden building on the monument grounds, were set in the upper part. These blocks were sawn down to panels between four and six inches thick and inserted into rectangular niches in the walls. Stones were set with lead shims and iron wedges; a cement grout was used to fill the void behind each stone. Thirteen stones were installed between 1913 and 1989, and the final stone – dating to 1855 and found at the bottom of the elevator shaft in 1959 – was inserted on 22 February 2000, George Washington's 268th birthday.

4. CONDITION OF THE COMMEMORATIVE STONES

By the end of the 1990s, conditions of the stones varied with many adversely affected by water, salts, loading stresses, and vandalism. Stones were covered with decades' worth of dust, soot, iron oxide stains, calcium carbonate crusts, and lipids from hand contact. Past cleaning and repair efforts were often damaging and unsightly.

The stones that were presented to the monument were created for an interior setting. With the break in construction, stones in the lower part were subject to an exterior environment and the luminous surfaces of polished marble, and the gold leaf and paint of inscriptions, were lost to erosion. Additionally, rainwater percolating through an open core with uncured lime mortar produced calcium carbonate crusts on walls. Uneven loading conditions produced cracks, breaks, and spalls along top and bottom edges of all masonry units.


3

Figure 3: **Water infiltration, 130ft level, 1997.** Note: all images pre-dating 2019 are scanned from slides; corrections for uniform colour, contrast, and lighting were only partially successful.

In the upper part of the monument, seeping or pouring rainwater – and condensation – has caused the rusting of iron wedges with associated cracks, spalls, and stains in the stones. Rainwater has also caused the rusting of the steel brackets and 'toe boards' of landings and large drip trails of iron-oxide particles on walls. During periods of drying, salts from cement grouts have caused disaggregation and flaking of stone surfaces.

Even before the monument had officially opened to the public, visitors and intruders scratched their names into the stones. With the help of chisels, many sculptural elements – ornaments, noses, raised letters – are now long gone.

Wholesale cleaning of the stones seems to have been carried out only three times: in 1889, 1931, and 1979. Observations of surfaces suggest the use of acids, sandpaper, wire brushes, steel wool, orbital sanders, and power-driven burrs or rotary files (the last for graffiti removal).

The interior of the monument has always been poorly illuminated. During the 1960s and in 1979, difficult-to-read inscriptions were painted or varnished to increase their legibility.

In 1979, missing sculptural elements were restored with stone pieces ('indents' in British English and 'Dutchmen' in American English) and resin fills. Indents/Dutchmen are in good conditions but fills have yellowed.

Since the completion of the monument, water from heavy rains has periodically seeped through open joints and cracks, prompting full exterior repointing in 1934 and 1964. By the late 1990s, rainstorms sent water pouring down walls, sometimes as far down as the 100ft level (Figure 3). Condensation on walls is an annual spring occurrence.

5. PRESERVATION GUIDELINES

In 1997, a set of guidelines was created to direct the nature and range of treatments to be executed. Guidelines would ensure that a collection of 193 disparate units could be presented to the public and appear as a cohesive whole. Despite their differing degrees of historical interest, craftsmanship, and rarity of material, all 193 stones are equal in importance and value. Therefore, treatments needed to reflect this equality. Both presentation and stabilisation treatments were executed; only the presentation treatments will be described in this paper.

Identifying the significance of the stones was critical to the creation of guidelines. Significance was determined to lie in the message that each stone bears through material, text, and iconography. The stone from Arizona is made from three slabs of petrified wood (Figure 4), the stone from Maine states 'MAINE' (Figure 5), and the stone from the Fire Department of Philadelphia depicts fire-fighting carts and the city's Fairmount Water Works in the background (Figure 6). To this end, the message of each stone was restored: material, text, and iconography were made readily legible. No attempt was made to restore stones to their original appearances.

While guidelines provided visual parameters for treatments, maintaining consistency of treatments for 193 stones was still a challenge. Other challenges included no running water, limited (and changing) electrical current, and climbing many stairs on a daily basis. Documentary photography (film) was challenged with tight spaces.

4

Figure 4:
Arizona (2' x 4' 10"), donated and installed in 1924, 320ft level, 2000.

5

Figure 5:
Maine (2' x 4'), donated in 1849 and installed in 1850, 30ft level, 2000.

6

Figure 6:
Fire Department of Philadelphia (3' 10" x 6'), donated in 1854 and installed in 1889, 250ft level, 2000.

Figure 7:
Kansas (2’ x 3’ 6”), donated in 1882 and installed in 1885, 210ft level, before treatment, 1998.

Figure 8:
Kansas, after treatment, 2000.

6. SUMMARY OF TREATMENTS

Rotating a small crew – the primary team consisted of two National Park Service conservators and two conservation interns – through different tasks helped to ensure consistency of treatments. In almost all cases, at least two people worked on a stone to eliminate individual variances in treatments.

To restore legibility of the material, stones were cleaned to remove or reduce dust, dirt, stains, mortar drops, paint spatters, calcium-carbonate crusts, and non-original paint. Scratches were visually minimised by toning with watercolours. Existing fills that had yellowed were painted to match the surrounding stone. Where there were remnants of original paint or gold leaf in letters, new paint and gold leaf were applied.

To restore legibility of the text, missing letters or numerals that could not be interpreted – and which were necessary for the understanding of the text – were replicated with fills. Where reading text in low illumination was difficult, inscriptions were ‘shadowed’, or painted with a dark watercolour wash. This translucent covering increased contrast without obscuring the stone itself.

To restore legibility of the iconography, missing figural elements that compromised the message were replaced with fills. Replacements were only made if the appearance prior to loss could be reasonably deduced based on historic documents or comparative iconographic images. In some cases, remnants of original paint or gold leaf indicated the original appearance of carved figural elements; in these cases, new paint and gold leaf were added.

The stone from Kansas was cleaned, iron oxide stains reduced, and the carved lines depicting the state seal were painted black, based on black-paint remnants (Figures 7 and 8). The stone from the Grand Lodge of Iowa was cleaned, non-original paint removed from the inscription, and the inscription then shadowed (Figures 9 and 10). The stone

Figure 9:
Masons, Grand Lodge of Iowa (2’ 8” x 3’ 11”), donated in 1876 and installed in 1885, 210ft level, before treatment, 1998. Note: black mark in the ‘G’ of ‘Lodge’ is an inclusion in the stone.

Figure 10:
Masons, Grand Lodge of Iowa, after treatment, 2000.


11


12

Figure 11: Pennsylvania (3' 1" x 6' 2"), donated in the 1850s and installed in 1885, 180ft level, before treatment, 1998.

Figure 12: Pennsylvania, after treatment, 2000.

from Pennsylvania was cleaned, iron oxide stains reduced, and discoloured fills painted to appear as marble (Figures 11 and 12).

During the break in construction, four stones had eroded to an almost completely illegible condition. To present the messages of these stones, bronze plaques bearing the original text and iconography – based on 1850s documents – were fabricated and mounted beside them on the wall.

In 2000, the monument opened to the public. Visitors could see some of the stones through windows in the elevator cab, and all of them on small, guided walk-down tours. A catalogue of the collection was written for an audience unable to join the tours. The catalogue contains a photograph of each stone and historical information obtained from Washington National Monument Society records, Army Corps of Engineers records, National Park Service records, and newspaper clippings. The messages that 193 donors presented to the nation are now available for all to see.

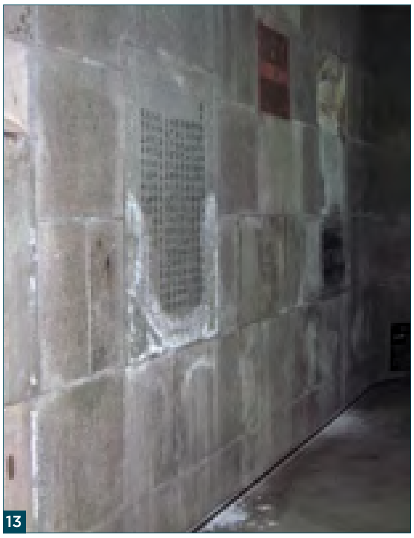
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Figure 13:
220ft level following a period of drying; salts from cement grout behind stones, 2009.

Figure 14:
210ft level following pipe leak and earthquake; iron oxide drip trails from water flowing over steel brackets and 'toe boards' of landing above, 2019.

Inset: drip trails from brackets underneath landing.

7. CURRENT CONDITIONS

Of the numerous environmental conditions that had led to the deterioration of the stones, many were thought to have been alleviated with exterior masonry repairs. An assumption was made that with the filling of cracks and pointing of joints, the interior would be dry, and to some extent, this was correct.

Following exterior pointing, the flooding following rainstorms ceased, even though small amounts of water continued to seep through walls in seemingly random locations. What was most surprising were the salt blooms that formed on stones in the upper part of the monument (those that had been set with cement grout). Damage to stones from drying was not expected (Figure 13).

A re-examination of reports describing previous conditions made clear that wetting and drying cycles are constant. During construction – including the break in construction – the monument was, to greater and lesser extents, wet. In 1885, with the setting of the capstone, the first drying period commenced. By the 1930s, wet conditions had returned and in 1934, the monument was subject to full repointing, leading to the next drying period. This cycle was repeated in 1964 and again in 2000. Disaggregation and flaking surfaces of the stones were determined to be due both to water running down walls and to water evaporating out from walls.

In 2008, a leak in a heating-system pipe sent water pouring into the monument. Walk-down tours were halted and the system turned off. On 23 August 2011, a 5.8-magnitude earthquake rocked the city of Washington, leaving cracks in the monument open to the sky. Rainwater freely entered the shaft for the next three years until cracks could be filled. The stones are again covered with dust, dirt, and iron oxide stains, and watercolour paints used for toning have been partially washed away (Figure 14).

8. RE-EVALUATION OF TREATMENTS AND PLANS FOR FURTHER WORK

As mortar on the exterior of the monument inevitably begins to fail, increasingly greater amounts of rainwater will seep into open joints and make its way to the interior. Periodic repointing campaigns will dry out the interior and produce salt blooms. Whether exterior mortar is in good condition or not, condensation on interior walls is an annual occurrence. It will be impossible to entirely eliminate water from the monument, and equally impossible to control the evaporation of water through stones during drying periods.

Removing stones from the walls is not an option, nor is installing a climate-control system that will provide a steady relative humidity throughout the year and spanning pointing cycles. New interventions are necessary for the protection, stabilisation, and presentation of the stones. None of these interventions will be easy, none will completely solve problems of water and salts, and all will be costly.

Since the earthquake and exterior repairs, the elevator has been completely overhauled and permanent security facility has been constructed at the base of the monument. Focus can now, again, turn to the interior of the monument and the protection of the stones. The first step will be to design and implement a monitoring programme to better understand the interior environment.

Considerations for interventions follow. Each intervention will require a development stage with trials.

1. Install sheet-metal flashing and/or a gutter system above select stones, or above rows, set into existing joints, and projecting out from the stones to divert dripping or flowing water away from stone faces.
2. Replace cement mortar around stones in the upper part of the monument with a porous lime mortar to direct the evaporation of water – or some water – through joints instead of through stone.
3. Re-clean the stones and re-apply presentation treatments as necessary. For stones not affected by salts, follow treatments with a protective wax coating. Wax may not be visually acceptable on stones that were not originally polished.
4. Remove iron wedges from stones in the upper part of the monument. Removal will require cuts in the wall that can be repaired with stone indents/Dutchmen. As pressure from rusting is released during the cutting process, there is a risk of stones cracking or shattering.
5. Design a maintenance plan for general housekeeping that may be implemented by maintenance staff under the supervision of a conservator.
6. Address rusting of steel stairs and landings.
7. Address low-illumination levels.
8. The photographs made in 2000, at the conclusion of treatments, are in 35mm colour slide format. While they were digitised for the catalogue, they need to be re-digitised at a higher resolution, colour corrected, rectified, and published in a new edition of the catalogue.

The goal of all the proposed interventions is twofold: to reduce the rates of deterioration, and to again present the stones to the public through walk-down tours and a re-issued catalogue.

9. CONCLUSIONS

The conservation treatments executed for the Washington Monument's commemorative stones were many and varied. Guidelines enabled an equality of treatments that would visually unify a collection of 193 disparate units for their presentation to the public, both in real-life walk-down tours and in a catalogue.

It is now obvious that within the monument, constant water infiltration, annual condensation, and periods of drying are conditions that will not change. The challenges of keeping both the monument and the stones in good condition – when environmental factors assure eventual poor condition – are enormous. Planning for an environmental monitoring program and discussion of water and salts management are now in progress. Protection treatments, designed to lessen deterioration from water and salts, are also being discussed. With the onset of this work, the commemorative stones will again receive full care and attention to pay their tribute to President George Washington.

ACKNOWLEDGEMENTS

With heartfelt thanks, this paper is dedicated to the memory of Steve Lorenzetti (1960–2014), former Chief of Cultural Resources, National Mall and Memorial Parks, whose friendship and steadfast support through every step of the project will always be cherished. Thank you too to Sean Kennealy, Chief, Division of Professional Services, National Mall and Memorial Parks; and Stephen Spaulding, Director, Historic Architecture, Conservation and Engineering Center, Northeast Region.

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WEST DOORWAY, TEMPLE CHURCH, LONDON:
PAST CONSERVATION AND FUTURE USE

David Odgers[1*], **Alexander Holton**[2] and **Jonathan Deeming**[3]

[1*] David Odgers, Odgers Conservation Consultants.
david@odgersconservation.co.uk

[2] Dr Alexander Holton, Purcell Architects.
alex.holton@purcelluk.com

[3] Jonathan Deeming, Purcell Architects.
jonathan.deeming@purcelluk.com

* corresponding author

ABSTRACT

The Temple Church is a late 12th-century church in the City of London built by the Knights Templar as their English headquarters. During its lifetime, the church has suffered its share of deterioration and neglect, including severe damage during the Blitz. The great West Doorway was constructed from Caen stone and was the subject of a significant restoration in 1842 and many other interventions at intervals since. These treatments provide a fascinating compendium of repair and consolidation technologies through the 19th and 20th centuries. It is approached down steps and set within a substantial porch; the stonework of the door therefore acts as the interface between the internal environment and the protected external environment. In 2017-18, a detailed project of analysis and investigation took place to understand the effect of the treatments, to assess the current stone decay mechanisms and to consider options for treatment. This was carried out within the context of exploring the potential for improving the visitor experience with level access through the doorway, and ascertaining how best the stonework might be protected from both the complex interaction of internal and external environments and the result of more general use.

Keywords:
medieval, doorway, investigations, access, environment

1. INTRODUCTION

Apart from the overall architectural impact, the most significant elements of the Grade 1 listed Temple Church are its round form (atypical in England), the Purbeck marble effigies of Templar Knights in the nave and the ornate West Doorway. The latter is generally only used for ceremonial occasions; it is somewhat hidden from public view and is normally closed off by metal gates in order to protect it from mechanical damage. Increasing concern has been expressed about its condition, with small fragments of stone often found on the ground; this, along with a strategic desire to enhance its accessibility and connection with visitors, resulted in the Honourable Society of the Middle Temple (who are responsible for the buildings in perpetuity) commissioning the detailed investigations described in this paper.

2. HISTORICAL BACKGROUND

The West Doorway is considered an original feature of the late 12th-century Temple Church, exhibiting the Transitional style of English architecture. The building was begun as the main church of the English Knights Templar, between what is now Fleet Street and the River Thames, in 1161. Following their persecution in the 14th century, the church passed into the hands of the lawyers of Middle Temple. It narrowly avoided the conflagration of the Great Fire and was subsequently amended and altered.

It then fell into a state of disrepair and decline. The West Door had by this time been closed up, and it spent much of the late 17th and early 18th centuries within a stationer's shop. When it was opened up again in the late 18th century, the lower levels were concealed beneath raised ground, but it began to be of interest to antiquarians. An article in the *Gentleman's Magazine* in 1783 refers to it as having 'suffered little by time, as it is secured from the effects of weather by being under the roof of the passage leading into the cloisters' (Griffith-Jones 2010).

The fascination of the doorway as a subject for drawings and etchings, notably an etching in 1813 by Smith and an engraving by Nash in 1818, has helped to develop an understanding of its history. Notable repairs were carried out in the early 1840s, with further interventions in the late 19th and then 20th centuries, including restoration works after World War II. The details of intervention – which are inextricably linked to its current condition and conservation needs – are explored in greater depth later in this paper.

Figure 1:
View of doorway and porch (© Purcell).

3. DESCRIPTION AND USE

The complex setting and context of the doorway contributes much to both the technical conservation conundrums it poses and the strategic challenges of enhancing visitor accessibility into the west end of the church. The late-12th-century church is believed to have comprised the round nave – known as the Round Church – and a possibly smaller chancel that was replaced in the early 13th century. Similarities between the treatment of surviving primary Norman masonry in both the doorway and the exterior of the nave indicate that the two were contemporaneous, with the doorway forming the primary grand entrance to the Templar church (Austin and Seary 2016). When opened, the doorway immediately gives way to the nave interior, a mausoleum-like setting for the spectacular Templar effigies.

The doorway is fronted by a vaulted porch, open on three sides. Outwardly the product of substantial restoration in the 20th century – using Portland stone, a widely used English oolitic limestone – apparent continuity in the fabric of the vault and doorway suggest that this element was also integral with the 12th-century arrangements. However, archive evidence illustrates evolution in the porch design, with a shift from a semi-enclosed structure that was recorded by R. W. Billings in 1838 to the fully open structure that was formed (or re-formed) in the early 1840s. As with many historic churches, the ground level around the building had significantly risen over time (Austin and Seary 2016). This was reduced as part of the 1840s work, sinking the levels around the building against the surrounding context of Middle Temple and effectively placing the porch and doorway within a 'well' accessed by stone steps; doubtless this was emphasised further when buildings adjacent to the west end of the church were cleared in the 1860s. Importantly, the implied consequences of these changes over time involve both an alteration to the environmental dynamics around the doorway and the introduction of physical barriers as a means of managing the distinctly awkward differences in levels.

The West Doorway itself is set within a recessed arch and was originally formed of eight orders, alternately moulded and enriched with sculpture. The three outer moulded orders were supported by plain detached columns (originally of Purbeck marble) with stiff leaf capitals. The four sculptured orders were supported by engaged and enriched semi-colonettes, with small demi-figures. Foliated abaci passed uninterrupted through all the orders, over both capitals and demi-figures.

4. HISTORY OF REPAIR AND CONSERVATION

The doorway was still considered to be in excellent condition in 1808, although in 1810 it was undergoing repair, probably involving cleaning and repairs with either Roman cement or plaster and paint, all of which have been found on the existing stonework. The 1840s saw the Temple Church extensively (and expensively) restored, with the bold and controversial aim of removing later features and alterations and returning the building to 'the manner and style and character of the Temple Church of 1185, and 1240, and with materials of the same kind, worked with the same ornaments, as those with which it was then constructed' (Griffith-Jones 2010).

The repair was carried out in a few months in 1842 under the direction of Decimus Burton and Sydney Smirke. The extent of renewal seems to have become increasingly comprehensive as new discoveries were made, particularly of decayed carved stones hidden behind plaster. The amount of replacement continued to challenge observers for the next 160 years, and only after a detailed assessment by the Canterbury Archaeological Trust (CAT) in 2015 was it possible to understand the full extent of the restoration and the significant amount of surviving original material.

It was clear, however, that the Caen stone (an oolitic limestone from Normandy in France) used in the restoration was very poor, and it decayed readily in polluted air; this problem also beset the contemporary construction of the Nash wing at Buckingham Palace. The application of white lead paint as a protection was the first of many subsequent treatments revealed by searches of the Middle Temple archive, SPAB records and photos in the National Monuments Record.

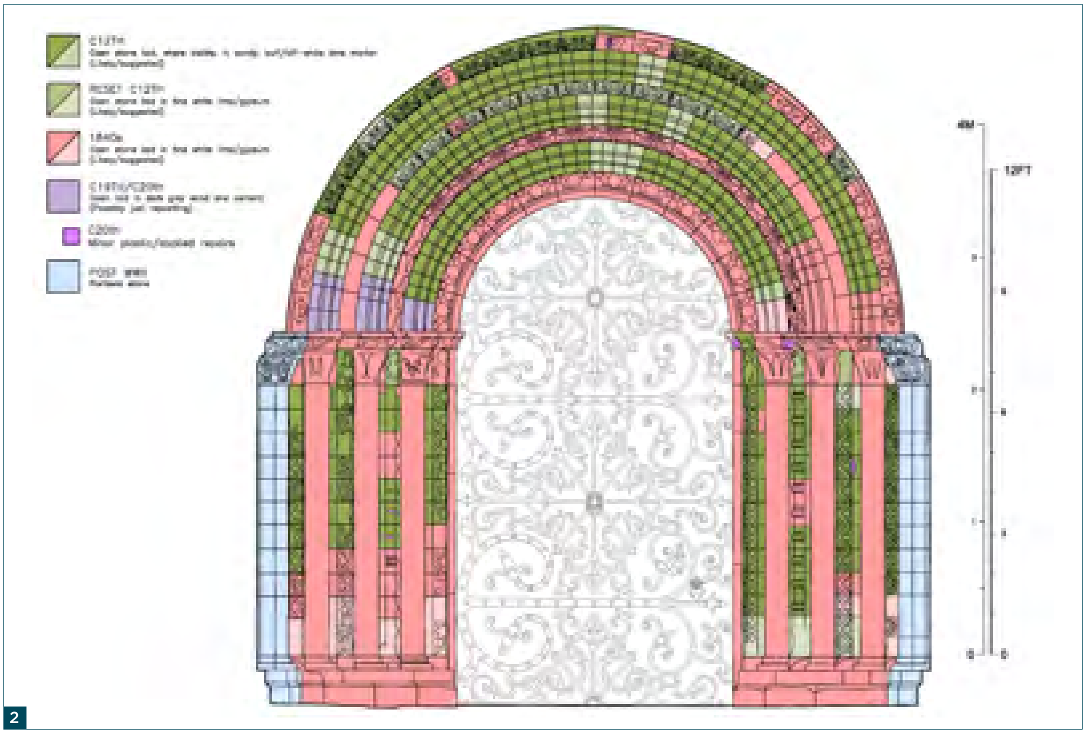

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Figure 2: Image showing age of stones (© CAT).

It is not always clear whether written recommendations were followed through into practical treatment but amongst the methods thought to have been used are ‘fluate’ (1895), Baryta water (1901), the ‘siassic process’ (1912), Zerelemey liquid and ‘plastic stone’ repair (1925), repairs with lime mortars and limewash (1927) and paraffin wax (1930s).

Bomb damage to the church in 1942 destroyed the roof of the porch and allowed water into the stonework of the doorway; this, combined with the inevitable surface impermeability and discoloration that resulted from the wax treatment, set in train further decay. There was some cleaning in 1951 prior to re-dedication following post-war repairs, and then in 1983 a report (Macfadyen 1984) summarised the situation as ‘Soot deposits on stone combined with traditional treatments of hot oil or wax and limewash had resulted in impervious skin of calcium sulphate with a build up of moisture and salts behind it. Where this skin had burst more rapid decay had set in causing deep pitting and the loss of much fine carved work’.

Then, following trials, the whole doorway was cleaned with an air abrasive; consolidation of the capitals and inner order was carried out using Brethane (a silane developed by the BRE). Further cleaning was carried out using a laser in 1998.


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Figure 3: Condition of doorway in 2017 (© CAT).

5. ANALYSIS AND INVESTIGATION

A number of different (mostly site-based) methodologies were chosen to establish the current condition of the stonework and assess the rate of its decay, and to understand its current behaviour along with any issues that might be attributed to previous treatments.

Detailed decay mapping was carried out by Purcell (Travis 2016), and this showed that almost all of the 1840s replacement Caen stone had deteriorated with the loss of almost all carved detail; this same detail was still retained on the original 12th-century stone. Comparative study was also carried out of 4 No stones removed from the doorway during the 19th-century restoration and now in the V&A. The condition and detail of these stones is such that under current conservation guidelines and ethics, they would not have been considered for replacement. Their untreated surface provides an invaluable benchmark to compare the consequent rate of decay in the contemporary in-situ carving.

Environmental data loggers were placed at various locations on and around the porch stonework, including in the interior of the church. These recorded surface temperature (ST), air temperature (AT) and relative humidity (RH) and allowed calculation of dew point, and therefore could identify condensation events. In summary, the physical structure of the porch was found to buffer the RH more than the temperature; in spring and summer, it reduces the fluctuation in RH and in the winter months, it tends to lower the RH when compared to external conditions. However, the fluctuations in RH on the doorway are still sufficient to allow deliquescent salts present on the surface to go in and out of solution. Surface temperature increases on the stonework nearest to the door as a result of heating within the church. The degree of ventilation and localised environmental conditions mean that there were very few condensation events over a twelve-month cycle of recording.

Salt analysis revealed the presence of some calcium sulphate, but the concentrations were not high, which is consistent with stonework that has been cleaned and is now subject to low levels of atmospheric pollution. There were some nitrates on stone near the ground of the interior of the church adjacent to the doorway.

A number of IR images were taken on three occasions at different times of year (February, May and November) using a FLIR One camera attached to an iPhone. This is not precise enough to record absolute temperatures but showed that finer areas of the carving can be up to 1.5°C warmer than the bulk surrounding stone; this may lead to thermal stress between the two. All low-level areas were found to be generally cooler and damper than higher-level stonework.

Selected stones were tested for surface permeability using a drop test, and the surface was also examined using a USB microscope. The information from these enabled some assessment of the residues from previous treatments as well as the effect on surface permeability.


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Figure 4: Detail of south side showing variable surfaces (© OCC).

6. CONSIDERATIONS FOR FUTURE TREATMENT

The detailed assessment and comparison of photos taken over the last 40 years suggest that since the treatment of the 1980s, there has been no significant change in the overall structural condition. The environment is quite stable, there are residual low levels of salts within the masonry, the levels of sulphur dioxide are historically low and the doorway is far enough away from traffic so as not to be too affected by particulates.

Given the plethora of treatments to which the stonework has been subjected, it might be thought appropriate to leave it alone. However, there is continuing small-scale decay, mostly spalling of residual coatings and stone surface, and if use and/or environment are to change then there is a minimum obligation to ensure that the possible effects on the stone are mitigated.

Small-scale trials suggest that this might be achieved by light cleaning of the surface using soft brushes and minimal water, followed by localised consolidation of powdering surfaces with E5 nanolime, mortar repairs using dispersed lime as a binder and application of thin lime putty-based shelter coat to all surfaces. The mortars would be used both as a protection for decayed surfaces but also as a means of enhancing – not recreating – missing detail.

Despite the ravages of time and the deterioration of significant parts of the carving, the doorway still stands as a testament to the design and skills of the 12th century. There is an ongoing debate about whether the reinstatement of missing carving might be appropriate; decisions on this can only be taken in the context of the intended use of the doorway and the effect on its overall significance.

7. ACCESS AND USE

The need to reinstate and enhance access down to, and through, the West Doorway into the nave of the Round Church is compelling and could be achieved with thoughtfully designed ramping arrangements. However, the continued care of the doorway relies not only on agreeing appropriate treatment of its stonework, but also the careful management of both the surrounding environment and visitor flow. This includes safeguarding the stone from potential impact damage and agreeing an access strategy that ensures environmental stability between the exterior porch and the nave interior. A range of scenarios are presently being explored with the relevant stakeholders (Athanasiou 2018).

In terms of protection and prevention from impact damage, three main options have been considered so far: (a) fixed low-level railings, offset from the doorway fabric; (b) operational low-level railings that can be moved into a guard position adjacent to the doorway when necessary; and (c) a fixed stone kerb or buffer, again offset from the doorway fabric, to control the path of visitors into the church. All are achievable in principle.

To manage the environmental challenges, very careful consideration needs to be given to the implications of reintroducing regular direct access via the West Doorway into the nave. At present, the monitoring suggests that the external porch zone has a relatively stable microclimate and the conditions within the porch area remain largely unaffected by the interior conditions of the nave. If the West Doorway is to be opened on a daily basis, warm air from inside the church will likely circulate out into the porch, mixing with the cooler external air; this could potentially have a detrimental effect on the decay process of the stonework through more frequent condensation events. Moreover, the open door would facilitate moisture exchanges with the church interior, which might put the Templar effigies and architectural masonry at risk.

Consideration will therefore need to be given to a method of environmental control or buffering within the nave itself to protect against unstable air exchange. On this basis, one option may be to encourage the door to remain open daily (enhancing the sense of welcome and visibility into the church), but with the addition of an internal lobby within the entrance to act as a buffer zone. The design would need to be carefully considered so as not to impact adversely on the architecture of the nave or setting of the effigies. A strategy for managing the internal environment of the church generally must also be developed (e.g. the introduction of new conservation heating controlled by humidistat) as a further means of conservation control.

8. CONCLUDING THOUGHTS

The project described by this paper is still at an interim stage. Consultation and further development of options, along with further investigation, trials and monitoring on site, will still be required before an informed solution can be agreed for practical implementation.

Nonetheless, what has been clearly demonstrated at this preliminary stage is the importance of a holistic approach to the conservation of the West Doorway. The involvement of a multi-disciplinary team is a model for approaching other similar projects. It is becoming increasingly common for ‘pure’ conservation exercises to coincide closely with strategic and societal needs to enhance access to a significant place, especially where public funding is being sought. As such, close co-ordination between the requirements of each workstream – fabric, environment and physical and intellectual access – is essential in ensuring the optimum outcome that both safeguards and presents heritage significance to the widest audience possible.

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MICRO-GROUTING OF BURNS MONUMENT, ALLOWAY, AYRSHIRE: A SYNTHESIS OF TRADITION AND INNOVATION IN BUILDING CONSERVATION

Kinlay Laidlaw

Kinlay Laidlaw BSc. (Hons) DipBldgCons MRICS,
Director of Laidlaw Associates Building Surveying Ltd.
kinlay@laidlawsurveying.com

ABSTRACT

Burns Monument was completed in 1823 to a clever Greek revival design by architect Thomas Hamilton. It was the first monument to Robert Burns and is now regarded as nationally important, being category-A listed by Historic Environment Scotland. Although carefully maintained throughout its life, in recent decades it has sustained severe damage from progressive water penetration through open mortar joints and voids within the masonry core. The National Trust for Scotland assumed guardianship in 2008 and began to understand the underlying issues via a comprehensive programme of monitoring, research and investigation. The emerging repair strategy required a further programme of research and development to develop a new method of injecting hydraulic lime grout through narrow ashlar mortar joints known as micro-grouting. This technique is able to fully fill deep ashlar joints in a way that has hitherto simply not been possible. Research and development to refine the technique was carried out in 2017. During 2018–2019 the monument was successfully micro-grouted and a wide-ranging programme of other conservation work was completed, following a comprehensively planned repair strategy designed to prevent further water ingress and restore the water shedding function of the exterior surfaces. Other key project elements include interstitial moisture monitoring, conservation heating, conservation cleaning, removal of inappropriate interventions, reinstatement of significant features and improvements to access and interpretation. Involvement of external stakeholders at all stages from research to fundraising and promotion helped secure our project imperative to ensure best quality outcomes.

Keywords:
conservation, lime, grouting, stonemasonry

Figure 1: Burns Monument, 2016 before conservation work.

Figure 2: The monument of Lysicrates, Athens.

1. INTRODUCTION

Robert Burns, internationally renowned Scottish poet, lived between 1759 and 1796. A monument was erected in his memory near his birthplace to a design by Edinburgh architect Thomas Hamilton (Figure 1), from 1820–1823. The Greek revival design was inspired by the choragic monument of Lysicrates, Athens, 334 BC, erected to celebrate choral achievement (Figure 2). The Burns monument design contains both classical symbolism and masonic allegory, as a clever way of referring to Burns's associations with freemasonry and immortalising his memory.

On completion the monument instantly became a popular visitor destination. It has maintained its fame and appeal to this day, and is listed by Historic Environment Scotland (HES) at category A in recognition of its national cultural and architectural importance. Its striking architecture and prominent position above the river Doon, enhanced by its ornamental garden setting, has also ensured its enduring popularity, now with around 125,000 visits per annum. The Burns Monument Trust (BMT) carefully maintained the property as a museum to Burns-related artefacts and as a visitor attraction until 2008, when all BMT assets were transferred into the care of the National Trust for Scotland (NTS).


3a


3b


4

Figure 3:
a) Carved pediment ornamentation.
b) Carved foliate tripod finial on upper dome.

Figure 4:
Damage from water penetration to interior masonry finishes.

Its construction is outstanding: built using the finest Scottish sandstone available and constructed in the best ashlar stonemasonry traditions of the time (Figure 3). Almost two centuries on, however, the exposed masonry is suffering from extensive water penetration leading to progressive, irreversible damage and disfigurement of the finely wrought ashlar interior.


5

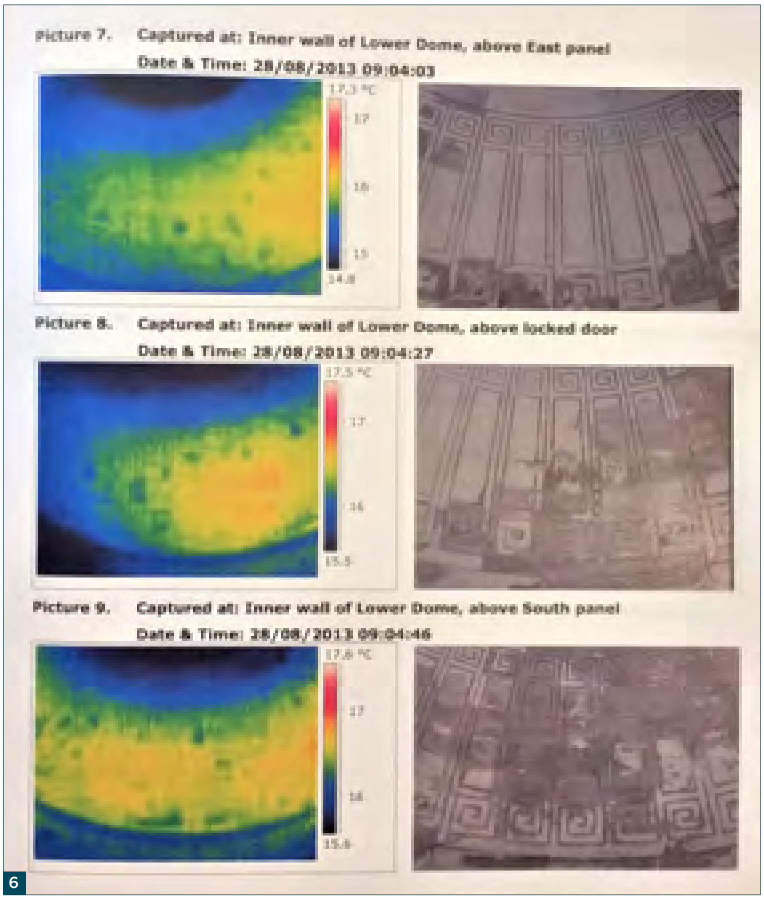
Figure 5:
Open mortar joints of upper dome probed by pointing key.

2. SURVEY AND INVESTIGATION

2.1 Physical inspection

After acquisition, the NTS carried out a comprehensive condition survey. Full scaffold access facilitated a measured survey and close inspection to establish why severe water penetration was occurring (Figure 4) so soon after comprehensive repair and repointing by the BMT in 1997.

Using both physical inspection techniques, including probing, minor raking and visual inspection (Figure 5), and technology such as infra-red thermography (Figure 6), it was quickly established that water penetration was indeed active and ongoing. Mortar depletion and voiding within the fine ashlar mortar joints was the major contributory factor causing water ingress. On-site tests clearly demonstrated water penetrating mortar joints that had been re-pointed in 1997 into a network of voids within deep joints and the wall core; these voids acting as interstitial drainage paths deep into the structure.



Picture 7. **Captured at: Inner wall of Lower Dome, above East panel**
Date & Time: 28/08/2013 09:04:03

Picture 8. **Captured at: Inner wall of Lower Dome, above locked door**
Date & Time: 28/08/2013 09:04:27

Picture 9. **Captured at: Inner wall of Lower Dome, above South panel**
Date & Time: 28/08/2013 09:04:46

6

Figure 6:
Infra-red thermography report extract.

2.2 Archival research

A concurrent programme of archival research revealed that Hamilton's mortar specification circa 1819 required the new stonework to be 'bedded on mortar with a close joint, well squared and laid with a cement composed of white lead and oil mixed with river sand, clean washed' (ref. 3.6493.r RBBM archives).

Over time, the organic linseed oil component appears to have decomposed and largely washed out of the joints. In contrast, the wall core comprises traditional lime and rubble fill: a permeable concretion of irregular stone and hot-mixed lime mortar, itself partly infiltrated with a network of interconnected voids and fissures.

2.3 Principal mechanism for water ingress

Attempts to re-point the very narrow outer ashlar joints in both cementitious and lime mortars up to 1997 evidently only succeeded in pushing mortar into the joints to about 20mm deep, in common with most attempts to repoint historic ashlar. Typically after a short time, rain succeeded penetrating past the 'tip pointing' i.e. pointing to only the outer portion of a joint, to the continued detriment of the fabric.

Furthermore, the mortar beds above lintels and copes were found to be empty. Mortar was generally evident only at the end bearings and at the outer edge ('tip' pointing). This is considered to be conventional traditional practice used by stonemasons to ensure quick placing


7a


7b


8

Figure 7:
a) An empty mortar bed above door lintel probed by panel saw
b) Panel-saw used as 500mm long joint 'probe'.

Figure 8:
Location of Burns Monument, Alloway in SW Scotland.

and levelling of stone units during the construction process. Unfortunately now, these voided beds, some measuring up to 1100mm deep (Figure 7) create effective primary pathways for water ingress into the core.

Effects of increasing rainfall and extreme weather events were taken into account. Annual rainfall in South Ayrshire (Figure 8) now amounts to around 1500mm and HES climate change research charts around 21% overall increase in annual rainfall since 1961. The masonry throughout was saturated and without substantial action to arrest ongoing progressive decline, the monument's significance would be further harmed and its future sustainability placed at risk.

Previous attempts to address deterioration and water ingress appear to have been limited to re-pointing techniques. In this case, these conventional approaches are insufficient to address the underlying issue of open joints and wall core voids.

2.4 Other defects

The survey also exposed other defects contributing to water penetration, summarised as follows:

- Defective and poorly designed leadwork on the flat roof areas
- Rust expansion of ferrous dowels splitting masonry and forcing cracks open in masonry features, creating a risk to public safety from loose masonry in addition to water penetration
- Previous poorly executed replacement stones (indents) left large voids behind the new stones, creating additional water ingress pathways and reservoirs
- Fragile and evidently damaged original sectional cast iron drainage through the mass masonry construction, creating major water ingress potential
- Absence of any form of heating, leading to severe condensation at times, further compounding already damp interior masonry
- Undesirable and destructive previous interventions including cementitious patch repairs and acrylic masonry paint coatings, evidently trapping moisture within the masonry.

3. DEVELOPING A REPAIR STRATEGY

3.1 Repair options

Taking a systematic and investigative approach to survey and analysis, the team developed a good understanding of the defects and deleterious mechanisms at work. Always acutely aware of the national significance of the monument, our strategic approach to repair was initially broad in order to consider a range of repair options and their potential impact on the integrity of the building. Alternative approaches to traditional masonry repair, such as lead coverings, were considered but rejected. They were considered too technically complex and invasive to install, furthermore altering the aesthetic to the detriment of its architectural integrity.

3.2 Philosophical considerations to practical conservation

Original details such as water joints on cornices, cope joints concealed under column bases and falls to encourage drainage from flat surfaces show care was taken to ensure the structure shed water. The building has little evidence of alteration, and it is evidently only in recent decades that significant damage has occurred to internal surfaces; thus it is reasonable to infer the original design successfully shed water and kept the interior reasonably dry for many years. Our approach to repair settled on maintaining the original design integrity and philosophy by aiming to restore the structure's ability to shed water. This could be achieved by working with the technology of the existing building by fully filling voids and open joints in situ with liquid lime grout to replace lost mortars, and filling voids to robustly prevent water getting into the core of the structure.

Grouting is an irreversible intervention – a philosophical action cautioned by conservation charters and guidance such as BS7913: 2013 Guide to the conservation of historic buildings, and indeed the NTS's own Conservation Principles. Ultimately, however, lime grout is another form of mortar and thus compatible with a conventional approach to repair, although much care must be taken to ensure success, given grouting cannot be undone.

Existing grouting technology such as the clay-cup method advocated by the Scottish Lime Centre is impractically slow where mortar joint widths are typically 1–3mm wide. Textured masonry joint faces and surface tension of grout create a high resistance to flow. A new method of grout delivery was developed to overcome these issues (discussed at Section 4 below).

3.3 Comprehensive repair strategy

In addition to grouting, a comprehensive programme of fabric conservation repair was established, designed to further bolster the above-mentioned aim of ensuring the structure can robustly shed water and improve conditions to enable interstitial moisture already absorbed to escape over time. Proposals included the following key elements:

- Replacement of rusting iron dowel and cramps embedded in the structure with stainless steel
- Replacement of poorly executed stone indents and repair of damaged stone, all to best traditional masonry practice
- Renewal of leadwork over flat roofs, installed on a raised ventilated deck to allow moisture to escape from the mass masonry below

- Renewal of existing cast-iron rainwater drainage pipes in robust stainless steel
- Removal of cementitious coatings and modern acrylic paint to release trapped moisture and allow the structure to breathe
- Replacement of all services including the lightning conductor, power and lighting, all installed discreetly
- Installation of discreet conservation heating to gently drive out interstitial moisture
- Interstitial moisture monitoring by environment data logging probes inserted at various wall depths to record the gradual drying-out process over three years post-contract.

4. DEVELOPING AND IMPLEMENTING A NEW METHODOLOGY OF GROUTING ASHLAR

4.1 Development trials

Research and development prior to executing the work was essential to ensure the performance characteristics of the grout specification were thoroughly tested (application method and long-term performance). It was also essential for the craftspeople carrying out the work to develop their skills and understanding of the process required.

This phase was undertaken during 2017, part funded by a technical research grant from HES, in association with mortar specialist Douglas Johnston and the NTS in-house stonemasonry team at Culzean Castle nearby. A test rig stone wall structure was built at the workshop resembling the characteristics of the monument masonry (Figure 9), i.e. closely built hand-worked ashlar sandstone blocks with a high proportion of voided mortar joints and beds, leading to a rubble core. A generic grouting methodology was prepared to cover all stages of the process, ready to be refined and adapted as testing progressed.


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Figure 9: Test rig ashlar wall and rubble core for micro-grouting trials at Culzean Castle 2017.

Grout was injected into the test wall using the initial methodology, then dismantled to observe grout flow successfully filling all open mortar joints and voided core beyond. All issues arising were considered, solutions found and tested further in subsequent trials.

The developed generic methodology finally employed can be summarised as follows:

4.2 Joint preparation and cleaning

Pre-wetting around and below the work area, then raking out defective mortars from joints and beds, taking care to avoid damaging stone arrises. A selection of hand tools were used, including hacksaw blades, mortar rakes, panel saws (Figure 10) and, in certain controlled situations, variable speed cordless rotating disc cutters. Water flushing throughout the raking process helped formation of a cutting paste, making joint raking and sawing more effective.

4.3 Joint flushing and recording

Flushing and probing joints is vital to reveal the depth and width of voids and type of mortar/ stone at their deepest extent. Concurrent flushing with a low-pressure water jet helps to reveal if the mortar joint is connected to deeper core voids, depending on whether water flows back out of the same joint, or other joints lower down, or not at all. In this way, the operator quickly gains a ‘feel’ for the joint characteristics, essential to inform decision-making regarding choice of grout, which technique to use and also what volume of material is expected to be absorbed. This information was recorded to build an important record of the joint conditions and joint-to-joint approach to grout injection.


10

Figure 10: A selection of tools used for raking defective mortar out of ashlar mortar joints.

4.4 Preparation immediately pre-grouting

Thorough pre-wetting of all open joints and voids is essential to control suction so the grout will flow as deeply as possible. Cleanliness throughout all processes is also necessary to ensure grout flow is not hindered by debris. Clay strips applied to joint faces prevent grout leakage, and tell-tale tubes (such as drinking straws) inserted at regular intervals help to relieve air pressure and indicate the progress of joint filling.

4.5 Grout selection

Hydraulic lime grout is critical to ensure a mortar set occurs deep in the structure, and to ensure sufficient durability develops at the surface to endure local conditions. Grouts with a range of hydraulic (compressive) strengths between 2 to 5 N/mm^2 after 28 days (BS EN 998-2) were specified as appropriate to each application/ location: high durability and lower permeability on upper dome surfaces, parapets and cornices; and lower strength, higher permeability for lower-level, less exposed areas. Two varieties of lime grout were used:

Figure 11:
a) Micro-grouting capital top bed using fully fluid lime grout.
b) Pointing an open joint using restricted flow lime grout.

1. Highly fluid hydraulic lime grouts, modified with synthetic plasticisers and colloidal agents to balance a very high fluidity requirement with lowest possible water content (up to 86%). These grouts can flow many metres through a voided structure at the consistency of 'runny custard'. They contain very finely ground aggregate fillers (particle sizes not exceeding 0.01mm). Fluid grouting is injected from the bottom of the structure upwards in small stages, the grout flowing and settling by gravity.

2. Modified hydraulic lime grouts with thixotropic restricted flow characteristics for ease of placing in situations where only the outer mortar joints and beds need to be filled. Again, these grouts contain finely ground aggregates and very low water content (up to 46%). Restricted flow grouting is applied from the top down to avoid working over freshly placed grout.

4.6 Joint and void filling by grout injection

Micro-grouting relies on injection via a range of narrow nozzles from 12-gauge (2mm diameter) up to 4-gauge (6mm diameter), using nozzle lengths from 150mm down to 50mm long (Figure 11). Crucially, nozzle injection is effective by probing deep into the joint in order to fill voids and open joints from the back towards the surface. This overcomes the issue of high resistance to flow caused by closely opposing joint faces of textured stone as described at section 3 above. Once in the joint, highly fluid grouts flow freely down through the network of voids and fissures by gravity, with no additional pressure required. Similarly, restricted flow grouts can fully fill voided joints in the outer leaf from the back, forwards to the face by injecting grout in overlapping layers. Here, any residual injection pressure forces grout in all directions from within the joint and this was found to be very effective at penetrating the finest extents of joints or cracks.

4.7 Joint finishing and aftercare

After an initial hydraulic set, joint surfaces are finished by tamping and/or scraping the mortar surface in the normal way, and good practice lime aftercare procedures must be applied to allow curing and to start the carbonation process in common with all lime work.

5. POST-CONTRACT CONSERVATION WORK

5.1 Project team

Conservation repairs were carried out between March 2018 and June 2019. All grouting work was carried out by the NTS Culzean stonemasonry team, as they had gained the necessary understanding and skills required to implement the micro-grouting methodology. Access scaffolding, site infrastructure and all other conservation works were managed or undertaken directly by Glasgow-based main contractors Conservation Masonry Ltd with their specialist sub-contractors sourced from Ayrshire or Glasgow (Figure 12). The design team comprised Gleeds as project managers, Robert Potter and Partners as conservation architects, Armours for quantity surveying services and Laidlaw Associates Building Surveying as conservation clerk of works and stonemason technical support.

5.2 Conservation challenges

In practice, the grouting process on the monument was more challenging than experienced during the trial phase. Some of the issues were:

Joint raking: New methods were devised to effectively rake out cementitious ‘tip’ pointing found to overlay more traditional lime putty pointing. These mortars in combination were very difficult to remove. When probing or drilling proved that joints were still filled with mortar below the pointing, only cementitious surface mortar was removed and new restricted flow lime pointing mortar applied over the top. However, when voids were found below the surface, all pointing was removed and the grouting process applied.

Extreme weather conditions: Unusually hot weather between July and September 2018 caused the grouts to stiffen and set very rapidly. Above 20°C, freshly mixed grout working time reduces to around 5–10 minutes, rendering any micro-grouting impossible. In contrast to conventional mass masonry grouting, micro-grouting uses small volumes of grout injected over longer timescales. Extreme weather working practices helped to alleviate the problem to an extent, including frequent masonry dampening, cold storing all materials and equipment, devising cold water supplies, small-volume batch mixing and keeping grout delivery hoses short. Work priorities were frequently changed to ensure progress was made somewhere in order to mitigate delays.

Figure 12:
a) Monument conservation works in-progress, 2018.
b) Replacement lead flat roof coverings in-progress, 2019.

Aggregate settlement within the grout: Fine aggregate fillers tended to settle out of the highly fluid grout soon after mixing. Frequent stirring was necessary to keep the aggregate in suspension. Revised proportions of synthetic plasticiser and colloidal agents were tested to develop a new additive recipe which balanced the opposing properties of high fluidity and high colloid more successfully. Natural variations in free-lime content of some hydraulic lime binders affected fluidity too. Greater amounts of high calcium lime (free-lime) tend to reduce fluidity by ‘fattening’ the grout.

These issues, individually or in combination, frequently delayed progress. Close working and co-operation between all parties throughout the grouting programme overcame all issues and found practical solutions. Careful co-ordination of other craftspeople was also essential to avoid other conservation work inadvertently contaminating recently cleaned and flushed mortar joints, as an example.

6. LESSONS LEARNED

Pre-contract trials were essential to test and refine the micro-grouting equipment and methodology. This preparation work undoubtedly mitigated post-contract practical challenges and ultimately led to a successful outcome. Traditional grouting is known to be an effective but demanding technique and micro-grouting is no different. All aspects of grouting must be correctly managed by an experienced, dedicated and skilled team to achieve success.

Maintaining a good team-working, co-operative spirit between all parties involved at all levels is essential. Keeping up open dialogue and a can-do attitude throughout the project helped us find practical solutions to every problem.

Close attention to detail maintained throughout ensured potential issues were avoided and enabled appropriate reaction to unexpected discoveries. For example, chases (or ‘raggles’) cut for new lead flashings exposed voided mortar joints at the back of the chase. Rapid intervention allowed the lead-workers to be moved to another task while the grouting masons were redeployed to fully fill these exposed joints, before they were concealed by new lead. Constant vigilance and appropriate action taken at every opportunity increased confidence that all issues causing water ingress were being addressed.

Figure 13:
SPAB scholars and fellows witness a demonstration of micro-grouting on the monument, 2018.

Some flexibility in the programme allowed time to ensure works were carried out in the correct sequence and quality when competing influences such as budget constraints, weather and availability of skilled craftspeople could otherwise have adversely affected the quality of work.

Pro-active public engagement and outreach throughout the entire project horizon helped with fundraising and kept stakeholders and interested parties on-side, informed of developments and feeling involved in the project (Figure 13). Everyone involved, including apprentices, NTS volunteers, local councillors and Burns groups, was thrilled to see the superb carved details up close from the scaffolding.

CONCLUSIONS

The project addressed all conservation objectives and, critically, extensive grouting of the monument has been successfully carried out using new equipment developed specifically for injecting grout into ashlar masonry. The structure absorbed approximately 8000L of hydraulic lime grout, equal to about 3% of its volume.

At the time of writing, early signs show the drying-out process is beginning, with inevitable emergence of salt efflorescence on interior surfaces. Temporary limewash has been applied for sacrificial protection of the surface, and salt blooms are dry-brushed and removed each week.

This project demonstrates that, if approached and applied correctly by experienced, knowledgeable and dedicated people, micro-grouting can be effective in fully filling deep interstitial voids and open mortar joints in a way that has hitherto simply not been possible, preventing water ingress into traditional ashlar masonry. It is an exciting development with much potential to improve the future conservation of historic buildings.

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CONSERVATION AND REINSTATEMENT OF THE CALDER STONES:

BALANCING BUDGET, DESIGN AND CONSERVATION WHEN MOVING MEGALITHS

Hans Thompson[1], **Maxwell Malden**[2] and **Jennifer Dinsmore**[3]*

[1] Hans Thompson, Orbis Conservation.
h.thompson@orbisconservation.co.uk

[2] Maxwell Malden, Orbis Conservation.
m.malden@orbisconservation.co.uk

[3]* Jennifer Dinsmore, HTMD llp.
jennifer.dinsmore@htmdpartners.co.uk

* corresponding author

ABSTRACT

As part of the Reader Charity's NLHF-funded project to renovate the 18th century Calderstones Mansion House, the Calder Stones, six sandstone megaliths dating from the late Neolithic (4000–2100 BCE) which originally formed part of a passage tomb, were moved and reinstalled in a purpose-designed shelter by Orbis Conservation Ltd. As the stones are a Scheduled Ancient Monument such a move was unusual, but it was deemed necessary owing to the dilapidated and unstable nature of their home since the 1960s. The precise location of the burial mound from which they were originally taken has never been identified, and the stones had been moved at least three times in their known history, their function and use being reinterpreted on each occasion. The relocation of these megaliths offered a valuable opportunity to carry out conservation while also developing long-term solutions to secure their future. Integral to this was Orbis Conservation's design of the installation and mounting package, developed to hold the stones securely and protect them from damp ingress and also to be fully reversible. Working with the architects, the conservators contributed to the design of the shelter to consider how to protect the stones from water ingress and soluble salt damage while meeting the project's aims of improving accessibility for visitors. The paper discusses the challenges presented by the project, including how budget constraints led to a reduction in the shelter's specification and how the conservation measures were modified in response.

Keywords:
megaliths, remounting, Neolithic, monument, visitor engagement

1 INTRODUCTION

The six sandstone megaliths comprising the Neolithic monument known as the Calder Stones were moved in February 2019 to a newly designed shelter adjacent to the 18th century Calderstones Mansion House, which will become the home of The Reader, a Liverpool-based charity that uses reading aloud as a means of improving well-being and social cohesion. As the stones are a Scheduled Ancient Monument, such a move is unusual; this level of protection generally presumes that the monument should be preserved unchanged, with any works closely regulated by scheduled monument consent (http://www.legislation.gov.uk/ukpga/1979). However, the stones had already been moved at least three times in their history, with reconfiguration and reinterpretation of their function and purpose on each occasion. This latest move aimed to make the Calder Stones more accessible while providing an appropriate level of protection through the design of a shelter and conservation and mounting methods.

1.1 History

The Calder Stones are worked from the Triassic Chester Pebble Bed sequence, a coarse-textured sandstone which occurs in large blocks in the area (Howard et al. 2007). They originally formed part of a tomb, probably situated close to the junction of Menlove Avenue and Druid's Cross Road close to their present location (Nash 2013). They range in height from 122cm to 244cm and are incised with shallow pecked patterns including single and conjoined spirals, concentric circles, arcs, cup marks and foot markings (Forde-Johnston 1957). The spiral and arc markings link the Calder Stones with late Neolithic passage tombs in Ireland, notably Newgrange, and with Barclodiad y Gawres and Bryn Celli Ddu on Anglesey (Cowell 2008). These parallels indicate that the Calder Stones once formed a passage grave, probably dating from about 3000 BCE, and although the form of the tomb is unknown, comparisons with the Irish and Welsh examples suggest that it probably had a simple burial chamber with a passage leading to it (Cowell 2008). Tombs of this type were typically covered with circular mounds of earth, and later descriptions confirm that the Calder Stones tomb was treated in this way (Herdman 1896).

The incised foot marks on the Calder Stones have comparisons with similar depictions on Bronze Age monuments in Scotland, Scandinavia, Ireland and Brittany, indicating that the site continued to be used in this period (Forde-Johnston 1957). A recent photographic survey identified a dagger with similarities to Bronze Age sites in Galicia (Nash and Stanford 2010).

1.2 Destruction of the burial mound

The presence of medieval carvings, including a Maltese Cross, a church and a bird, indicate that the Calder Stones continued to be known and visited (Cowell 2008; Shennan 2015). By the late 18th century, according to contemporary accounts, when grand houses were being built in the area, the tumulus mound was exploited as a source of sand for mortar (Herdman 1896). Contemporary drawings and witness accounts give a sense of the stones scattered around the site, with some possibly moved elsewhere (Herdman 1896; Roberts 2010).

Figure 1:
Calder Stones from a postcard c.1905
(https://www.dailygrail.com/2013/03/the-calderstones-of-liverpool/).

By 1836, the six stones now comprising the Calder Stones were arranged in a circle opposite the entrance to Calderstones House (Herdman 1896). In 1845 the owner of the house, J. Need Walker, placed a wall around them and may have stood some of them upright (Roberts 2010) (Figure 1). They remained in this location until 1954, when they were lifted and taken to a city council depot (Forde-Johnston 1957).

1.3 New historical interest in the Calder Stones

The impetus for removal of the monument was both a growing interest in the stones and their markings, and a concern that they were at risk from weathering, vandalism and pollution. Forde-Johnston, who undertook the process of recording the monuments, describes them as ‘covered with a strong black patina’ (Forde-Johnston 1957).

In 1964 the stones were relocated to the Harthill Vestibule, a glasshouse in Calderstones Park that formed the entrance to Liverpool’s Indoor Botanic Collection, and were arranged in a circle (Figure 2). Since the closure of the glasshouses in the mid-1980s, access to the stones became limited to school groups and others by arrangement (Reppion 2012). In 2005 concern was raised that prolonged exposure to damp ingress had contributed to decay and vandalism had resulted in all of the stones being inscribed with graffiti (Nash and Stanford 2010). A 2012 blog post highlighted the condition of the Vestibule, which was missing areas of glazing, and the impact of this on the Calder Stones (Reppion 2012). In chronicling his correspondence with Liverpool City Council Reppion noted how budgetary pressures meant the works had to be carried out in phases, exposing the stones to ongoing risk (Reppion 2012).

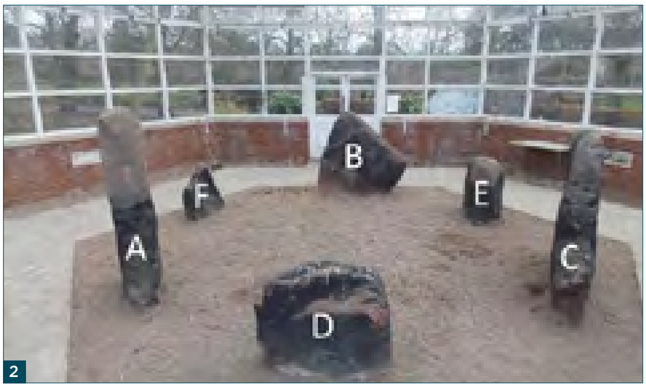

Figure 2:
The Calder Stones in the Harthill Vestibule. The identification of the stones follows the convention developed by Forde-Johnston.

2. RELOCATION PROJECT

In 2017, The Reader developed a project to relocate the Calder Stones to an area behind Calderstones Mansion. Designed to offer improved protection, interpretation and access to the monument, the relocation also provided the opportunity for necessary conservation work to be carried out. Understanding that any future display conditions would be crucial to the successful long-term preservation of the stones, the conservation project was started at the stage where the conservators were able to be involved during the design of a new shelter and the installation of the stones within it. Orbis Conservation's main objectives were to ensure that this new building offered a stable environment and sufficient protection from the elements, adequate access for future conservation and maintenance work, and a high level of security to protect against vandalism. As the stones are a Scheduled Ancient Monument, all methodologies had to be approved by Historic England.

2.1 CONDITION AND CONSERVATION CONSIDERATIONS

Due to the requirement that approximately one third of the stones' total height is found below ground level, the conservation treatment focused on eliminating the contact of the stones with any potential ground water.

Initial assessment indicated that areas of damage existed on each stone in a zone between ground level and approximately 20cm above. In this zone the black crust-like surface found on all the stones was significantly reduced, revealing the pink-coloured sandstone beneath and illustrating that deterioration of the surface was occurring. Below this were bands of white efflorescence from soluble salt activity and areas of friable substrate. It was felt that the damage cycle was caused by the direct contact of the stones with the ground, enabling movement of moisture and soluble salts.

In order to ensure a reduced risk of ground water contact with the stones, systems mitigating against it were designed at three crucial project interfaces: protection applied directly to the stone itself, protection offered during installation and protection provided by the new install location. The relocation of the Calder Stones was the only time at which this type of conservation work could take place. Once reburied again, they would not be able to be treated in this way without great expense and risk to the stones themselves. It was therefore decided that conservation treatment had to be executed during this phase of the stones' life. Furthermore, by carefully designing these protective measures more interventive conservation could be minimised at this stage but could, if necessary, be enacted in future.

3. DESIGN DEVELOPMENT OF THE NEW EXHIBITION SHELTER

Prior to the first meeting with the architects, concept sketches were provided. The proposal was for a large 'living roof' to be erected over the stones, with glass boxes enclosing them in two rows (Figure 3). This design was intended to echo the structure of the original burial chamber while physically protecting the stones in a way that enabled them to be viewed closely. However, the design was problematic from a conservation perspective. Firstly, the design involved moving the stones into a potentially less environmentally controlled area than where they presently were; the microclimate created could cause further degradation of the stones. Secondly, the addition of skylights would allow solar gain to destabilise the environment, particularly as there was no provision for ventilation or environmental control within the boxes. And, finally, the dimensions of the glass cases would limit future access for maintenance, monitoring and conservation, as there would be insufficient room between the glass walls and the stones.

Concerns over future access requirements led to the proposal of either a glass wall around the perimeter of the canopy or the replacement of the cases with sliding glass doors. Unfortunately, neither option was accepted due to budget restrictions, which had also led to the removal of the skylights from the design. The options were therefore to agree to the glass case design, or to remove the glass entirely.

The latter option introduced the risk of the stones being exposed to high winds and lateral rain in storm conditions. If the stones became wet they could again be vulnerable to soluble salt activity and freeze–thaw damage. In addition, this proposal would limit the choice of materials for this, or any future, conservation treatment; for instance, in selecting an appropriate consolidant for external use. For these reasons, ensuring that the Calder Stones had little chance of any contact with water became the main focus of successful 'treatment' in the case of the shelter.

One option was to increase the size of the canopy in order to decrease the possibility of driven rain reaching the stones. The glass end panels could stay, which formed the entrance to the neighbouring garden, ensuring security of the stones while also enabling them to be viewed from that angle. Although the architects wanted the canopy to be as small as possible, the notion of increasing the size was accepted and so began a negotiation

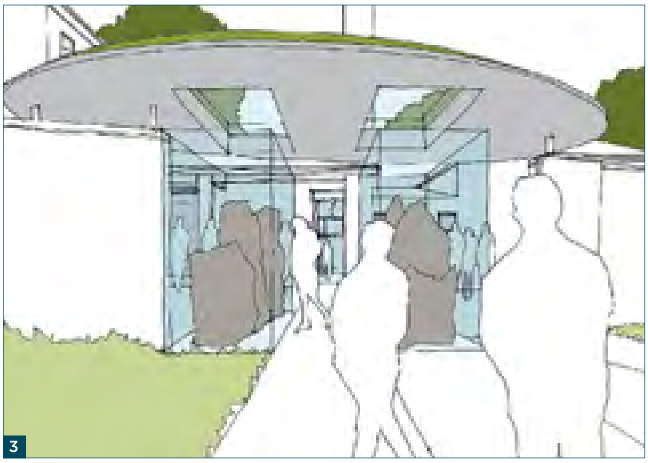

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Figure 3: Visual of architects' initial design.

on the aesthetics of the canopy versus an increase in protection for the stones. An effective compromise was eventually reached – the architects agreed to the installation of shutters around the perimeter of the canopy, which could be closed in the event of severe weather, and to the incorporation of an incline in the groundwork to encourage rainwater run-off away from the stones. In addition, the use of steel stanchions, set into the ground to discourage visitors from touching the stones, was also specified to the architects.

Another conservation consideration during the planning phase was how the installation of the stones would affect, and be affected by, the construction of the new shelter. The internal ceiling height was much less than the expected headroom necessary for the installation of the Calder Stones underneath; the dimensions of the stones had been unconfirmed at the time of planning, as they were still in the ground. Ultimately this meant it was necessary to phase the work so that the stones were installed prior to the canopy and main structure being built. This was not an ideal situation for the safety of the stones, and significant measures had to be designed to protect them while building work continued.

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4. CONSERVATION

4.1 Mounting

To provide protection from damp ingress, and to hold the stones securely and unobtrusively, the mounting system was carefully detailed and constructed. The principal water-impermeable layer, designed to fit snugly around the stones, was Jesmonite AC100, a solvent-free casting and laminating resin. In conjunction with glass fibre matting, the application of this resin provided a strong and snug-fitting jacket on each stone. Each jacket was applied in order to finish 50mm above ground level, but also to be visually unobtrusive, as it would be covered by a washed aggregate pebble bed placed around the stones.

In order for the resin to be easily removable, should this be required in future, a reversible barrier layer of aluminium foil adhered to the stone with Paraloid B72 (20% w/w in acetone) was applied over the entire buried area. The Jesmonite resin was then applied over this.

The Jesmonite jackets were also designed with a series of sacrificial raised walls of plaster of Paris, between 20mm and 25mm high, which would act as cutting zones where the blade from a powered cutting tool could penetrate without coming into contact with the stone, enabling the jacket to be easily and quickly removed. Finally, to assist future conservators, schematic diagrams showing the layer structure of the mount jackets, the sacrificial plaster walls and instructions for the removal of the mounts were etched into stainless steel plates and embedded into jackets on each stone (Figure 4). It is hoped that the conservator of the future will easily understand and unpack the materials, enabling safe removal of the mount from the stone, even if all documentation of the project no longer exists.

Figure 4:
Steel plate showing how to remove jacket, embedded in the mount jacket itself.

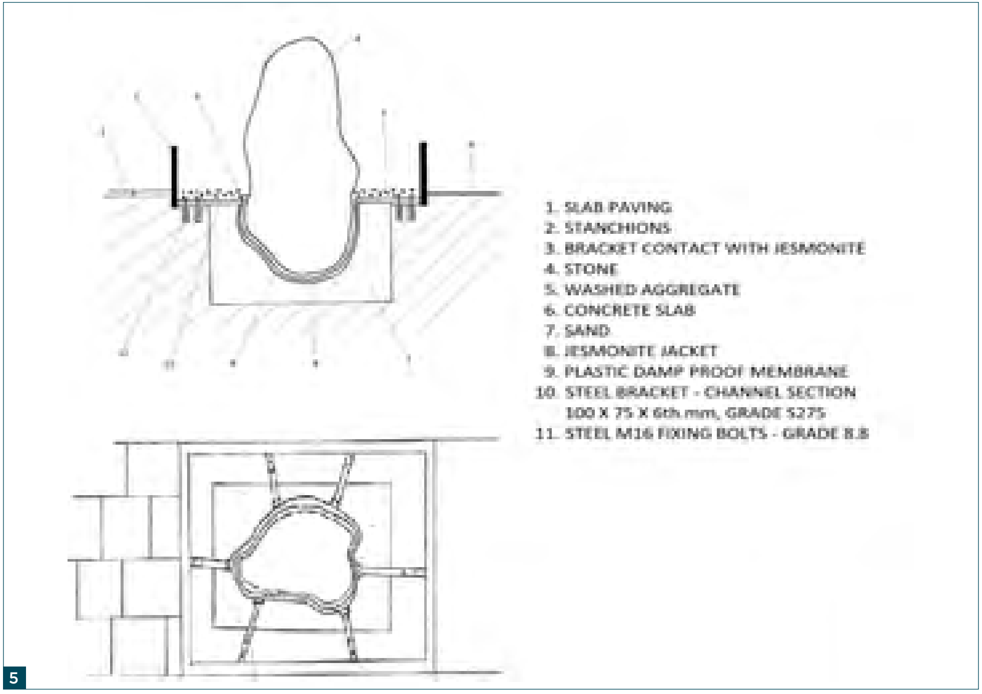

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Figure 5:
Mounting system.

4.2 Installation location

Significant thought was also given to the install location to mitigate against ground water ingress. A socket was individually designed for each stone to accommodate the area underground and was formed on site in reinforced concrete. Although this further reduced potential ground water contact with the stone, because the revised designs for the building now allowed for greater weathering risks than the initial concept, there was a danger that these trough-like sockets might end up retaining water. A drainage system was therefore designed, attached to a central channel, to allow any water to drain away rather than being held within the trough.

4.3 Installation

During installation, additional protection against moisture was provided by seating the already protected stones into a damp-proof membrane (DPM). This was pulled snugly around the Jesmonite jackets, and the void between the DPM and the walls of the concrete socket was filled with kiln-dried sand (Figure 5). To protect the stones from water ingress and impact damage during the last phases of construction, the entire area was draped in plastic and plywood cases were then built around each stone to protect against water.

4.4 Layout of the stones

A key priority in improving interpretation and understanding of the Calder Stones was to change the misleading circular configuration in which they had been shown since the 19th century. The Reader consulted with the Merseyside Archaeological Society, National Museums Liverpool, Historic England and others and decided to display them in two ranks of three, alluding to a passage within a Neolithic grave. As there is no firm evidence of the original layout, the stones are positioned so that visitors can see the most significant markings (G. Hawkins, Calderstones Development and Heritage Manager, pers. comm.) (Figure 6).

Figure 6: Installation of the Calder Stones.

5. CONCLUSIONS

As on the previous occasions when the Calder Stones were reordered, some conjecture about their arrangement has been inevitable. How well they are understood and valued will rely on interpretation, and The Reader plans a permanent exhibition that will place them in context and consider the significance of the markings as an early form of written language (G. Hawkins, Calderstones Development and Heritage Manager, pers. comm.)

This conservation project focused on mounting the stones in a way that would eradicate future damage from ground water ingress. Relocating the Calder Stones presented a rare opportunity to carry out the treatment which was given priority so as to avoid the difficult and potentially destructive process of disturbing the stones again. Balancing limited budget, the architects' brief, and conservation best practice necessitated constant dialogue and the establishment of a working hierarchy of need for the stones. This element of compromise ultimately benefited the entire project and the future of the stones; not only were the stones treated safely and thoroughly, but their new situation has vastly improved potential visitor engagement in accordance with the client's brief. When funds become available, further conservation work can easily be carried out in the new display space following the adaptations made by the conservation team to the architects' initial design.

ACKNOWLEDGEMENTS

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Kirsten Walsh, Sculpture Conservator, Orbis Conservation.

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CAPTURING GODS AND MONSTERS: PRESERVING VIKING SCULPTURE ON THE ISLE OF MAN

Christopher Weeks[1*] and **Allison Fox**[2]

[1*] Christopher Weeks, Collections Care and Conservation Manager, Manx National Heritage.
christopher.weeks@mnh.gov.im

[2] Allison Fox, Curator of Archaeology, Manx National Heritage.
allison.fox@mnh.gov.im

* corresponding author

ABSTRACT

One of the greatest legacies of Viking settlement on the Isle of Man is a corpus of over two hundred memorials and markers carved in local stone, the decoration of which ranges from simple incised crosses to complex interlace and depictions of Christian and Scandinavian themes. These ‘Manx crosses’ are displayed in the Manx Museum, dispersed across the island in churches, in churchyards and even fields. The island’s national heritage agency is engaged in a multidisciplinary project to improve access, interpretation and conservation. There are many stakeholders. All two hundred and eight of the crosses were recorded in 3D using a FARO Edge ScanArm blue light laser scanner. The comparison of one of the resulting point-cloud datasets and a corresponding point cloud taken from a historic plaster mould of the same cross is assessed to see whether the technique may be useful to gauge the rate of decay of the crosses in future.

Keywords:
Viking, stone, sculpture, scanning, Sketchfab, CloudCompare

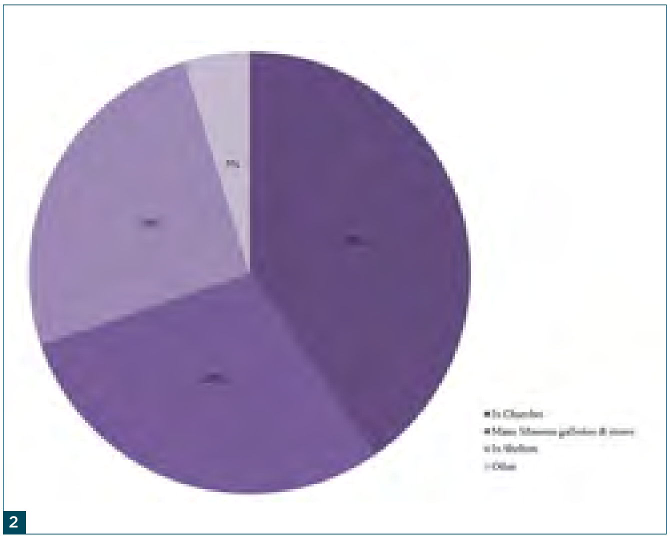

Figure 1: Thorwald's Cross, Kirk Andreas (MC128).

Figure 2: Distribution of the Manx Crosses.

1. INTRODUCTION

The Isle of Man is a 25-mile-long mountainous outcrop situated in the Irish Sea between England, Ireland, Wales and Scotland. Today it is a British Crown Dependency, but from the 11th to the 13th centuries it was part of a Viking kingdom stretching through the Western Isles to Orkney.

The subject of this paper is a corpus of early medieval stone sculpture on the island, and initiatives led by the Manx Museum and National Trust (Manx National Heritage, or MNH) to safeguard and preserve it. MNH is the island's national heritage agency and the legal guardian of the crosses, but it owns just a minority. This peculiarity severely complicates matters.

The Manx Crosses currently number two hundred and eight and consist of grave markers and memorials ranging in size from tiny sculpted fragments to 3-metre monoliths. They are carved in stone from the Manx Group of Ordovician stones (Ford 2001: 5), which are slate-like with a well-defined cleavage. Around a third of them are elaborately carved with Norse/Scandinavian ornament and scenes from Norse mythology, as well as Christian motifs. Their design is eclectic, fusing themes from Pictish and Anglo-Saxon sculpture, and Scandinavian metalwork (Wilson 2018). Many are inscribed with runes, ogham or uncials. No polychromy has been observed. The crosses have identifying numbers, referred to in this text in the format 'MC***' (Figure 1).

Stone sculpture in Scandinavia from this period is rare, and the Manx Crosses are therefore an internationally significant corpus and unique to the island (MNH 2015).

The crosses are scattered across the island in groups. A few are exposed directly to the weather but the great majority are housed inside churches or in purpose-built open shelters. Over the last century some have been rescued for display at the Manx Museum in Douglas. In addition, a considerable number have been found over the last seventy-five years during ground works and excavations; these are mainly held in the Manx Museum stores. Today, one third of the total are owned by the state, the remaining two thirds by the respective parishes (Figure 2).

The crosses in churches and shelters are retained to walls with metal brackets, or set in cement mortar in the floor or on pedestals. Those on display in the Manx Museum are mounted to modern museum standards.


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Figure 3: Maughold Cross Shelter (1906).

2. THE MANX CROSSES PROJECT

In 2014 MNH launched the Manx Crosses Project with the aim of widening access and improving knowledge and conservation of the crosses. Under this aegis the team is addressing several work streams. It is addressing gaps in knowledge through a desk-based assessment and is working to incorporate the data into the Historic Environment Record (via the Arches database). It is revisiting the legal deeds of guardianship and clarifying responsibilities. It has convened stakeholder meetings to gather opinion and formulate strategy and is working towards an overarching interpretation strategy.

An important part of the remit is a reassessment of the condition of the crosses and our strategic objectives, underpinned by risk analysis.

Risk analysis against ten agents of deterioration (Waller 1995), on the basis of normalised data, suggests the crosses at two locations are at particular risk. Maughold cross shelter (locally pronounced 'mackold'), with forty-six crosses, is the largest single group on display (Figure 3). The shelter is underperforming, and risks associated with elevated relative humidity are particularly salient. The group displayed inside the


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Figure 4: Manx Crosses at St Michael and All Angels, Kirk Michael.


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Figure 5:
A typical Manx Group stone, Port Mooar, Isle of Man (scale 1.5m).

Figure 6:
MC97 at Maughold – detail showing losses at exposed foliations.

church at Kirk Michael are amongst the most elaborate and are regularly handled by visitors (Figure 4). The risk of mechanical damage here is prominent.

Separately, the condition of all the crosses was assessed and a score assigned to each against a consistent range of damage categories. Scores ranged from 1 to 10 against the following manifestations of damage: gross de-lamination, cracks, flaking/friable, salts, mechanical damage, corrosion of fixings, crayon etc., erosion, algae, lichen/other flora, bird/bat droppings, cement pointing, insects, cement stains, grease. The survey helped the team arrive at general conclusions, characterise the kinds of decay causing the greatest concern and establish which crosses are most vulnerable to the risks they face.

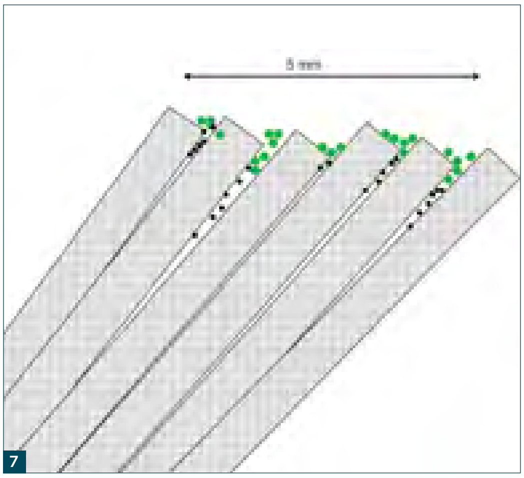
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Figure 7:
Possible role of algae and fungi (smaller dots) in the decay of Manx Series stones.

Of particular concern is gradual surface loss. In many cases the sculptural relief and inscriptions are very shallow. A feature of the Manx Group stones is foliations angled to the cleavage plane caused by repeated folding (Figure 5). The exposed foliation edges are vulnerable to edge-loss (Figure 6).

Prevalent bio-films in the shelters at Maughold and Lonan may be contributing to these losses, but this has not been experimentally confirmed (Figure 7).

In 2017 a combination of risk analysis and detailed condition survey was used to draft conservation recommendations. Meanwhile, a vocal constituency is convinced the crosses are decaying at an alarming rate and there have even been public calls for the entire corpus to be removed by MNH to safe storage and/or display in a new museum. Gauging the rate of decay is critical to addressing this concern.


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Figure 8:
Osruth's Cross (MC107) in the porch, St John's.

Figure 9:
Osruth's Cross (MC107, 1.15 x 0.32 x 0.15 metres), St John's, detail.

3. WORKING WITH STAKEHOLDERS: CASE STUDY

The Royal Chapel of St John the Baptist at St John's is situated opposite Tynwald Hill, site of the world's oldest continuous parliament. Every summer, crowds gather here for an open-air sitting of the legislative body, Tynwald.

In the porch of the church stands Osruth's Cross (MC107) (Figure 8). The cross is decorated on the front and side, where a runic inscription reads 'but Asruthr carved these runes'. Of all the crosses in the corpus, this one gives the greatest cause for concern. It is set directly into the concrete floor (Figure 9). The stone is fragile, with obvious voids underlying the carved surface. It has been broken and very poorly repaired with Portland cement.

During the summer the church is heavily visited, and on Tynwald Day it is crowded. A recent inspection revealed the cross to be loose in its footing. As legal guardians, MNH would like to substitute a replica or display the cross inside the church.

The church building is a British Crown property and not under the jurisdiction of the Church of England Diocese of Sodor and Man. Its maintenance is the responsibility of the Isle of Man Government Department of Infrastructure. Separately, the parliamentary Tynwald Arrangements Committee exists to ensure the church is fit for the annual visit of the legislature and Crown representatives. The vicar and congregation, meanwhile, have little say over the ordering of the church. The cross itself is Crown property and, even though one might assume that would give MNH freedom to act, in practice each constituency must be catered to respectfully. Given the risk to the cross, effective recording is an essential precursor to any other action we may take.

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Figure 10: Dr James Miles and Gianna Gandossi from Archaeovision at Andreas Church.

4. GAUGING THE RATE OF DECAY

In order to identify the rate of decay in the future, a means of recording details accurately down to one tenth of a millimetre is needed.

The historic photographic record is very limited. Sixteen gypsum plaster moulds made around 1900 survive. Cast copies of half the collection made at that time also survive, but all have been over-painted numerous times. 1:1 scale drawings made in the late 19th century of one hundred of the crosses emphasise inscriptions and iconography, and are unreliable and imprecise records.

MNH had previously used reflectance transformation imaging (RTI) and considered whether it could be used to record surface changes in the Manx Crosses. RTI has the advantages of being straightforward and cheap, and does not require specialist knowledge or equipment. However, although the results can reveal detail not otherwise visible, metric comparison of successive RTIs of the same object is not possible. A number of very accurate techniques used for characterising stress and deformation in objects have the same limitation (Dulieu-Barton et al. 2005).

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Figure 11: Scanning at St Adamnan's Church, Lonan.

5. DIGITAL RECORDING

Techniques of 3D imaging have been transformed by improved computing power and their utility in a wide variety of industries. The latest generation of laser scanners use blue lasers in place of red. The shorter wavelength of blue light contributes to greatly improved accuracy and overcomes many of the difficulties previously encountered with capturing dark, shiny surfaces.

Manx National Heritage commissioned Lancaster University's Digital Humanities Hub to capture every one of the Manx Crosses in 3D. Archival standards were central to the project aims from the outset, and the file formats were chosen to afford the maximum conceivable future utility. Dedicated space on the Isle of Man Government server was budgeted for from inception. Specialist subcontractor Archaeovision (archaeovision.eu) undertook the work over three weeks during August 2018 (Figure 10). The scanner used, the FARO Edge ScanArm blue laser scanner, is accurate to +/- 35μm (under one tenth of a millimetre) (FARO 2017).

Manx National Heritage arranged access to the sites and churches, transporting the equipment across rough ground in a 4 x 4 truck, erecting access towers where required and in one instance temporarily removing a cross from the wall for scanning. The FARO equipment is robust and handled uneven ground and the aggressive Isle of Man weather very well. The hardware and software functioned continually for three weeks without a hitch. However, the campaign was not without its technical difficulties.

5.1 Access difficulties

Arranging access to churches, while avoiding funerals, marriages and Sunday services and remaining within the three-week window set aside by the contractor, was not straightforward. The Manx weather, often very wet, meant open-air work had to be fitted in opportunistically. Access to private land and across fields was sometimes physically challenging. The largest cross on the island, MC100, is on a public verge next to a road junction and opposite a school.

The crosses in shelters needed to be cleaned by the MNH conservator to remove algal film and bird droppings before they were scanned (Figure 12).

5.2 Size of each scan

The result of 3D scanning is invariably a point cloud. At +/-35μm these were comprised of anything up to several billion points. The data was captured directly into Rhino 3D modelling software and the size of the datasets put the laptop under very considerable strain, especially during saving and post-processing.

Figure 12: Removal of algae from MC76, Lonan cross shelter.

Figure 13: Aligning point clouds of MC42 and its 1905 plaster mould.

6. DATA USAGE

6.1 Publication of 3D images

The most obvious output of the scanning is the online publication of small, photo-textured mesh versions of each cross scan, provided by Archaeovision. This resource is offered simultaneously through the MNH digital collections portal, iMuseum, and 3D sharing platform Sketchfab. With our IT partners Gooii and Knowledge Integration, we have built a seamless bridge between iMuseum, Sketchfab and object data held on our collections management database (MimsyXG) using Knowledge Integration's Collections Information Integration Middleware (CIIM).

The laser scanner used does not capture colour, so the textures for the small, published models were created from photographs.

6.2 Comparisons using CloudCompare

As mentioned above, historic moulds of a small number of the crosses survive in the national collection. Using the open-source 3D point-cloud processing and editing software CloudCompare, accurate scans were compared at full resolution of Blackman's Cross from Maughold Cross Shelter (MC42) with one such mould, taken from it in 1905. The software is designed to compute the differences between two scans of the same object. Here the differences could equate to material lost in the last one hundred years through decay or mechanical damage.

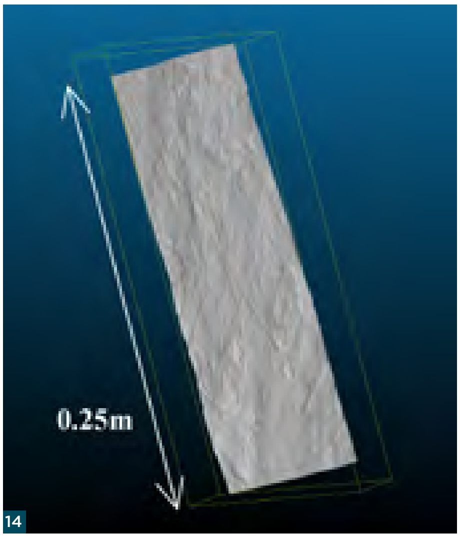

Figure 14: Part of the aligned clouds of MC42 and its 1905 plaster mould.

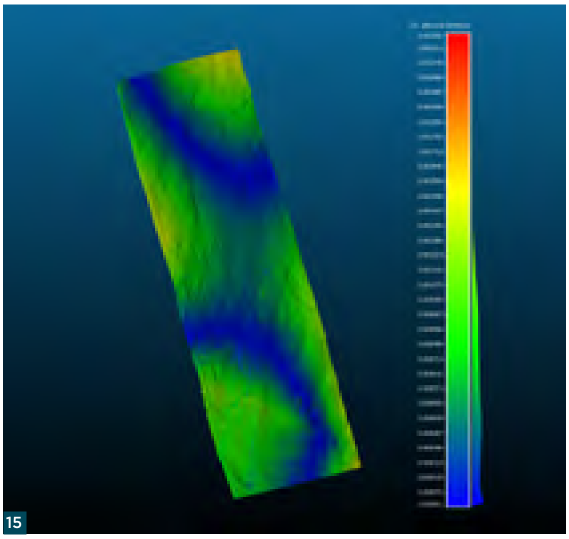

Figure 15: The metric distances between the two clouds, colour-coded.

7. DISCUSSION

Figure 14 and Figure 15 show initial results of the comparison of MC42 and its plaster mould. The scalar field representing the distances between the two scans is colourised according to the scale on the right. The blue areas are very closely matched, the green slightly less so. These are preliminary results, but the technique shows promise. The registration of the two point clouds was quite straightforward and the proximity of the reference and comparison clouds is close. However, the scalar field is not easy to interpret, and small variations (blue to green) might be the result of noise. Careful surface preparation of the moulds before scanning would be desirable in future, because in this instance shellac (identified by solubility tests in alcohol and by UV fluorescence) had been used as a sealant to aid the release of casts from the mould. While the remains of shellac on the mould in question were very slight, they may well have contributed noise to the comparison. More work is needed to characterise residual coatings on the mould surface. It is also possible that tension induced by expansion of the plaster during crystallisation may have altered its shape (tension in plaster artefacts is released if they break, which complicates subsequent reassembly). When in due course portions of vulnerable crosses are re-scanned for comparison, care will have to be taken to clean the surface of dust, bird droppings and bio films. In this case there are no obvious gross differences showing, which suggests on a superficial reading that there are none.

Meanwhile, the publication of the small, textured models is showcasing our work and is broadening access to the crosses worldwide.

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CHALLENGES OF COMPLEX SALT CONTAMINATION:

ST ANDREWS CATHEDRAL MUSEUM, UK

Sarah Hamilton[1*], **Callum Graham**[2], **Christa Gerdwilker**[3] and **Rob Thomson**[4]

[1*] Sarah Hamilton, Conservation Scientist, Historic Environment Scotland, UK. sarah.hamilton@hes.scot

[2] Callum Graham, Laboratory Scientist, Historic Environment Scotland, UK. callum.graham@hes.scot

[3] Christa Gerdwilker, Stone Conservator, Historic Environment Scotland, UK. christa.gerdwilker@hes.scot

[4] Rob Thomson, Freelance Preventive Conservator, UK. rob@rob-thomson.co.uk

* corresponding author

ABSTRACT

St Andrews Cathedral Museum houses a highly significant collection of early Christian and medieval carved stones. Dating from the late 19th century, the buildings are restored from remnants of the Augustinian Priory. However, the semi-subterranean structures now suffer from severe salt contamination, which is having a detrimental effect on the displays. Multidisciplinary investigations have identified an unexpectedly large and complex range of salts and a poorly controlled environment. The salts identified are dominated by sodium sulphates and sodium carbonates, including several which are potentially highly damaging. A number of these salts are known to form in the presence of cement. A hypothesis for the release of cement components and their likely reaction with an episode of lime putty repointing is presented. The challenges of addressing the long-term stability of the museum and its collection are also outlined.

Keywords:
salt analysis, conservation, environmental monitoring, salt mixtures, 'cement' salts

1. INTRODUCTION

Crystallisation of soluble salt is one of the major decay mechanisms affecting stone monuments (Steiger et al. 2014). Salt growth within stone pores exerts pressure on the pore walls, leading to deterioration if these pressures exceed the internal strength of the stone. Repeated cycles of crystallisation and dissolution resulting from fluctuating moisture levels can be especially damaging (Watt and Colston 2000). Environmental control can reduce the occurrence of these damaging cycles in an internal environment (Doehne 2002). However, predicting appropriate conditions for this control is more difficult when complex salt mixtures are present (Steiger and Heritage 2012).

St Andrews Cathedral Museum is situated in the grounds of the 12th century cathedral, on the east coast of Scotland. The museum houses 'an outstandingly important collection of early Christian and medieval carved stones' (Historic Environment Scotland 2017: 9). The collection is presented in three rooms within two adjoining buildings (Figures 1–3), referred to as the Undercroft (UC), Dunino (DU) and the Warming House (WH). Situated to the south-east of the Cloister, the buildings are formed from 13th-15th century remains of the Augustinian Priory. In the 1890s the 3rd Marquis of Bute undertook major reconstructions in this area, largely rebuilding UC and WH, following the original forms but using red sandstone external masonry to distinguish from the original buff sandstone (Historic Environment Scotland 2017).

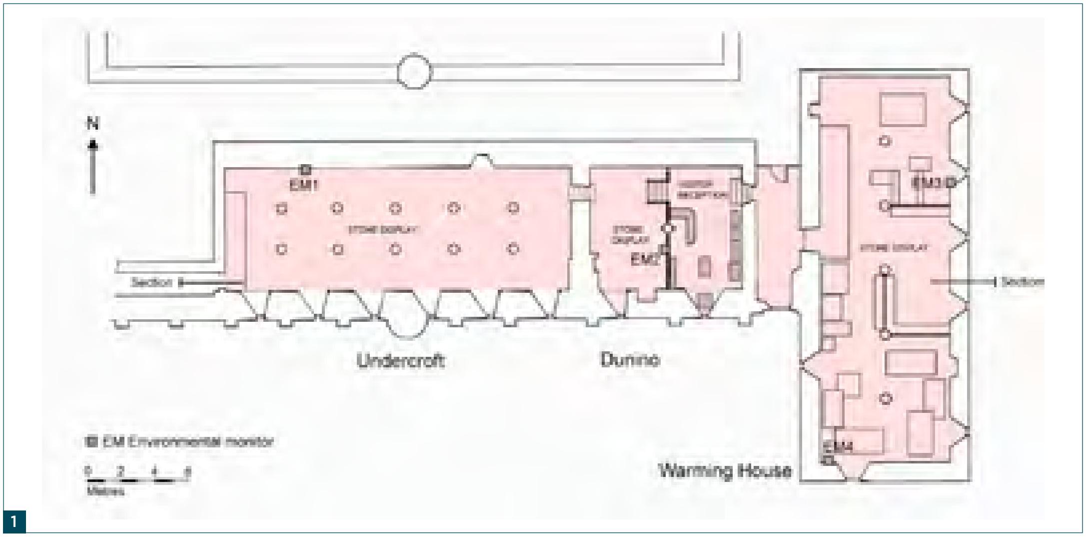

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Figure 1:
Floor plan of St Andrews Cathedral Museum.

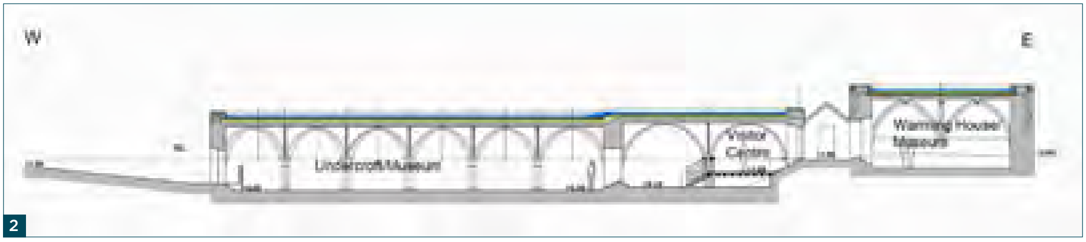

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Figure 2:
Cross section through St Andrews Cathedral Museum.

Extensive salt deposits have been an issue in all rooms since the 1990s, severely affecting the appearance of the internal masonry and leading to contamination of the collection by falling salts or from direct contact with salt-laden masonry. Stones are routinely removed for conservation, but an overall deterioration in condition has been observed over the past 20–25 years, resulting in the need for further consolidation treatment within this period. This is of particular concern in UC, where a greater proportion of stones are displayed in direct contact with the walls.

The current phase of investigation aimed to identify the salts affecting the museum to determine the most appropriate environmental conditions for long-term stability of the collection and buildings, while informing planned upgrades to heating and lighting.


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**Figure 3:
Stone displays in the Undercroft, St Andrews Cathedral Museum, © Crown Copyright HES.**

2. METHODOLOGY

Since November 2016, the internal environment has been monitored using four Tinytag Ultra2 data loggers, recording temperature and relative humidity (RH) at 30-minute intervals (Figure 1).

Between August and December 2017, 125 salt efflorescence samples were collected from the walls of the three museum rooms. The sampling strategy aimed to identify potential variations in salt species in relation to substrate (Victorian red sandstone, earlier buff sandstone lower courses and mortars), height (visible salt ‘tide marks’ and external ground levels), aspect and proximity to heat sources, ventilation or doorways, where a more varied microclimate might be expected. Sampling was limited in certain areas due to strong surface adherence of some deposits, and access restrictions due to display positioning.

In December 2018, eleven additional samples of efflorescence or surface debris were gathered from carved stones on display to determine if the range of salts specifically affecting the collection could be ascertained. All samples were prepared as acetone slurries and analysed by X-ray diffraction using a Thermo Electron ARL X’TRA XRD with a copper X-ray tube. Power settings were 45mA 44kV, scanning from 5°–70° at 1° per minute.

Since January 2019, two Brinno TLC200 Pro HDR time-lapse cameras have been employed in UC to monitor active salt crystallisation and dissolution.

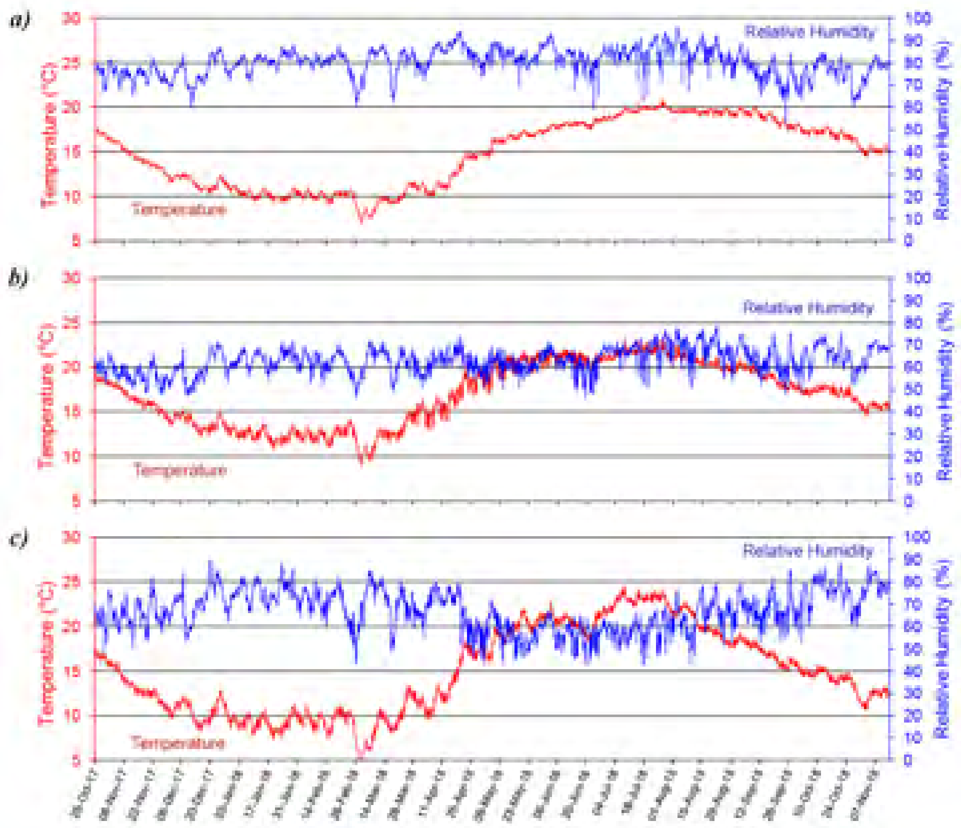

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Figure 4: Variations in temperature and relative humidity, 24 Oct 2017–13 Nov 2018, a) Undercroft, b) Dunino, c) Warming House (SW).

3. RESULTS

3.1 Environmental monitoring

Environmental monitoring revealed contrasting but also poorly controlled conditions across all rooms (Figure 4 and Table 1). Figure 4a illustrates the frequent RH fluctuations observed in UC between extremes of 53%–96%, with a mean value of 80%. A minimum RH of 45% was recorded in the preceding year. DU and WH (Figures 4b and 4c) show similarly frequent and extreme variations, although mean RH is typically a lower 63%–67%. In all rooms, these variations occur diurnally as well as throughout the year.

Temperatures in UC and WH show seasonal fluctuations from minimum 4.6°C–7.2°C, to maximum 21.1°C–27.1°C. DU is, on average, several degrees warmer than the adjacent UC, owing to its proximity to the visitor centre. Data gathered from the preceding year (November 2016–October 2017) shows broadly similar patterns of temperature and RH.

Location	Measurement	Mean	Minimum	Maximum	Range
Undercroft	Temperature (°C)	14.9	7.2	21.1	13.9
	Relative Humidity (%)	80	53	96	43
Dunino	Temperature (°C)	17.0	9.0	23.3	14.3
	Relative Humidity (%)	63	45	78	33
Warming House NE	Temperature (°C)	15.3	5.0	27.1	22.1
	Relative Humidity (%)	66	40	91	51
Warming House SW	Temperature (°C)	15.0	4.6	24.6	20.0
	Relative Humidity (%)	67	43	90	47

Table 1: Summary of yearly environmental monitoring data (24 Oct 2017–13 Nov 2018).

Common name	Chemical formula	Chemical name
Thenardite	$NaSO_4$	Sodium sulphate
Thermonatrite	$Na_2CO_3.H_2O$	Sodium carbonate hydrate
Trona	$Na_3H(CO_3)_2.2H_2O$	Sodium hydrogen carbonate dihydrate
Burkeite	$Na_6(CO_3)(SO_4)_2$	Sodium carbonate sulphate
Aphthitalite	$K_3Na(SO_4)_2$	Potassium sodium sulphate
Gaylussite	$Na_2Ca(CO_3)_2$	Sodium calcium carbonate
Halite	NaCl	Sodium chloride
Gypsum	$CaSO_{4.}2H_2O$	Calcium sulphate dihydrate

Table 2: Salts identified across all rooms.

3.2 Salt analysis

Analysis revealed an unexpectedly large and complex range of salts (Table 2). These are dominated by sodium sulphate and sodium carbonates, with the notable presence of calcium, potassium and chloride salts.

Figure 5 illustrates the variation in distribution of these salts by room. UC was found to contain the narrowest range of the identified salts, while WH exhibited the most complex mixture. Thenardite was the most commonly occurring salt found in all rooms. Thermonatrite and gypsum were found in similar proportions in each room. Trona was more widespread in DU and WH, but with notable absences in specific areas of UC. Aphthitalite and halite were found at limited locations in DU and a greater number in WH (mostly as minor-trace quantities) but were not detected in UC. Burkeite is typically found in association with thenardite.

Salts were plotted on photographic elevations of the museum walls (Figure 6) to analyse their distribution, but significantly, no clear patterns could be determined in relation to any of the factors outlined in 2. However, trona, thermonatrite, thenardite, aphthitalite and burkeite belong to a group of highly soluble salts known to form in the presence of cement (Matović et al. 2010, Steiger et al. 2014, Siedel 2018).

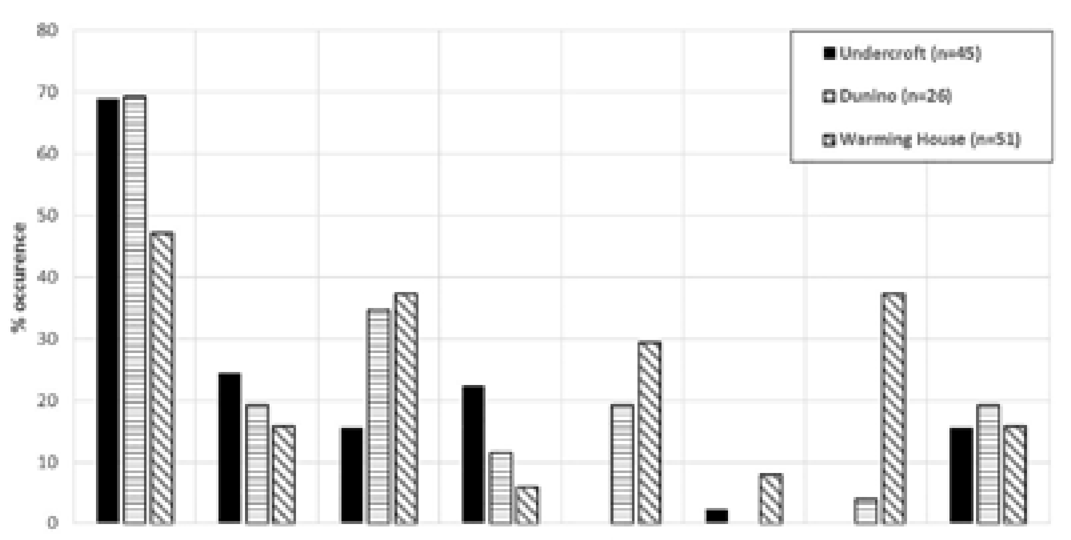

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Figure 5: Distribution of identified salts by museum room (% breakdown by presence in sample only).

Efflorescence and surface debris samples from stone displays (UC n=10, WH n=1) were dominated by thenardite and gypsum, although thermonatrite, trona, aphthitalite and burkeite were also detected.

3.3 Time-lapse video

In UC, time-lapse footage demonstrated an active system. Rapid growth and dissolution of salt efflorescence was observed across entire masonry units in multiple cycles during periods of only several days.

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Figure 6: Salt analysis results for Dunino, N wall, October 2017 (Th=thenardite, Tn=thermonatrite, Tr=trona, Bk=burkeite, Gy=gypsum).

4. DISCUSSION

4.1 Cement-related salts

4.1.1. Brief history of salt contamination and previous interventions

Staff report that salt contamination began after internal repointing with lime putty in the early 1990s. While the detailed construction history of the buildings prior to entering State care in 1948 is poorly understood, it is known that cement-based materials may be present. The flat museum roofs are formed from concrete slabs. Cement is suspected in the rough-racking forming a coping of recreated masonry on top of the remnants of the ruined priory structures. It may also be present in earlier phases of repointing in the Victorian masonry walls. Sea sand, known to be used in the 1990s lime putty mix, may not have been washed. The identification of 'cement' salts and observations of a relatively rapid onset of salt contamination led to the following working hypothesis.

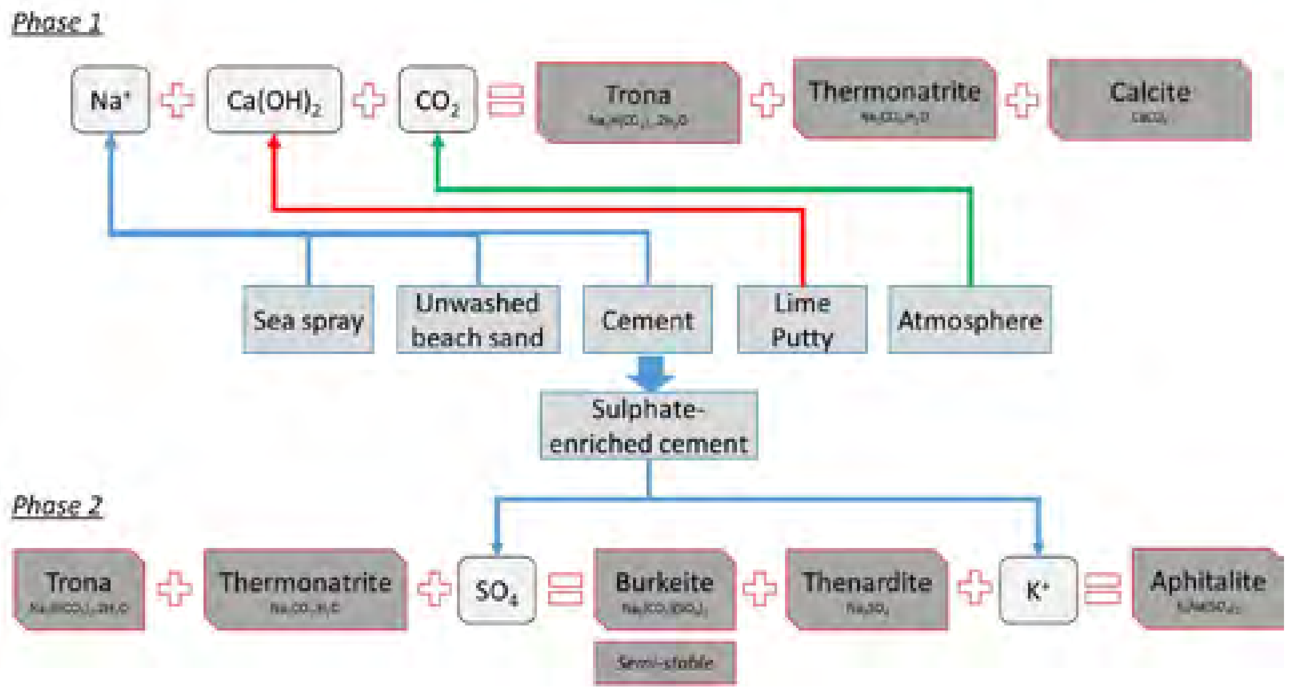
4.1.2 Working hypothesis for salt formation

Trona, thermonatrite, thenardite, aphthitalite and burkeite are highly soluble salts known to form in the presence of alkaline materials such as Portland cement (Matović et al. 2010, Steiger et al. 2014, Siedel 2018). Charola and Lewin (1979) report that trona and aphthitalite are characteristic efflorescences resulting from water percolation through cement. Analysis of relevant literature (e.g. Figg et al. 1976, Charola and Lewin 1979, Matović et al. 2010) and the specific situation at St Andrews led to the proposal for a two-phase salt formation (Figure 7).

Phase one: trona and thermonatrite are thought to form by reaction between:

a) Sodium ions (Na+), leached from cement, and/or sea salt in masonry, and/or use of unwashed beach sand in mortar.

Figure 7: Illustrative flow diagram for the potential two-phase formation of salts identified in St Andrews Cathedral Museum.



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b) Calcium hydroxide ($Ca(OH)_2$), from uncarbonated (fresh) lime putty (see 4.1.1).

c) Atmospheric carbon dioxide (CO_2).

Phase two: thenardite, burkeite and aphthitalite are considered to form as follows:

a) Thenardite is formed from reaction of sulphates leached from cement with sodium carbonates (trona and thermonatrite), or directly with sodium ions. When sodium carbonates are formed through leaching of cement, the remaining cement is relatively enriched with sulphates (Matović et al. 2010).

b) Burkeite is considered as a semi-stable or intermediate phase during reaction of sodium carbonates with sulphate ions (SO_4^-) to form thenardite. It is typically observed in association with thenardite, and its presence/absence may be controlled by variations in environmental conditions and the complex chemistry of the site.

c) Matović et al. (2010) observed two possible modes of formation of aphthitalite, involving reaction of either sodium carbonate or sodium sulphate with potassium and sulphate ions released from cement. Aphthitalite was commonly observed in association with sodium carbonates (thermonatrite and trona) and sodium sulphates (thenardite), also noted at St Andrews.

If the presence of cement is indeed a key source in formation of these salts, this source might continue to replenish, and thus physical removal of salts may be of limited benefit. The complex nature of the buildings also provides several potential pathways for salt mobilisation, from rising damp, groundwater penetration through semi-subterranean walls, and water penetration through deteriorating wallheads and roofs.

4.2 Challenges of progressing investigations at St Andrews Cathedral Museum

Whilst this situation may not be unique, the investigations have faced a number of challenges relating primarily to the complex nature of the salts identified, the variability of the environmental conditions and the complex construction history of the building.

4.2.1 Limitations of non-destructive investigations

Sampling of surface efflorescence offers a non-destructive and efficient method for the extensive sampling required. This gives only a snapshot of salts crystallising under surface environmental conditions at the time of sampling and the potential for damage from subflorescence of these same salts (Siedel 2018). Destructive investigations are required to gain an understanding of all potential salts in the system (Siedel et al. 2014). However, the possibility of undertaking more invasive investigations is limited by the Scheduled Monument status of the buildings, where the presumption is to undertake the minimum work necessary to counter deterioration (Historic Environment Scotland 2015).

4.2.2 Potential for multiple salt sources

In addition to the cement/lime putty pathway presented in 4.1, the carved stones are composed of varying lithologies, known to have been buried in the cathedral complex. Potential exists for thenardite and an even wider range of salts than currently identified to be sourced directly from the stones.

4.2.3 Modelling behaviour of salts

At the outset, it was hoped that salt identification would ultimately allow modelling of salt phase transformations, enabling determination of environmental conditions to minimise damage. While the equilibrium RH of individual salts are well documented, the presence of other salts in a mixture can significantly affect the equilibrium RH of the individual salts (Price and Brimblecombe 1994). ECOS/RUNSALT (Price 2000; Bionda 2005) is a thermodynamic model capable of predicting the crystallisation behaviour of salt mixtures as a function of temperature and RH (Godts et al. 2012), and the only software generally available to conservation scientists. However, it is not capable of modelling mixed salt solutions containing alkali carbonates (Steiger and Heritage 2012). Sampling from the collection, undertaken in the hope of narrowing the range of salts affecting these critical items, also identified a similarly wide range. These issues present difficulties in accurately determining a suitable T/RH range within which the salts are stable.

4.2.4 Contrasting conditions in museum rooms

The fluctuating environmental conditions identified raise concerns over the frequency of crystallisation and dissolution cycles generated (see 3.1 and 3.3), as well as the risk of periodic condensation on colder masonry surfaces in UC and WH. Conditions are poorly controlled by uncalibrated extraction fans, inappropriately scheduled storage heaters and draughts from doors and windows. While these aspects could be addressed individually, they are scheduled as part of a wider upgrade to the heating, lighting and ventilation systems, for which a target set of conditions is sought. Each room will also require its own solution due to the contrasting microenvironments resulting from the semi-subterranean nature of UC and DU, the visitor centre influence on DU and the contrasting above-ground position and greater levels of solar gain in WH.

Thenardite, thermonatrite, gypsum, trona and burkeite are present in all rooms, with RH=55–83% at the times of sampling. This implies these salts were in crystalline form despite the broad RH range. However, RH is noted to vary considerably in each room, even within the space of a few days. Observations on the presence/absence of particular salts in specific areas of each room (see 3.2) also point to the presence of localised microclimates, suggesting limited air circulation.

The need to understand the range of salts present and controls on their distribution led to a sampling exercise of a scale that was time- and resource-heavy, as it became clear that the issue went beyond simple diagnosis and remediation. This was, however, justified by the range of salts identified and to establish that, in fact, no obvious control patterns could be identified (see 3.2). Results also suggested that localised microclimates exist within each room. The results have not, however, permitted targeting of appropriate environmental controls to limit salt damage. This must be achieved on the basis of sound evidence, as Sawdy and Price (2005) warn of the risk of increased damage by applying environmental controls incorrectly.

5. CONCLUSIONS

A complex range of cement-related salts have been identified in St Andrews Cathedral Museum. The presence of carbonate salts precludes the use of modelling software to predict appropriate environmental controls. Fluctuating and poorly controlled environmental conditions have been identified, with contrasting climates and localised microclimates observed.

As it currently seems unlikely that an appropriate RH range to control the damaging effects of salts can be ascertained, alternative steps may be required to minimise further risk to the collection. It is hoped the following proposed steps will provide further evidence for an effective way forward:

Correlation of environmental monitoring data with time-lapse footage. UC environmental monitor was moved adjacent to a time-lapse camera to assess the localised microclimate (March 2019), enabling a more detailed study of controls on the observed changes. This will allow further insight to the conditions influencing the dissolution and recrystallisation cycles, and whether this a localised phenomenon.

Cycling of salt samples through varying T/RH regimes using an environmental chamber. Observations of salt behaviour in relation to these changes will develop understanding of the environmental conditions controlling crystallisation of these complex salt mixtures.

Sampling of (a) cement and concrete from the roof and/or rough racking and sampling of (b) mortar drillings for ion extraction across all rooms. This could confirm if cement is the source of the salts identified, and establish the presence of any other ions that may result in salts not seen under the present conditions. (a) is achievable due to planned roof renovations, but (b) requires Scheduled Monument Consent, requiring a strong case for benefits to the care of the structure and its contents.

Analysis of poultice-extracted salts and ion extraction from drill profiles on architectural fragments from the museum collection. This may help us to broaden understanding of those salts specifically affecting the collection.

Stabilisation of the existing environment to reduce fluctuations in temperature and RH, and continued observation and sampling to understand the impact of this change.

The time and resources required to address this future work also need to be considered, especially when an appropriate solution still may not be achieved.

If the above proposals are not sufficient to inform a control mechanism, a more pragmatic approach may be necessary. To secure the future of the collection, the displays may need to be isolated from the salt-laden masonry, by installation of dry-lining boards. This is not an easily achievable solution, due to the practicality of physical removal of the stones during work, and the provision of sufficient and suitable environmentally controlled on-site storage. Further consideration must be given to whether the desired improvements in the museum environment are truly achievable, and whether thought should also be given to the permanent removal of the collection from this structure.

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PREVENTIVE CONSERVATION FOR MONUMENTS: MONITORING AND ADAPTING THE ENVIRONMENT WITHIN A BUILDING

Rob Thomson

Rob Thomson, Freelance Conservator, United Kingdom.
rob@rob-thomson.co.uk

ABSTRACT

An understanding of the environment inside a building can inform the decay processes affecting the monuments in the building. Intervention to control relative humidity levels through changes to heating, dehumidification or ventilation can slow or halt ongoing decay processes by reducing the crystallisation of salts or by preventing microbiological growth. Intervention on behalf of the monument and building needs to be balanced with the needs of building users – visitors, staff or congregation. Intervention also has to take into account the variability in airtightness of historic structures.

Keywords:
relative humidity, environmental monitoring, salts, preventive conservation

Figure 1:
Aerial view of Dryburgh Abbey.

Figure 2:
Chapter House at Dryburgh Abbey.

1. INTRODUCTION

The most common form of preventive conservation with regard to buildings is the obvious – keeping the gutters clean, the windows and doors weathertight and the drains working. This paper is about the sometimes less obvious type of preventive conservation – looking in detail at the physical decay processes at work and predicting whether either stopping or slowing the decay processes is possible. The role of relative humidity is often crucial in understanding why a monument is decaying at an unacceptably rapid rate – whether that is because of salts efflorescence, condensation forming on cold surfaces or chemical changes such as iron pyrites decay.

This paper uses three case studies to discuss the process of gathering and using environmental data to inform the decision-making processes of caring for these sites.

Figure 3:
Parlour at Dryburgh Abbey.

2. DRYBURGH ABBEY: CHAPTER HOUSE AND PARLOUR

This is a mostly ruinous 12th century monument (Figure 1) and is in the care of Historic Environment Scotland. This paper discusses a part of the site – the Chapter House – which is the earliest complete example of its type in Scotland (Figure 2) (Historic Environment Scotland, 2011) and the Parlour (Figure 3). Both are large unheated stone vaulted enclosures, with the Chapter House containing remnants of wall paintings (Peter McGowan Associates 2018) and carved stone. Some window openings are glazed, but those facing the cloister are not, so air exchange with the outside is mostly unrestricted.

A concern was expressed that every few years the inside of the Chapter House needed to be scaffolded to allow conservators access for cleaning of microbiological growth from the surface of the stone. The growth appears as a sheen of green biofilm that may not be particularly damaging (Warscheid and Braams 2000) but does detract from the attractiveness of the monument to visitors. However careful the conservators are during the clean, there is a risk of erosion to the internal decorative scheme.

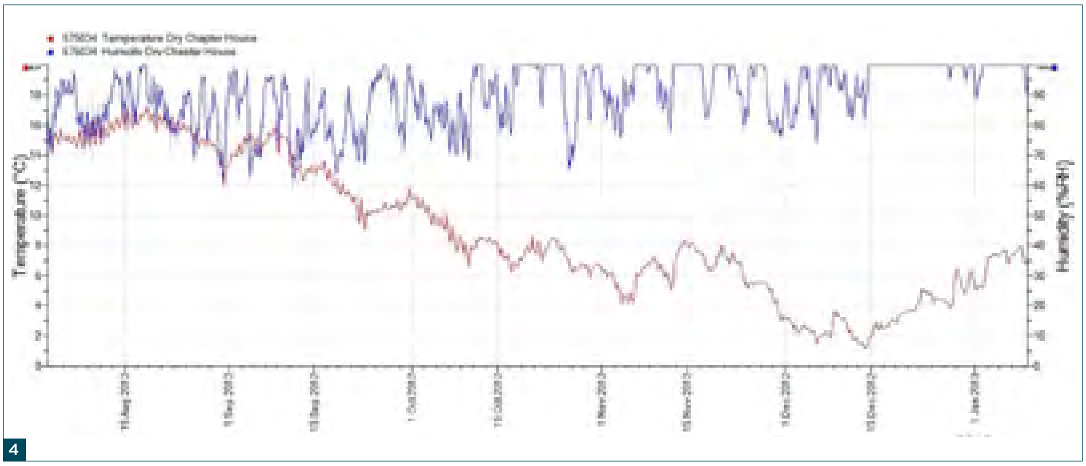

Figure 4:
Chapter House temperature and relative humidity.

The application of biocides had been used in the Chapter House to reduce the frequency of these conservation cleans, but the more toxic biocides are no longer used – for good reason, as they may be dangerous to human health and the more general environment (Warscheid and Braams 2000).

Investigations were undertaken to find a preventive approach to stop or slow this microbiological growth. A Tinytag Ultra2 temperature and relative humidity data logger was installed in the Chapter House and set to take a measurement every thirty minutes. A year of data was gathered to see how the internal environment changes through different seasons. The cause of the microbiological growth was found to correlate to regular readings of 100% relative humidity. Figure 4 shows the temperature and relative humidity over a six-month period with regular and persistent condensation. This meant that liquid water was available to the microbiological growth, so encouraging its colonisation.

The technical solution would have been to isolate the internal environment of the Chapter House (Figure 5) from the outside by glazing all the windows, reinstating a door and adding either a small amount of heating or dehumidification to keep the temperature of the walls above that of the dew point of the air. This would stabilise relative humidity, preventing condensation and therefore reducing microbiological growth. This may also be beneficial for the stonework as it reduces relative humidity fluctuations and therefore reduces salt efflorescence/deliquescence cycles.

However, there were aesthetic concerns raised by the Historic Environment Scotland Cultural Resources Advisor

Figure 5:
Parlour with dehumidification.

Figure 6:
Parlour partition.

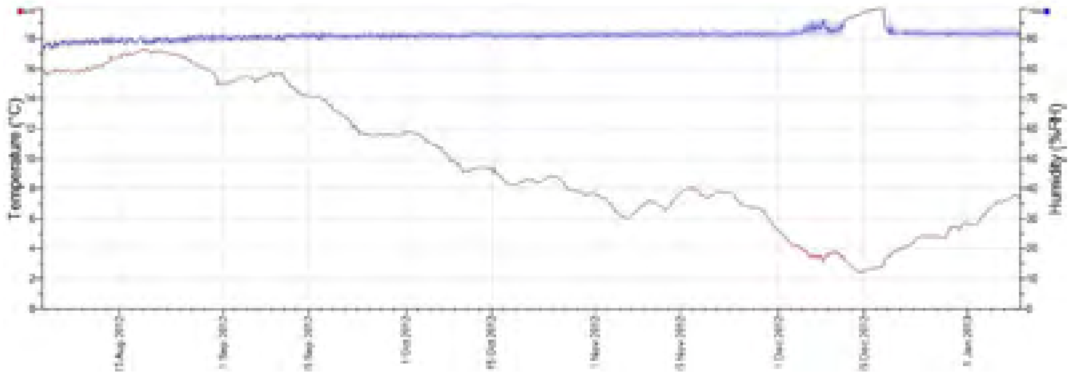

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Figure 7:
Chapter House with dehumidification.

about the visual effect of re-glazing this part of the site. Dryburgh Abbey is a scheduled monument under the Ancient Monuments and Archaeological Areas Act 1979. The Scheduled Monument Consent Policies of Historic Environment Scotland (Historic Environment Scotland, 2018) state that works to scheduled monuments will normally only be permitted if they have minimal impact on a monument's cultural significance. It may be that the technical solution of re-glazing would not be given scheduled monument consent and so could not proceed.

Discussions continued, and a trial was set up in the smaller and less decorative Parlour (Figure 3) adjacent to the Chapter House. The room was partitioned off with a temporary screen (Figure 6) and a desiccant dehumidifier installed (Figure 3). This dehumidifier was controlled by a Rotronic hygroclip sensor to accurately measure relative humidity at persistently high relative humidity levels, something that most sensors cannot do. Relative humidity was kept high to keep as many salts as possible within the wall in solution whilst still preventing condensation. Figure 7 shows the environmental monitoring data in the dehumidified Parlour and Figure 8 from the unmodified Chapter House over the same period. One hundred per cent relative humidity was avoided in the trial area except for a short period where the dehumidifier efficiency dropped due to cold temperatures. A visual assessment was made after a year of dehumidification. There was a visible lessening of the

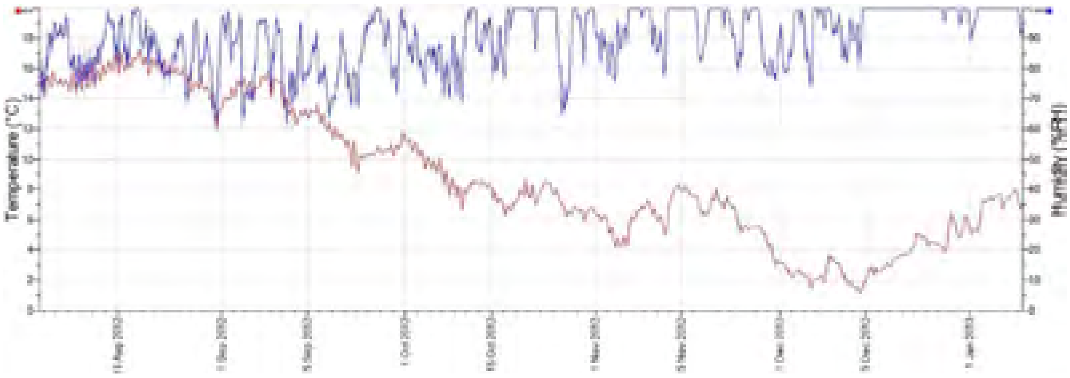

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Figure 8:
Chapter House without dehumidification.

Figure 9: Parlour salt efflorescence.

Figure 10: Skelmorlie Aisle.

green sheen of microbiological growth on the masonry inside the partition, compared to outside where the environment was uncontrolled.

However, even keeping relative humidity high at around 90%, there was still considerable salt efflorescence (Figure 9). The efflorescence formed mostly in the mortar joints but also on the surface of the ashlar. There was concern that the stone was being put under pressure from this salt efflorescence.

After due consideration, the decision was taken to not proceed with controlling the environment in the Chapter House, and also to discontinue the dehumidification trial in the Parlour. The potential risks from salt damage and the aesthetic changes from re-glazing were considered to outweigh the need to remove the microbiological growth.

3. SKELMORLIE AISLE

This building is a 17th century church (Figure 10) in Largs on the West coast of Scotland and in the care of Historic Environment Scotland.

The Montgomery monument in the middle of the building (Figure 11) is carved of very fine-grained sandstone with a crispness of carving rarely seen in this material. The monument dates from 1636 and is unparalleled in Scotland (Historic Environment Scotland 2005). Some of the lower sections of the monument were actively disaggregating. Research into the cause of the disaggregation continues (Young et al. 2017). Preliminary results suggest that very high levels of relative humidity – 100% at times – were leading to liquid water forming on the stone as condensation. This is likely to be damaging the carved stone for four reasons:

1. Petrological and X-ray diffraction analysis has found the stone includes dolomite ($CaMg(CO_3)2$), siderite ($FeCO_3$) and calcite ($CaCO_3$), which may be being dissolved due to the presence of small amounts of iron pyrites (FeS_2) that are also found in the stone. In the process known as pyrite decay (Larkin 2011) iron pyrite can oxidise in the presence of water to create sulphuric acid as shown below:

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Figure 11: Montgomery Monument and ceiling.

Figure 12: De-humidifiers and insulated window.

$(4FeS_2 + 13O_2 + 2H_2O) >> (4FeSO_4 + 2H_2SO_4 + 2SO_2)$

(pyrite, oxygen, water) >> (ferrous sulphate, sulphuric acid, sulphur dioxide)

The dolomite, siderite and calcite in the sandstone would be readily dissolved by this acid.

2. It is also be possible that clays in the stone (kaolinite and illite) might absorb liquid water, although these clays are not the type that expand in the presence of water, so this is probably a less important reason for the stone disaggregation.

3. A significant contributing factor to the stone deterioration is likely to be due to the presence of small amounts of different salts in the stone, predominantly halite (NaCl) – the site is 150 metres from the seashore, as well as being downwind of prevailing winds. Smaller amounts of gypsum ($CaSO_4 \cdot 2H_2O$), potassium nitrate (KNO_3), potassium chloride (KCl) and thenardite (Na_2SO_4) are also present. The stone has almost no open porosity, a very small pore size and poor bonds between grains, probably making it vulnerable to formation of salt crystals (Young et al. 2017).

4. The fourth possible factor is that the stone columns of the monument have an orange-coloured stain to them. This suggests that the columns were painted and then the paint removed. A treatment report from 1940 also states that the monument was chemically consolidated (Office of Works 1940).

Temperature and relative humidity have been monitored in the building since 2006. This was more recently augmented by the installation of two Tinytag surface temperature data loggers. Surface temperature of the stone was compared to air moisture content, and it was found that the conditions were right for condensation to occur during winter and spring.

The only environmental control in the building when the investigations started was a small electric radiator. The site is not staffed during the winter months, and it was observed that well-intentioned people often turned the heater off in the belief they were saving money and energy. This lack of heating would go unnoticed, and so there was nothing to reduce relative humidity in the building.

It was decided to install a pair of dehumidifiers (Figure 12) to keep the dew point temperature of the air safely above the surface temperature of the

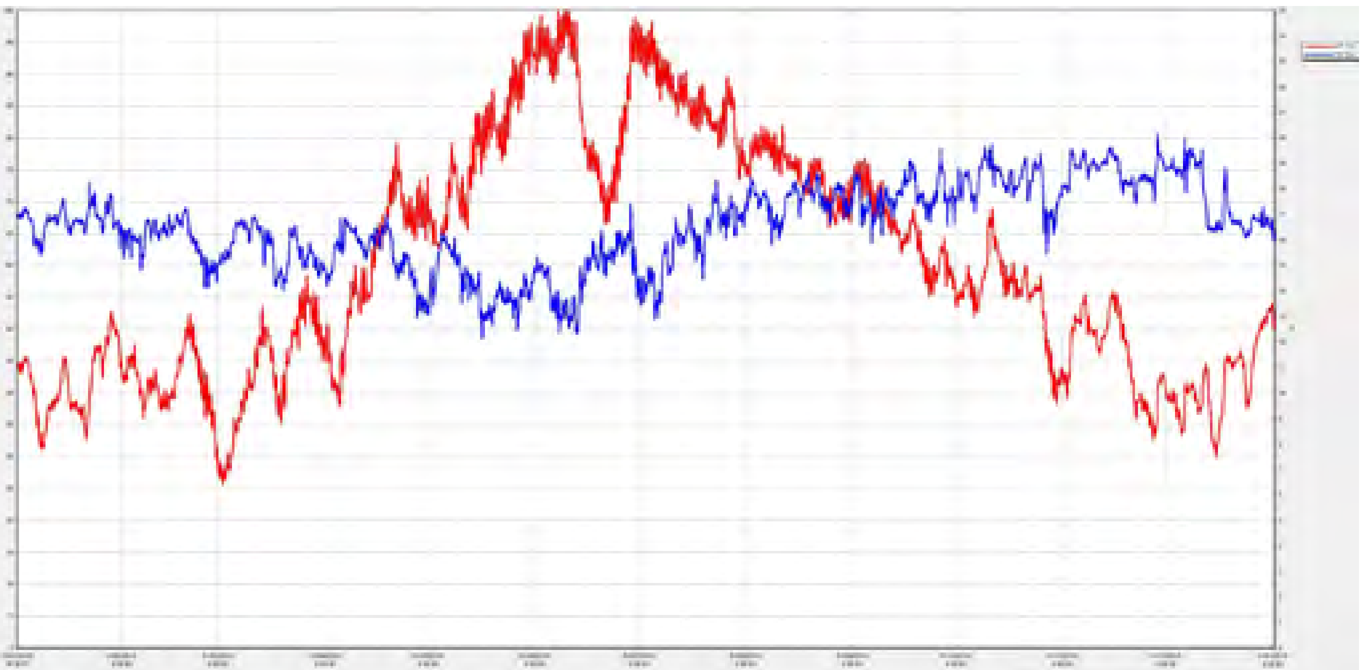

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Figure 13:
Environment in 2018.

stonework and so prevent condensation. The dehumidifiers are set to switch on when relative humidity rises above 65%. Two smaller dehumidifiers with separate controls and separate condensate pumps were chosen, rather than one large one, so there is some redundancy in the event of a mechanical fault. As well as being beneficial to the stonework, this dehumidification reduces the risk of woodworm, wood rot or paint flaking to the 1638 painted timber ceiling above the monument. Associated with this dehumidification install was a small amount of draught-proofing to the building, to improve airtightness. Draught-strip was fixed around the door to the outside, vents to the crypt were reversibly blocked and window vents sealed up.

Another related issue was raised by the environmental monitoring. In the summer months, solar thermal gain through the large south-facing window would warm the building. With this increase in heat came a reduction in relative humidity and associated increased risk of efflorescence of salts. To help ameliorate this problem, a simple screen was made up with a timber frame and fluted polypropylene translucent sheet, trade name Antinox (Figure 12). This helps to insulate the window from the warming effect of the sun.

The dehumidifiers, together with a two-kilowatt electric radiator, have been reasonably reliably controlling the environment since March 2015 with the latest data shown in Figure 13. The intention is to never let relative humidity rise above 75%, so preventing condensation on the stonework and providing a reasonably safe level of dryness for the prevention of wood-boring insect infestation or fungal attack to the ceiling. This also tries to avoid the 75% relative humidity efflorescence/deliquescence point of halite (NaCl). The monitoring shows that relative humidity rose above 75% at times towards the end of 2018. This was due to a mechanical fault with one of the dehumidifiers. This dehumidifier has now been replaced, and the trial continues.


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Figure 14: Rosslyn Chapel.

4. ROSSLYN CHAPEL

This 15th century chapel (Figure 14) is just south of Edinburgh and is managed by the Rosslyn Chapel Trust. It has a long and complex general history as well as a complex conservation history. Most relevant here is that all the internal carved sandstone surfaces of the building received a coating of cementitious slurry in the mid-20th century (Figure 15), probably as an attempt to consolidate the carved stone surfaces. The next major conservation intervention a few decades later was when the whole building was covered in a temporary scaffold roof to protect it and dry it out (Figure 16). A major programme of works was completed in 2013 that included putting in a new biomass heating system, environmentally protective glazing for the stained glass, restoration of the church organ, a large amount of external masonry work and internal conservation and cleaning of stonework. The cementitious slurry was left in place as only laser cleaning would remove it and this proved to be prohibitively expensive. The conservation project culminated in removing the temporary roof that covered the building.

The installation of the heating system was a major change for a building that had, for a very long time, even with its temporary roof, been both cold and damp inside. There was green microbiological growth on the stonework inside, caused mostly by high relative humidity levels but also localised water leaks. In order to get a fuller understanding of the changes in the internal environment, a wireless Eltek environmental monitoring system was installed at the same time as the heating system to measure temperature and relative humidity in different parts of the building. The monitoring system was supplemented to include condensation sensors, surface temperature sensors

Figure 15: Interior of Rosslyn Chapel.

Figure 16: Rosslyn Chapel temporary roof.


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and anemometers to assist the stained-glass conservators with the design of a protective glazing scheme. The environmental monitoring system was designed to answer the following questions:

1. What is the effect of the new heating system on the internal cement-slurried stonework, especially now the temporary roof has been removed?
2. What is the effect of the new heating on the newly restored church organ?
3. Is the new secondary glazing on the stained-glass windows working as designed to prevent condensation on the water-soluble glass decoration?
4. Is the new heating system working as intended for staff and visitor comfort?

The monitoring system was set up to take a reading from wireless sensors to give information on temperature and relative humidity in:

- the nave of the chapel
- the organ loft
- the lower level sacristy.

Outside conditions were also monitored so that a comparison could be made between inside and outside, in order to know how the building envelope responds to changes in weather.

Analysis of the environment in the chapel showed that the heating was very effective in keeping relative humidity stable. A target of between 50% and 75% was set, since the relative humidity in the chapel would have historically been on the high side. A lower target range (40%–65% is more typical for a historic building) would have been possible to achieve, but drier air would risk the formation of salts in and on the stonework, as different salts will effloresce and deliquesce at different relative humidity levels. The formation of new decay processes as a result of drying the environment too much was to be avoided. A lower relative humidity target would also use more energy to achieve.

This stability in the heating system is due to the heating being managed to control humidity rather than temperature. For example, when crowds of wet visitors on a rainy day come through the doors, the humidity in the building rises. The humidistats that control the heating notice this rise in humidity and the heating then gets turned on, lowering the relative humidity. Once the environment is dry again, the heating switches off. This system, known as conservation heating, works well in temperate parts of the world where the weather outside is usually just a bit colder and a bit damper than we would like it to be inside.

The following outcomes have been achieved at Rosslyn Chapel:

- Stable relative humidity, reducing salt efflorescence /deliquescence cycles in the stonework
- Prevention of persistent high relative humidity, preventing microbiological growth on the internal stonework
- Condensation being prevented on the fragile stained-glass windows
- A church organ that stays in tune longer because of stable relative humidity
- A warmer and drier building that is better for staff and visitors – although it does get cool in winter due to the conservation heating.

5. CONCLUSIONS

An understanding of the internal environment of a building will often be useful in preventing or slowing decay processes in stonework, whether it is stonework of the building fabric or of a monument within the building. Incorrect relative humidity – whether too high or too low – can be a destructive force and, unlike temperature, it is not a parameter that humans are naturally able to feel. The right equipment is needed to record data. The equipment can be simple to install with the results of the monitoring used to inform conservation decisions. A secondary but important use of the data is to aid discussions with other interested parties such as building users (guides, congregations, visitors) or building owners responsible for environmental control equipment such as heating or dehumidification.

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PRESERVATION OF THE HISTORIC INSCRIPTIONS AT EL MORRO NATIONAL MONUMENT, NEW MEXICO

Angelyn Bass[1]*, **Douglas Porter**[2], **Katharine Williams**[3],
Shari Kelley[4], **Talon Newton**[5] and **Steve Baumann**[6]

[1]* Angelyn Bass, Research Assistant Professor, Department of Anthropology, University of New Mexico. angelyn@unm.edu

[2] Douglas Porter, Research Assistant Professor, Department of Civil and Environmental Engineering, University of Vermont. douglas.porter@uvm.edu

[3] Katharine Williams, PhD Candidate, Department of Anthropology, University of New Mexico. kwilli19@unm.edu

[4] Shari Kelley, Senior Geophysicist, Field Geologist, New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech. shari.kelley@nmt.edu

[5] Talon Newton, Hydrogeologist, New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology. talon.newton@nmt.edu

[6] Steve Baumann, Resources Management Chief, El Malpais and El Morro National Monuments, National Park Service. steve_baumann@nps.gov

* corresponding author

ABSTRACT

For centuries, people have been inscribing their names and symbols into the surfaces of a sandstone *cuesta* in the Zuni Mountains of New Mexico (US). There are over two thousand carvings along three kilometres of the cliff face, which include petroglyphs made by the ancestors of the Zuni people, as well as signatures left by Spanish conquistadors, explorers mapping routes for a transcontinental railroad, and soldiers and settlers traveling westward. In 1906, this site was designated El Morro National Monument to preserve the inscriptions and the ancestral Pueblo cultural sites in their natural setting. The petroglyphs and inscriptions are carved into the weakly cemented Zuni Sandstone, which has a pronounced fracture (joint) system that penetrates the entire thickness of the unit. The outcrop surfaces are soft and friable, making them easy to carve, but also susceptible to weathering and erosion. Since 1990, the National Park Service has collaborated with universities and Pueblo partners to develop preservation strategies that consider the site from both cultural and natural perspectives. In 2014, the University of New Mexico and the New Mexico Bureau of Geology and Mineral Resources partnered with the park to characterise the local hydrology and modes of rock deterioration. This multidisciplinary project focused on rock composition and the impacts of surface deposits and microflora on weathering; the local hydrological system to understand the processes by which water moves through the rock and the unconsolidated alluvium at the cliff base; and evaluation of previous condition assessments and conservation treatments. These studies emphasise the importance of accounting for site ecology in the development of treatments for landscape-level monuments and sites.

Keywords:

El Morro, case hardening, sandstone, rock art conservation, hydrogeology, cultural landscapes

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Figure 1: The sandstone cuesta at El Morro National Monument. Photo: NPS.

1. INTRODUCTION

Towering above the blue grama grassland in north-western New Mexico is a 60-metre-high sandstone *cuesta* that is a natural landmark and part of the traditional homelands of the Zuni, Acoma, Laguna and Navajo peoples (Figure 1).

There are over 2,000 petroglyphs and inscriptions carved into a three-kilometre stretch of cliffs at El Morro National Monument. The inscriptions were made by Indigenous communities, Spanish explorers, American settlers, military expeditions and others stopping there for water from the natural pool (Figure 2). In 1906, the site was designated a National Monument to preserve its natural features, the inscriptions and the ancestral Pueblo sites as a cultural landscape.

Since its establishment as a protected area, there have been numerous studies to better understand the area's natural and cultural landscapes and the environmental processes impacting them. Preserving thousands of inscriptions in this arid landscape (average temperatures between <0°C

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Figure 2: Historic Inscription from 1859. The white haze is a naturally occurring kaolinite coating that helps isolate the surface from water flow, wind-blown particle abrasion, and temperature variation. Photo: NPS.

Figure 3: Example of slab detachment and undercutting of panel XX2. Photo: UNM.

and 32°C, with ice and snow in the winter) is a complex and ongoing challenge for the park. Our project builds on previous studies by advancing geologic investigations and hydrogeologic testing to better understand the deterioration mechanisms affecting the inscriptions, and by evaluating the condition of fifty previously assessed inscription panels and forty-five panels conserved by the park and their academic partners between 1992 and 2006 (Bass et al. 2018; Padgett and Barthuli 1995; Oliver et al. 2004; Fix et al. 2006).

2. PRESERVATION HISTORY

2.1 Twenty-four years of condition assessment (1992–2016)

The first full-scale recording of the inscriptions at El Morro took place in 1955 and involved grouping inscriptions into panels and photographing them. Between 1992 and 1994, the condition of 610 inscription/rock art panels was assessed in the most comprehensive condition survey to date (Padgett and Barthuli 1995).

In that project, a standardised condition assessment form was developed and a numeric priority rating system applied based on combined values for condition (presence and extent of primary deterioration types) and threat level (a subjective measure defined as the likelihood an inscription panel will fail without intervention within 2–5 years). The primary deterioration conditions included: 1) detachment of the rock surface from the substrate by slabbing, scaling, flaking and spalling (Figure 3); 2) erosion (Figure 4); 3) clay washes; and 4) microflora (Padgett and Barthuli 1995).

Figure 4:
Example of rock erosion, panel T8. Photo: UNM.

Some of the panels were also included in an inscription monitoring programme designed to evaluate changes in condition and to track rates of erosion, microflora growth and clay wash deposition (Oliver et al. 2004). Subsequent assessments (1996–2006) focused on 111 panels thought to be highly at risk (Oliver et al. 2004; Fix et al. 2006). As a consequence, relatively little information has been produced on about 80% of the inventory since 1994.

2.2 Twenty years of conservation treatments (1996–2016)

Between 1906 and 1990, inscription preservation efforts at El Morro were limited to experimenting with waterproofing and 'hardening' coatings such as paraffin, aluminium stearate and polyurethane; and modifying water catchment and diversion channels to redirect ground and surface water runoff away from important inscriptions.

Beginning in the 1990s, a more formal, interdisciplinary approach to preservation was taken by the park and their academic partners who began research, laboratory testing and trial application of conservation treatments that included: a) grouting to re-adhere detached slabs (Matero and Melbourne 1994); b) pinning to create mechanical connections between detached slabs and the substrate (Kreilick 1996); (c) consolidating disintegrating rock surfaces with ethyl silicate (Matero and Aplenc 1996), and; d) edging and filling losses along fractures with natural hydraulic lime-based mortars to support undercut surfaces. From 1997–2004, forty-five historic inscription panels were treated because loss of the inscription was considered imminent (Oliver et al. 2004). In 1994, Zuni Pueblo requested that the prehistoric petroglyphs not be treated and allowed to weather naturally.

3. GEOLOGY AND HYDROGEOLOGY

3.1 Geology

El Morro National Monument, on the south-western flank of the Zuni Mountains, is situated on an uplift that formed during the Laramide compressional deformation 50–75 Ma. The cuesta where the inscriptions are carved is a Zuni Sandstone outcrop with a cap of Dakota Sandstone that has largely eroded. The Zuni unit is the result of eolian deposition of sands in dunes (Cross 1996; Kelley 2008; KellerLynn 2012), and is prominently jointed. The Zuni Sandstone has been divided into twenty subunits consisting of layers characterised by large-scale cross-beds separated by units with smaller-scale cross-beds and tabular to undulatory bedding (Cross 1996). Most of the historic inscriptions fall into subunits 17–20.

To identify key conditions and mechanisms driving deterioration of the historic inscriptions, we examined rock samples using scanning electron microscopy (SEM-EDS), electron microprobe (EMPA), and X-ray diffraction (XRD). The goals included characterising clay cements and rim coatings in the geologic subunits where the inscriptions are found, and investigating the influence of surface deposits and microflora on inscription weathering.

Zuni Sandstone is 73–86wt% fine-grained sand, 5–18wt% silt, and 9–11wt% clay (Austin 1992; Cross 1996). We confirmed that the cementing materials are primarily kaolinite and chlorite, which results in weak cementation. In the samples we examined with SEM, levels of cementation clearly varied, sometimes within the same subunit. Weathering of the clay leaves washes and runnels on the rock surface that often obscure the inscriptions. The poorly cemented sandstone is at once easy to carve and easily lost to weather.

Much of the outcrop is covered in clay washes, including a kaolinite+chlorite coating ≤150μm thick, over an indurated layer (<80μm) similarly composed but with minor amounts of entrained quartz, feldspar and gypsum (Figures 5 and 6) (Kelley 2019). The clay chemistry indicates that many of the washes originated upslope, carried down by sheeting water, so that the presence of these washes alone cannot be considered

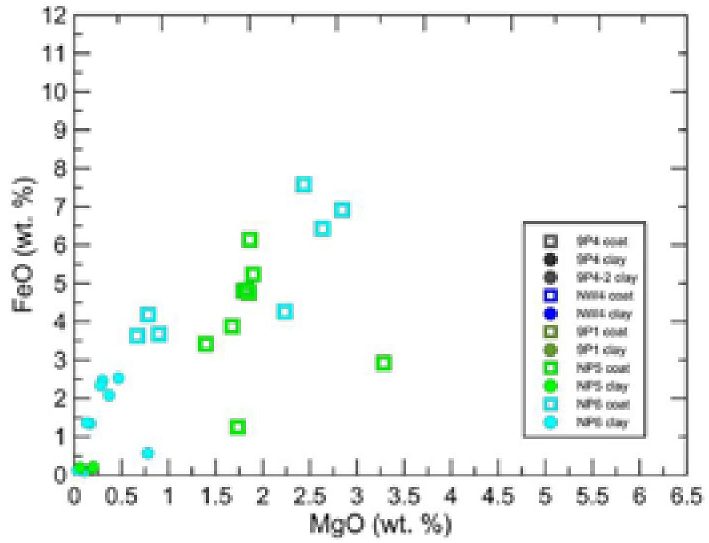

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Figure 5:
Plot of FeO versus MgO for samples NP5 and NP6 (Inscription Trail). The legend is arranged by stratigraphic order, from the youngest unit to the oldest unit sampled. MgO and FeO concentrations are a proxy for chlorite concentration. The small amount of chlorite in clay matrix cement and the large amount in the exterior rim coats implies that the coating material is derived from chlorite-bearing units in the cliffs above. Analysis and plot by Shari Kelley.

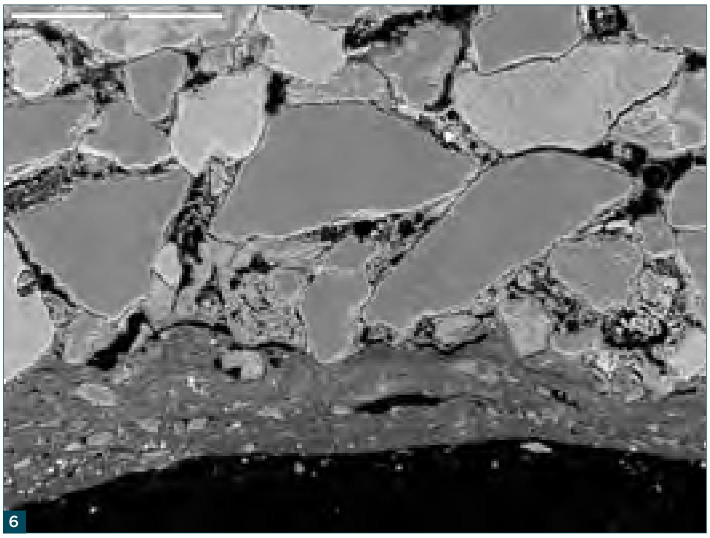

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Figure 6:
BSE micrograph of indurated clay rim coat, indicating episodic deposition. This sample, NP5, was collected along the main Inscription Trail in Cross' subunit 17 (scale bar = 100 microns). Photo: UNM.

a proxy measure of disaggregation of inscription panels. These surface coatings offer protection to the underlying rock by isolating them from direct contact with weather (Figure 2).

In many of our samples, we also found secondary minerals precipitated in the near-surface pore space, including clays, barite, gypsum, manganese oxide, iron oxide, calcite and silica cements. These minerals improve the weather-resistance of the rock surfaces by increasing cementation and reducing the number and size of pores, which decreases imbibition rates and weathering associated with freeze–thaw and the crystallisation of soluble salts (Porter et al. 2017; Marszalek et al. 2014). Interestingly, these case-hardened surfaces occur consistently on rock surfaces with abundant lichen growth. Lichens express weak organic acids that contribute to the dissolution of feldspars and the precipitation of secondary silica and kaolinite in the near-surface pore space (Figure 7). In addition, the lichens have microfungal filaments that invade open intergranular pores (Knight et al. 2004; Porter et al. 2017); our SEM studies confirm that these filaments bind surface sediments and dislodged particles (Figure 8).

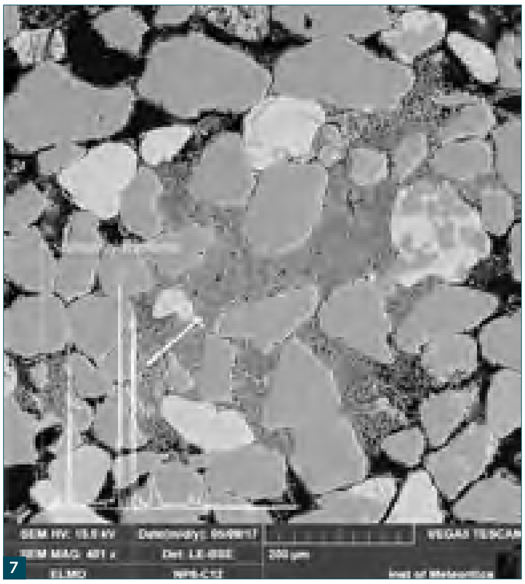

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Figure 7:
EDS-BSE of secondary kaolinite precipitated in the near-surface pore space (sample NP, taken along the main Inscription Trail in Cross' subunit 17). (scale bar = 200 microns). Photo: UNM.

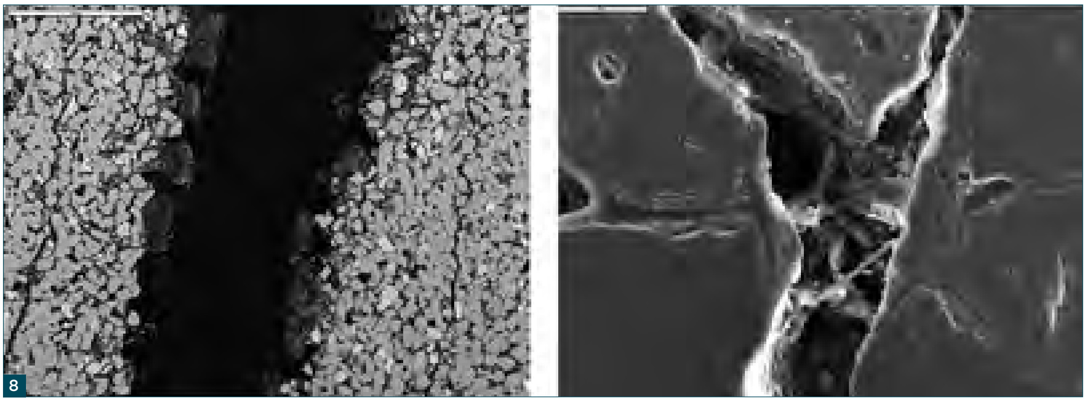

Figure 8: BSE of cracks parallel to the lichen-covered surface (left), and microfungal filaments binding the detached surface to the bedrock (right) (scale bars = 1 millimeter (left); 20 microns (right); sample NW2L, collected along the main Inscription Trail.

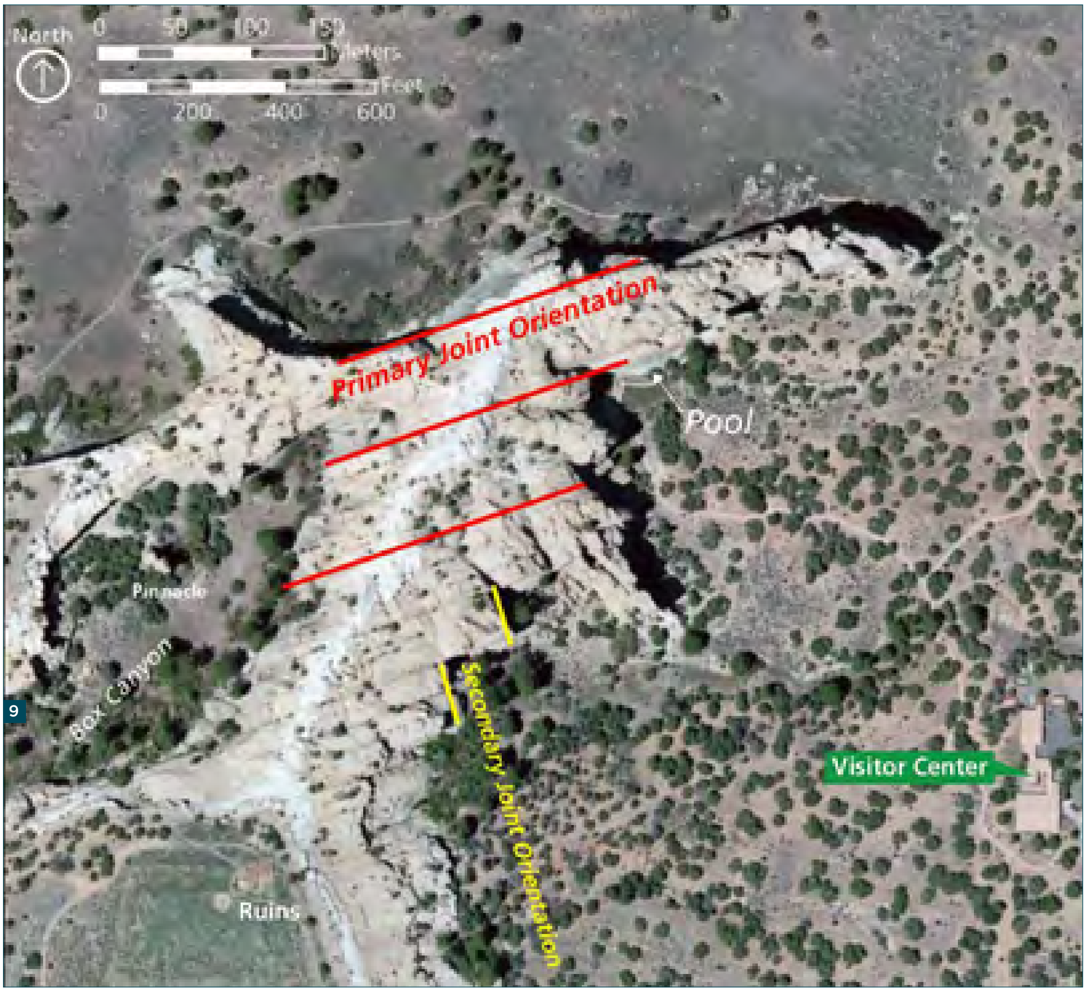

Figure 9: Aerial photograph of Inscription Rock at El Morro National Monument, showing the location of North Point and the primary and secondary joint orientations. Graphics by Talon Newton.

3.2 Hydrogeology

Our scope included hydrogeological investigations to better understand water transport in the cliff and the unconsolidated alluvium at the cliff base, as well as the connectivity of the pool and groundwater systems (Newton and Kelley 2019). The results of this study have important implications for understanding inscription deterioration. Our pool drawdown test and water chemistry analysis confirm that the primary water sources for the pool are precipitation draining from the top of the outcrop and rainwater falling directly into the pool (Austin 1992; Cross 1996). The higher total dissolved solids and silica concentrations in groundwater, and the stable isotopic composition of shallow groundwater, strongly suggest that there is no connectivity between the pool and the perched aquifer at the base of the outcrop, as previously thought (van Dam and Hendrickx 2007). Since the pool system is independent of the perched aquifer, it is unlikely to have played a role in the deterioration of inscription panels to the north-east.

While the pool and the aquifer are both fed by precipitation, differences in water chemistry indicate the aquifer is charged by precipitation flowing through the joint system visible at the top of the outcrop (Figure 9). Modelling groundwater level increases during monsoons revealed that water flow through these fractures can transmit enough water to develop a shallow saturated system in the alluvium at the base of the cliff. It was assumed that the ephemeral water table supplied water in contact with inscriptions through capillarity, but measures of hydraulic conductivity indicate that the more important transport mechanism is by the flow and/or storage of water in fractures that are close to the outcrop surface. This is especially true of points along the outcrop that are perpendicular to the strike of the primary joint system. Test well monitoring at North Point, where inscription deterioration is most severe, revealed that fracture flow may be partially responsible for elevated deterioration levels there.

4. REASSESSMENT AND TREATMENT

4.1 Reassessment (2016–18)

Using results of the geologic and hydrogeologic investigations, we reassessed the condition of fifty panels covering a range of deterioration types and geographic distribution. We compared current conditions with previous documentation (assessment and monitoring forms, and photographs), noting new deterioration and approximate rates of change. From this reassessment we learned the following:

- The 1992–4 survey data determined that detachment from the outcrop was the primary mode of deterioration for 24% of the panels surveyed. We found that detachment is prevalent on south-facing elevations, signalling that temperature gradients and/or frequent changes in moisture content may contribute to this condition.
- The 1992–4 survey considered erosion a primary deterioration condition. We found that erosion was generally modest except adjacent to the pool and at North Point (Burris 2007), where it affects inscriptions by a factor of seven times that in other areas. Our hydrogeology study demonstrates that North Point is one of the places where precipitation moisture is preferentially delivered by the joint/fracture network.
- The 1992–4 survey considered clay washes the primary mechanism of deterioration for 20% of the surveyed panels. We found that, although surface sediments may obscure inscriptions, they do not cause damage and are not a reliable proxy measure of deterioration.
- For 24% of the panels in the 1992–4 survey, colonisation by microflora was thought to be the primary mode of deterioration. Since lichens disrupt surfaces, they can be considered deteriorative, but through SEM analyses, we found they also catalyze the development of durable rinds that confer a level of protection to the outcrop surface.

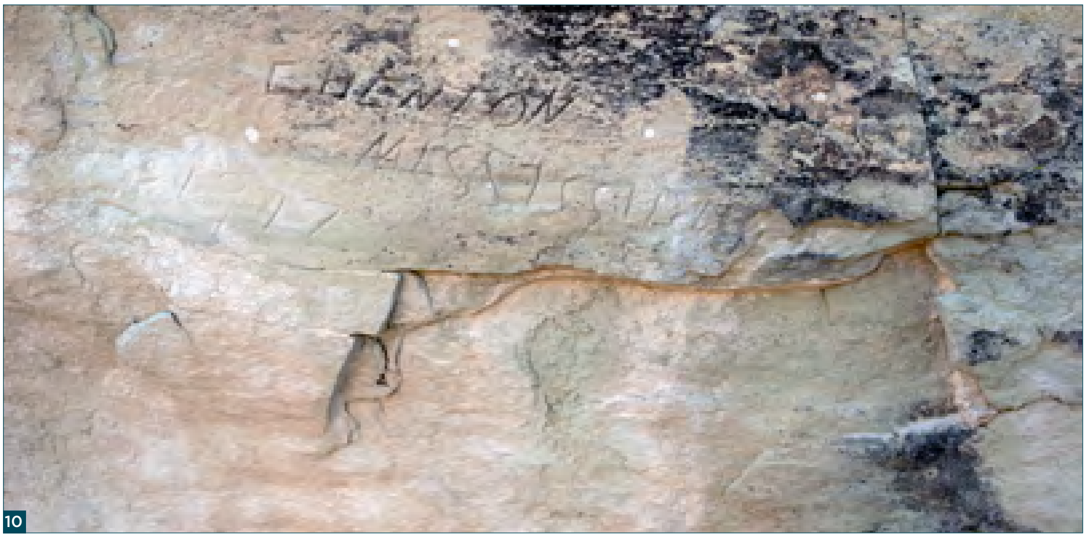

Figure 10: Example of previous treatment: pinning and edging, panel WW5. Pins are concealed with a natural hydraulic lime fill, which can be seen as white circles. Photo: UNM.

Of the fifty panels we reassessed, over half had a change in condition since 1992–4, and 26% had losses since 1955. We used statistical clustering methods to highlight correlations between the 1992–4 survey and our 2016 assessment and found: (1) the proportion of panels with severe deterioration is increasing, and (2) past threat assessments do not correlate strongly with panel condition in 2016; therefore, Threat Level is unlikely to be an effective assessment parameter. (Engineering faculty at the University of Vermont – John P. Hanley, Researcher Analyst, Microbiology and Molecular Genetics, and Donna M. Rizzo, Professor, Civil and Environmental Engineering – have developed proprietary evolutionary algorithms focused on 'feature selection' that are likely to be very useful in the future to highlight correlations in the data).

4.2 Treatment (2017 and 2018)

Our team evaluated the condition of the forty-five panels conserved between 1996 and 2004. We visually compared current condition to after-treatment images, and inspected the treatment areas and materials for failure and/or additional damage. Results revealed:

Mechanical pinning and grouting for reattachment were among the most successful treatments (Figure 10). None of the twelve pinned panels failed, but the extent of delamination bordering treated areas increased in six cases. This was often because edging and fills were not maintained, and water flowed into cracks and voids. Grout failures (separation at the grout/rock interface) were limited to two cases, and were likely due to the friable condition of the joined surfaces, suggesting that disaggregated adherends should be consolidated before grouting to improve the bond.

Figure 11: Conservation treatment (grouting and filling) of detachment at North Point, panel BB8. Note pronounced preferential growth of lichens and other microflora on right. Photo: UNM.

Twenty-nine inscription panels were treated with ethyl silicate (some multiple times) to consolidate friable surfaces. There was no additional loss of the inscription or the adjacent rock, which suggests that the treatment is performing satisfactorily. At North Point, where erosion rates are as high as 0.275 mm/year (determined by measuring losses at erosion monitoring pins installed in 1997–8 (Oliver et al. 2004), panels required re-consolidation every 3.6 years on average.

Edging and filling with natural hydraulic lime and sieved sand mortars was the most common treatment applied. It also had the most failures, which included cracking and separation from one or bothadherends. This is not surprising, since the mortars were designed to weather preferentially and require regular maintenance, which had not been done. Inspection intervals for this type of treatment should be every 2–3 years.

By 2017, approximately 44% of the conserved panels required additional treatment. Most of the treatments were over twenty years old and had not been maintained. In 2017–2018 we retreated twelve inscription panels, primarily by grouting and replacing failed edging (Figure 11).

Conservation treatments developed in the late 1990s have been largely effective in countering the effects of panel detachment. Evaluation of the conserved panels indicate that the treatments have limited service lives, especially those continually exposed to the environmental factors that resulted in inscription damage initially. Through reassessment of the treated panels, we were able to establish inspection intervals for different treatment/condition types, as well as create a prioritised list of panels needing additional treatment and monitoring.

5. CONCLUSIONS

The assessment and treatment programme developed and implemented from 1992 to 2006 established a condition baseline for the inscription panels at El Morro, and our condition reassessment and geologic and hydrologic studies, conducted 25–30 years later, yielded invaluable information concerning the manner and rates of inscription deterioration (Bass et al. 2018)

A full-scale reassessment of all 610 panels is overdue. Before undertaking this reassessment, it makes sense to eliminate some of the subjective criteria and update assessment protocols in view of our current knowledge of deterioration phenomena, focusing on detachment and erosion as the primary conditions. Pinpointing previously unrecognised correlations in the data using quantitative 'feature selection' analysis is likely to help in the prediction of future losses and identify a subset of inscription panels requiring more intensive monitoring/treatment, focusing conservation resources where they are needed most.

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THE SIR JAMES TILLIE MONUMENT – PENTILLIE CASTLE, CORNWALL: THE REPAIR OF A MONUMENT AND THE DISCOVERY OF A BODY

Tom Flemons

Tom Flemons, Somerset Workshop Manager,
Cliveden Conservation Workshop Limited, UK.
tomflemons@clivedenconservation.com

ABSTRACT

The monument to Sir James Tillie is housed within an unroofed structure thought to be one of the earliest mausolea in the country. The monument is of a seated, wigged gentleman on an armchair within a canopied tomb. The whole had been reclaimed by nature and it was unclear whether it was being held together or pulled apart by the plants and ivy. The stonework required rescuing from its parlous state, and analysis of stone, paint and period dress were undertaken to inform the repairs; archaeological assessment and recording also played a key role. The project involved recording the monument, dismantling it and transferring it to a controlled workshop environment. Cautious and targeted cleaning followed with lime mortar repairs, grouting and shelter-coating. Limited replacement of stone was agreed for weathering elements, string course and cornice together with prominent features of the sculpture. Following dismantling of the monument, a vault was discovered directly below the monument housing the remains of Sir James Tillie. Return of the sections to Cornwall was followed by reconstruction. The works were carried out under the guidance of surveyor Richard Glover, with archaeological input from Oliver Jessop and control by English Heritage.

Keywords:
monument, mausoleum, sculpture, analysis, investigation, conservation


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Figure 1:
View from Mount Ararat.

Figure 2:
Mausoleum taken during initial survey.

1. INTRODUCTION

Sir James Tillie, who built Pentillie Castle in 1698, left instructions in his will that he should not be buried. Instead he wished to be dressed in his finest clothes with his hat, wig, rings and best apparel on, surrounded by his books and tied with wire to his favourite chair. As far as the stories go, the faithful servants carried out these instructions, placing Sir James's body in his folly on Mount Ararat overlooking his favourite view across the Tamar (Figure 1).

The servants continued to bring the deceased wine and food for two years until they could bear it no longer. Then they had his remains interred and a statue built in his place. None of the stories surrounding this period relate exactly what happened to Sir James's body, but it had always been assumed that his remains were moved to one of the local parish churches.

With Sir James's statue residing comfortably in the building on Mount Ararat, it became known as 'the Mausoleum'. It is noted by Howard Colvin as the earliest of its kind in the country (Colvin 1991). Ted and Sarah Coryton inherited Pentillie Castle in 2007, and since then they have actively repaired and rejuvenated the estate, including its mausoleum (Pentillie Castle 2017).

The mausoleum had fallen into disrepair and been all but reclaimed by nature. The monument itself was shrouded in moss and had become overrun by plants and ivy. The Coryton family were already working with surveyor Richard Glover, who drew up the specification and scope of works for repair of the mausoleum and separately the dismantling and repair of the monument (Glover & Felus 2011). Archaeologist Oliver Jessop was responsible for surveying and investigating the structures and the history surrounding the estate. The works to the mausoleum and monument were enabled through funding organised by Natural England and the Country Houses Foundation.

Cliveden Conservation became involved following a tender process. Initial sight of the monument was through the gates to the mausoleum (Figure 2), the summer sunshine penetrating to illuminate the lush vegetation which had overtaken the paving and the memorial itself.

During the early assessment it appeared that weathering and the possible expansion of hidden ferrous fixings had forced elements apart, opening joints and weakening the structure. As the evaluation continued, it became apparent that there was no rust staining and only limited

Figure 3:
Monument before dismantling.

Figure 4:
Sir James Tillie Monument – site sketch.

Figure 5:
Example of disruptive plant growth.

splitting of the stones themselves. There was extensive ‘jacking’, opening joints, but this had been caused by expansion and thickening of the ivy stems, which were disrupting the structure and causing mechanical damage. Some of the considerable losses to both flanking sections of the cornice mouldings could, however, have resulted from masonry falling from above (Figure 3).

1.1 Dismantling

Prior to dismantling, documentation of the monument was undertaken, collecting measurements, recording datums, preparing a drawn record (Figure 4) and taking record photographs. Any carved or worked fragments found at the base of the monument were collected to recover details for later re-use or replication. Moss and plants that were easily removed were cleared using stiff bristle brushes, wooden spatulas and scrapers. As the layers were carefully peeled back the record information was updated. Extreme care was required during this operation because the monument could easily have been destabilised by removal of the root material (Figure 5).

An access and lifting scaffold was then erected, allowing manipulation and safe handling of the larger stones. Sections were systematically dismantled and with the upper portion of the monument removed, the core was revealed as a coarse assembly of limestone blocks and lime mortar with a large amount of soil and root growth. The panels of the lower ‘box’ section were removed and the core dismantled. This revealed that no ferrous or any other kind of fixing had been employed. Although the lack of fixings had allowed sections to move and become detached, it meant that there was no damage caused by corrosion or expansion. The unsecured construction also allowed the stones to

**Figure 6:
USB microscope image, magnification x 200, left sample from gadrooned table-top, right of Hartham Park Bath stone.**

be moved apart without the additional strain caused by rigid mechanical ties. This lack of ferrous fixings prevented significant fracturing given the root jacking and presence of moisture.

The stone sections were carefully removed from site to the Cliveden Conservation workshop for treatment.

1.2 Workshop repairs

1.2.1 Material survey and identification

On arrival at the workshop each element was given a light clean, removing moss and soil, which allowed a full assessment of each part. A survey was undertaken and recommendations drawn up, with the condition of each stone assessed to determine individual state of repair, structural integrity and future weather shedding ability.

An initial assessment of the stone types was undertaken using the 'in-house' stone library and knowledge, togetherwith a basic USB microscope (Figure 6). The bulk of the construction appeared to be of a pale cream oolitic limestone. By contrast the figure and some of the dressings, including the cornice, were carved from a paler off-white limestone with a third, apparently polishable limestone used for the lettered inscription panel.

Early in the project it was established that some stone replacement would be likely, therefore samples were sent for analysis. The geological report identified that the principal limestone was 'Bath Stone most probably from the Middle Jurassic, Combe Down Oolite. If it is an original stone from the initial early 18th Century construction, a source on Bathampton Down or Combe Down, immediately to the south of Bath, is indicated' (Sanderson 2013). The best available geological match for replacement was advised to be Hartham Park Bath stone (Figure 7).

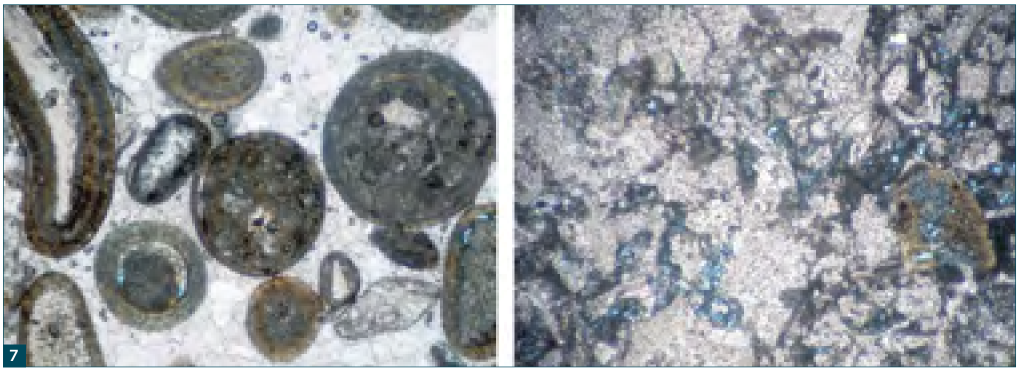

**Figure 7:
Geologists' photomicrographs. Left; Bath stone oosparite grainstone Right, Beerstone biomicrite packstone. Both samples width 2.2mm, open pores filled with blue resin.**

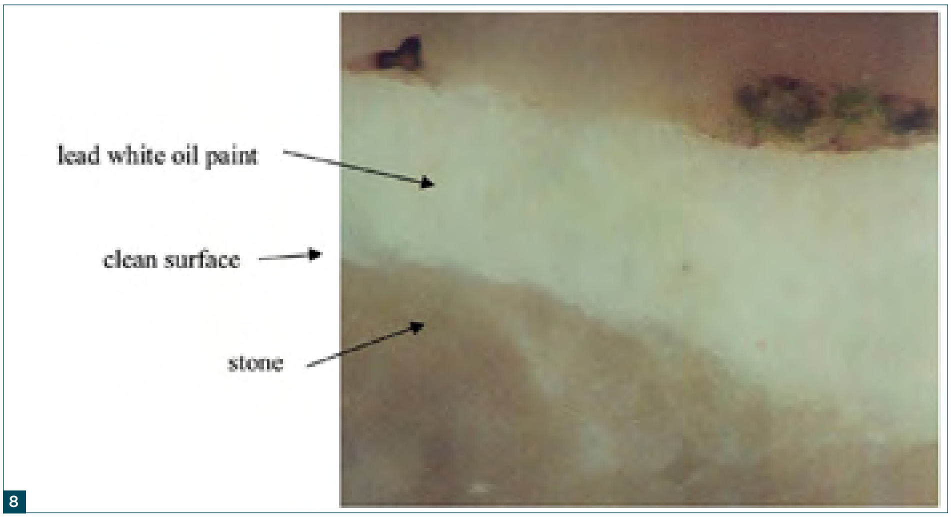

Figure 8:
Cross sectional analysis of paint sample.

By contrast, some of the other elements including the sculpture of Sir James Tillie carved in two pieces were a much finer, tighter-grained limestone, presumably selected for its ability to take and hold fine arris and carved details. This was found to be Beer limestone, from about 70 miles up the south-west coast in east Devon (Sanderson 2013). 'Beer stone was not sufficiently available for the necessary repairs, therefore a source of geologically similar limestone was found, a French limestone – Richmont Crème' (Sanderson 2013).

1.2.2 Stone cleaning

Whilst cleaning, samples of what appeared to be paint were noted on the sides of the chair frame: a dark substance suspected to be the corrosion product of a lead white paint. Samples of this paint were taken for analysis. This identified that all samples showed a single layer of greyed white oil paint applied directly onto the stone, suggesting application early in the life of the monument. The paint was lead white based with traces of carbon black particles (Hassall 2013) (Figure 8).

Due to the discovery of lead content in the paint, the level and extent of the cleaning was kept to a minimum, with care taken not to disturb any paint identified in the interstices.

1.2.3 Stone repairs

Following this analysis, treatment options were established (Cliveden Conservation 2012) ranging from the least invasive light cleaning, removal of the soiling and moss to additional minor lime mortar repairs to support worn or decayed stone. More deteriorated stones required repair by dowelling fractured pieces back together with 316 grade stainless steel rods. Dowels were secured within the stone using epoxy resin. Once the structural repairs had been undertaken, any minor fractures or surface cracks were injected with a finely sieved lime bound grout, limestone dust < 150μm with Natural Hydraulic lime NHL2 as a binder. The surface was then mortar repaired using mortar bound with NHL2, aggregate of washed blond sharp sand <2.36mm and Bath stone dust.

The chosen option for sections of the gadrooned box tomb lid and the cornice was a 'pieced repair'. This involves integrating new stone, carefully measured to follow the original setting out and geometry. Both sections perform a weather shedding function; the gadrooned box lid also has an important structural role, with further stone including the central sculpture supported by it.

The Ashburton marble lettered plaque was almost illegible, as the inscription was originally not carved with any depth. Because visitors would often view the monument from a distance, it was felt that increasing the definition was important. Following trials, a colour was established that provided a good contrast with the weathered stones but didn't make the panel appear over-restored.

The final items of treatment could be seen as cosmetic; however, they were felt important by the project team. They included replacement of the missing nose, fingers and toes to Sir James himself. These were carved in stone following research into the original form, and approval of clay modelling.

1.3 On-site investigations

The off-site treatment of the monument offered the opportunity for further investigation to be undertaken on site. Oliver Jessop undertook archaeological building recording and developed a watching brief during the restoration of the mausoleum (Jessop Consultancy 2013). Four trial pits were excavated by the main contractor, William May Somerville, and his team during the project which revealed the top surface of a vault and also a series of granite lintels.

A vaulted plastered space was discovered below the mausoleum paving, entered via a series of eight granite steps and sealed over by a series of granite lintels below the paving. Exploration of the vault revealed decayed wooden planking, fabric remnants identified as a woollen textile, metal fixtures and fittings, fabric and nails together with human remains. A full survey and study together with archaeological conservation was undertaken; however, the family requested that the vault was re-sealed and the burial space returned to a peaceful resting place for Sir James. The excavations and investigations were monitored by experts and representatives from the local council and English Heritage.

The floor of the vault was covered with 1cm of standing water. There were decomposed remains of wooden planks which had formed a structure or structures. The planking and its construction was not suggestive of a conventional coffin, but through reconstruction was interpreted as forming a box perhaps visually representing the chair in which Sir James Tillie had been placed after his death. The wood was analysed as part of the archaeological investigations as being oak by Durham University Conservation Services.

Other materials recovered were fragments of woollen textile found to have a plain weave which, with its slight 'nap' forming a pile, is suggestive of velvet. There were 550 upholstery nails, a sample quantity of which was taken for analysis and conservation. These were found to be leaded brass, which when new would have had a bright golden appearance. At either side of the planks nine ferrous metal fixings or handles were discovered of differing designs.

The human remains were neither removed nor subjected to testing; however, the photographic records were examined by the York Osteoarchaeology Laboratory (Jessop Consultancy 2013).

In his conclusion to the archaeological survey and study, Oliver Jessop stated: 'The remains found within the vault have been reconstructed, and it is suggested that he was buried within an oak container that imitated a high-backed chair, and covered with a woven woollen fabric and decorated with brass studs.' Handles and grip plates discovered bore resemblance to the manufacture of more traditional coffins. Other handles discovered indicate that there may have been boxes or chests to store books and other personal effects (Jessop Consultancy 2013).


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Figure 9: Reconstruction in progress.

Figure 10: Setting out during reconstruction using setting out template.

1.4 Reinstatement

Prior to the return of the monument, a new foundation was laid by the main contractors to reduce the risk of future movement and settlement. All elements were carefully packaged and reloaded for the transfer from Somerset to Cornwall. An independent scaffold was commissioned to allow safe access and lifting capability. The datums recorded during the dismantling together with 'shadow lines' and incisions left on the rear wall of the building were used to guide the setting out and repositioning of the monument. Because there were no plans to reinstate a roof across the mausoleum, reconstruction was undertaken in anticipation of future adverse weather using materials suitable for external conditions (i.e. not plaster for refixing nor polyester resin).

Although there had previously been no fixings, the decision was taken to include stainless steel restraints at strategic points to ensure the monument held together going forward. The owners will undertake regular monitoring to ensure the upkeep of the monument.

A bitumen-coated, sanded lead damp-proof membrane was inserted

at the base of the plinth. The rear wall of the structure was not felt to be conveying any moisture or salts into the structure, therefore a vertical membrane was considered to be unnecessary. The plinth course was reconstructed with the internal structure replaced with concrete blockwork built using a hydraulic lime bound mortar, with an air gap maintained between the stone and the new core.

The lower box section was constructed with three internal concrete block columns, leaving some space within to allow for air movement (Figure 9), the central one built in such a way that the imposed load of the sculpture was directly borne by it. This ensured that no additional load was imposed on the relatively thin gadrooned table-top lid. The setting out of the 'table-top' section was completed using the rigid template created to determine the geometry for the replacement gadrooned sections in the workshop (Figure 10).

Figure 11:
Monument completed with canopy in place.

The flanking scrolled outer panels were then fitted, followed by the cornice/canopy stones, which were re-set into their previous pockets in the wall. A wooden centring was used to support them until the keystone was fitted, and all were then grouted and pointed with NHL2 hydraulic lime bound mortar with clean washed sharp sand, 2.36mm blended with Bath stone dust.

The two large sections of Sir James Tillie himself were then carefully installed and all joints pointed with lime mortar. All works were recorded in an extensive treatment report (Cliveden Conservation 2013).

Following completion, a glass and stainless steel canopy was commissioned. This ‘light touch’ modern intervention, suspended from the rear wall of the building, provides shelter to the monument and responds to the future conservation needs of the monument (Figure 11).

1.5 Conclusion

The project involved relatively straightforward conservation practice and principles. However, what made it stand out were the discoveries made. The Pentillie Mausoleum is a unique structure and houses the unparalleled burial of Sir James Tillie. The form and circumstances of his ‘burial’ contribute to the understanding of the life and death of a wealthy, eccentric gentleman.

ACKNOWLEDGEMENTS

This was a fascinating project to be involved with. The principal team undertaking the work for Cliveden Conservation were Brian Bentley and Andrew Hebden. Our thanks to Ted and Sarah Coryton for being supportive clients, and to surveyor Richard Glover, archaeologist Oliver Jessop, and William May Somerville and his team as main contractors.

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CONSERVATION OF THE ALABASTER ARCHIVOLT TO THE WEST DOOR AT THE CHURCH OF ST MARY, TUTBURY

Sabina van de Bruck

Sabina van de Bruck, Dipl.-Rest. ACR,
Senior Conservator, Hirst Conservation.
sabina@hirst-conservation.com

ABSTRACT

Alabaster has been used for centuries to produce carvings and ornamental decorations. However, its use externally is rare and the alabaster archivolt at the former priory church, Tutbury, is a unique example in the UK. This paper focuses on the conservation treatments undertaken in summer/autumn 2018 to the alabaster elements of the highly significant Norman doorway, dating from 1160–1170. Condition assessments, archive research, material analysis and extensive treatment trials informed the conservation strategy. The results from these assessments are summarised to highlight the extent and causes of deterioration and explain the decision-making process. Additional measures undertaken to the surrounding fabric to reduce the impact of water ingress are also discussed.

Keywords:
alabaster, deterioration, consolidation, nano-lime,
dispersed hydrated lime, laser cleaning

Figure 1:
The doorway.

1. INTRODUCTION

The church, formally known as the Priory Church of St Mary the Virgin, is located in the Staffordshire village of Tutbury. The building work started in 1080 but stretched over several decades due to the size of the project. The doorway (Figure 1) dominates the west front and dates from 1160–1170. The stonework of the arches is believed to be predominantly original, whilst the lower sections were replaced with modern copies in the 19th century.

The doorway consists of six orders of finely carved sculptures, and a flat band with zigzag decoration surrounds the wooden door. The first order comprises a total of thirty stones of local alabaster, while all other elements of the doorway are constructed of sandstone. According to recent research, the alabaster was sourced at Chellaston or Fauld (Kloppmann et al. 2014). The doorway is of outstanding significance as it represents 'the earliest specimen of ornamental carved works in alabaster' in England (Richardson 1853) and the only known surviving example used externally in the country.

In January 2013, damage to the alabaster order was reported when fragments of the stone material were found on the ground beneath the arch with significant material loss to one of the stones. Although members of the congregation were concerned that the damage was an act of vandalism, the architect concluded that the material loss occurred in connection with the unusual wet weather during the winter months of that year and the already advanced disintegration of the alabaster. This incident prompted a series of condition assessments which formed the basis of the conservation work undertaken in summer/autumn of 2018.

2. CONDITION ASSESSMENT; SUMMARY

2.1 Alabaster archivolt

The alabaster archivolt was examined in the context of the surrounding fabric to obtain a comprehensive understanding of the deterioration issues, but in this article only the alabaster will be discussed.

Alabaster is a cryptocrystalline sedimentary rock formed from gypsum ($CaSO_4 - 2H_2O$). In its purest form the stone is white but often incorporates iron minerals and veins, which provide the unique colouring of the stone; alabaster can be milky to semi-transparent. It is water soluble (~2 g/L, 25°C) with a hardness of 1.5–2 on the Mohs scale, and its solubility increases when exposed to alkaline or acidic atmosphere.

The survival of the alabaster elements is attributed to its sheltered position within the arch, where the stone is mostly protected from direct rain. The pattern of deterioration suggested that the decay was mainly linked to material-specific qualities (inherent problems), exposure (natural weathering and environmental conditions) and historic damage.

Driving water and airborne particles impact at a higher rate on the north side of the arches due to the prevailing SW wind direction. With higher moisture levels, the dissolution rate increased and in combination with air pollution crust formation intensified, encapsulating soot and other airborne particles within its substrate. The physical properties of the newly formed surface, although chemically similar to the alabaster, differed from the original stone. The dark gypsum crust not only changed the appearance of the stone, but an increase in surface temperature could be expected compared to areas of unsoiled alabaster. The simulation of sun/light exposure, used to illustrate changes throughout the day, demonstrated greater values to the north side (south facing) than to south side (north facing), suggesting higher thermal stresses and potentially greater fluctuations of environmental conditions within the north side of the arch. Such mechanisms contributed to the weakening of the stone matrix, which in turn led to a greater retention of moisture, heightening the risk of freeze-thaw damage. This accelerated the deterioration rate and resulted in further formation of fractures, multiple scaling, crumbling and granular disintegration.

The damage within the central part of the alabaster arch is directly linked to the historic damage seen in the orders above, introduced decades or even centuries ago. Changes in the configuration of the structure above redirected the water, saturating and weakening the matrix of the stones in its path. The decay continued, although at a much reduced rate, even after changes were implemented.

Isolated mortar repairs have been detected throughout the archivolt together with remains of protective shelter coats within the most degraded stone sections. The pointing within the alabaster archivolt was generally stable, but was mostly covered by a dark surface tracing crust, indicating that lime-based materials were used (later confirmed through material analysis).

Although the condition assessments established that the deterioration rate was generally slow, it remained active; a comparison of photographic images taken in 2013 and 2017 showed that six of the thirty stones within the alabaster archivolt were affected by new material losses. All alabaster blocks had been affected by weathering processes with different degrees of severity, and sympathetic conservation to minimise the risk of further deterioration was required to the entire alabaster arch.

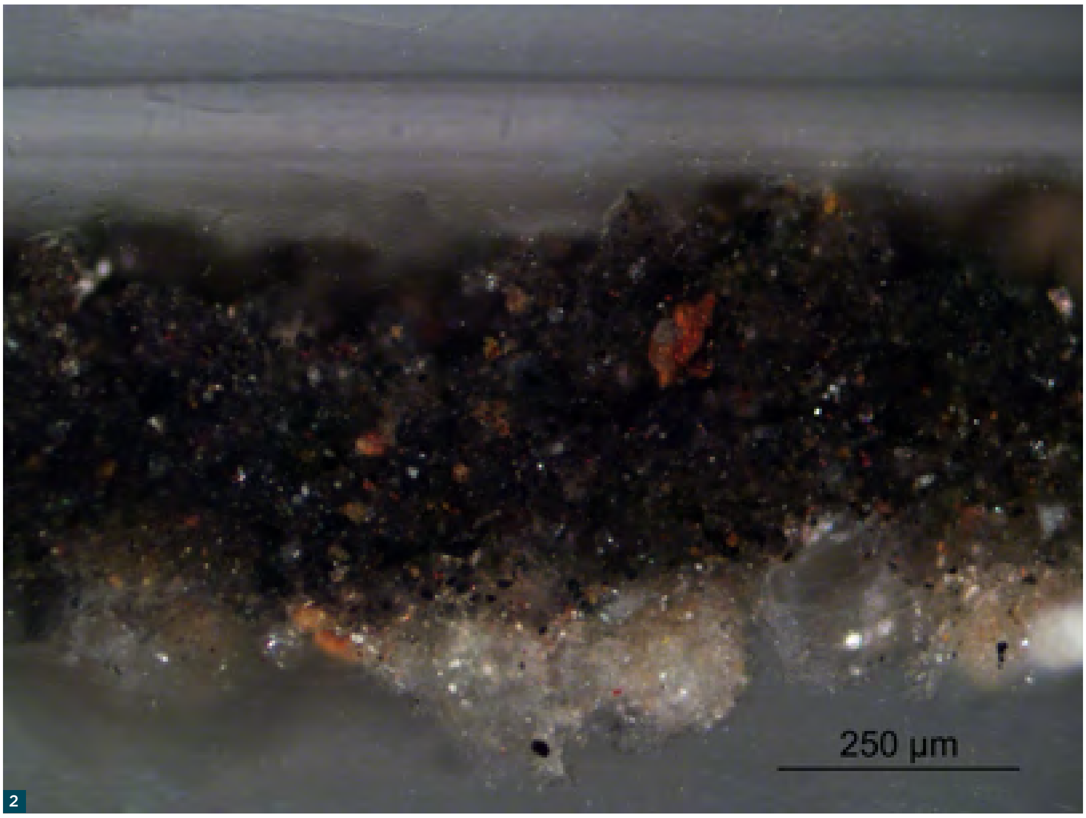

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Figure 2: Cross-section of the gypsum crust.

3. MATERIAL ANALYSIS; RESULTS SUMMARY

Limited materials analysis was conducted, and the analysis of repair and pointing mortars indicated essentially the same composition in both mixes, suggesting both were undertaken as part of the same phase of works. The mortars consist of a light pinkish-yellow, fine- to medium-grained, lime-based material. In one instance gypsum mortar was confirmed, where the material was used to secure a detaching stone scale. Its isolated application would indicate emergency treatment or a previous test.

No traces of historic polychromy were found in any of the cross-sections; only a compact, dark grey pollution crust was determined, composed of gypsum and oxidised iron particles (Figure 2). Entrapped within the mineral matrix were organic components mostly deriving from fossil fuel, while the red particles may originate from the red-brown veining of the alabaster. The exact composition of the crust was governed by the particular airborne pollutants within each area.

Results from soluble salt content determined 99% sulphates, 0.02% nitrates and negligible concentrations of chlorides. Further analysis confirmed that the sample consisted of dislocated particles and flakes of the alabaster itself (calcium sulphate) together with dissolved and re-precipitated calcium sulphate from the stone. The role of other soluble salts in the deterioration process was insignificant.

4. CONSERVATION TREATMENTS

4.1 General

All parts of the doorway showed signs of material deterioration, but while the deterioration of the sandstone elements was progressing gradually, the decay of the alabaster was developing exponentially with significant risk of material losses. Therefore, with the limited funding available, it was concluded that the preservation of the alabaster carvings should be prioritised.

The possibility of dismantling and repositioning of the alabaster elements within the church was considered but quickly ruled out due to the invasive nature and the complex issues of such a scheme, which could put the integrity of the entire doorway at risk. Therefore, the conservation of the alabaster elements in situ was seen as the most appropriate way forward. To support the long-term preservation of the alabaster, additional risk factors within the surrounding fabric of the doorway were addressed.

4.2 Cleaning

4.2.1 Evaluation of treatment options

The dark crust covering large sections of the alabaster surface contributed significantly to the deterioration of the material and prevented conservation treatments from being implemented. Therefore, in this instance, surface cleaning was considered essential and an integral part of the conservation strategy.

In 2015 various cleaning methods were tested including commercial stone cleaning poultices and laser cleaning. Although partially effective, the poultice methods were discounted. Given the hydric properties of alabaster and the friable nature of the stonework, it was felt that these cleaning techniques were not suitable as they either relied on substantial mechanical action and water usage (ammonium carbonate poultice) or their active ingredient (EDTA in Monumentique Paste C) could potentially etch the alabaster surface. Testing determined that laser cleaning offered the most effective and controlled method of removing the dark surface crust, even on the most friable surfaces.

4.2.2 Laser cleaning

The laser cleaning (Figure 3) was carried out using a Q-switched Nd: YAG laser type (1064nm wavelength and approx. 5ns pulse length). The cleaning was mainly carried out at a fluence within the range 0.5 – 0.7J/cm2 (+/-20%) with a beam approximately 5–7mm in diameter (130mJ single pulse). The repetition rate (mostly 15–20Hz at single pulse) was individually adjusted according to the surface condition of the stone and was reduced to 5Hz for the more fragile areas. By dampening the surface, the level of cleaning was significantly enhanced; the rapid vaporisation of the water molecules increased the efficiency of the dirt particles being mobilised (Cooper 1994: 150–9).

The intention of the laser cleaning was not to completely remove the pollutant crust, but to reduce the harmful impact the crust had on the alabaster. Cleaning was undertaken only to a level where it was deemed not to inflict any damage to the fabric, and therefore cleaning levels to each individual carving varied depending on the extent of disintegration.

Figure 3:
Laser cleaning, stone to the left before and to the right after (A), upper section of stone cleaned (B), cleaning in progress (C).

4.3 Consolidation

4.3.1 Evaluation of treatment options

Where the surface of the alabaster had been lost, the friable and extremely soft white crystalline matrix of the stone was exposed. To stabilise these areas and facilitate any subsequent repairs, consolidation was required. Initially, the use of calcium-sulphate nano-particles suspended in alcohol was considered. However, the lack of research related to the use of nano-gypsum particles on comparative conservation projects was of concern, and it was felt that as gypsum requires water to react under increase of volume, this could have a negative effect on the material. Furthermore, research determined a 2–3 times higher hardness within nano-gypsum particles compared to alabaster (Osterwalder et al. 2007); in conservation such an effect would be unwanted.

The decision was made to use nano-lime products and although these materials were developed for the consolidation of limestones and lime plaster (D'Armada and Hirst 2012, Otero et al. 2017), it was thought they provide the most suitable alternative to other commonly used organic and inorganic consolidants used in stone conservation.

4.3.2 Nano-lime consolidation

Following trials, CaLoSiL E25 (IBZ-Salzchemie GmbH & Co.KG) was used to consolidate friable stone; both for pre-consolidation to reduce the risk of any material losses during laser cleaning and for further consolidation following cleaning. CaLoSiL E25 contains nano-particles of calcium hydroxide suspended in an organic solvent (in this case in ethanol), resulting in the formation of solid calcium hydroxide after evaporation of the solvent. This converts into $CaCO_3$ in a way similar to traditional lime mortars by reaction with atmospheric carbon dioxide. As the product is suspended in ethanol, this method reduced the amount of water introduced into the stone.

4.4 Filleting repairs, grouting and shelter coating

4.4.1 Evaluation of treatment options

During the course of investigation, the use of lime mortars and in one instance gypsum was confirmed. The longevity of modern gypsum materials in an exterior environment is questionable and as the existing lime-based materials had performed well, it was decided to continue this approach. In order to minimise water content within grouts and mortar mixes, dispersed hydrated lime binder suspended in ethanol was used. Research has shown that the specific characteristics of dispersed hydrated lime significantly increases the carbonisation rate compared to conventional hydrated lime and as such provides a higher degree of material strength and weathering resistance, while retaining high porosity (Strotmann 1999).

Assessment of the trials undertaken in October 2017 showed that all of the tested mortar mixes performed well and that all samples achieved appropriate physical strength following curing. Informed by these trials, all further repairs were conducted using dispersed lime suspended in ethanol and fine aggregates. The injection grouts were also based on dispersed lime binder. The mixes showed good stability and flow properties as well as little shrinkage and sufficient adhesion to the surface.

4.4.2 Dispersed hydrated lime repairs and grouting mixes

Filleting repairs were generally carried out with a 45° bevel to allow the water to run off and to provide adequate support. However, the angle of the repairs was adapted in places to reduce their visual impact. Grout materials, consisting of fine aggregates and dispersed lime, were injected through openings left within the repairs to fill gaps behind delaminating stone sections. For very fine voids pure dispersed-lime binder suspended in ethanol was used, diluted with water to adjust consistency.

A variety of coloured repair mortars was used to achieve a visual balance between areas of repair and the original stone surface. The aggregate size was reduced to provide finer mortar mixes where required.

4.4.3 Shelter coating

Coloured shelter coats, modified from the repair mortar recipes, were locally applied to reduce the surface area, slow down the rate of deterioration and improve legibility of the carved details.

4.5 Temporary protection measures and spot-fixing with acrylic resin

In isolated areas, temporary support was required to facilitate mortar repairs and grouting. This consisted of surface facing with strips of gauze secured with cyclododecane (CDD). CDD is a volatile binding medium of wax-like consistency when in solid form, which sublimes into the atmosphere without leaving any residuals and therefore does not require after-treatment. The sublimation rate depends on the thickness of the film as well as the environmental conditions present (Stein et al. 2000).

Figure 4: Stones during pre-consolidation with nano-lime (A and B), filleting repairs and grout injection to detaching scale (C), detail image of fractured and degraded stone prior to conservation (D) and same detail following completion including spot-fixing with acrylic resin, grouting and mortar repairs.

Detaching, minor stone fragments (mostly in the form of thin scales) were either secured by the injection of small amounts of acrylic resin or removed, the void and the reverse side cleaned and fixed back into position by spot-fixing with acrylic resin of high viscosity (30–35% Paraloid B72 in Acetone).

4.6 Accompanying measures

In general the pointing, as well as previous repairs to the alabaster elements, proved to be in reasonable condition with only isolated areas of failure to the pointing. All sections of failing pointing were removed and re-pointed. Pointing mortar was designed to match the existing material and integrate with the surrounding fabric, using dispersed lime as binder. Further to the conservation of the alabaster archivolt, re-pointing of joints within the hood moulding and emergency consolidation of the most valuable areas within the sandstone archivolts were undertaken. Treatment was limited to areas of detaching stone fragments at risk of imminent loss to carved detailing. Hydraulic lime mortars were used in this instance to reduce the amount of free-lime within the material, which is known to have a damaging effect on some types of sandstone. To protect the doorway from water damage, the lead covering to the window sill above the doorway was improved and extended.

5. CONCLUSIONS

The cleaned alabaster order integrates well with the surface appearance of the surrounding sandstone elements, without creating an aesthetic imbalance. Furthermore, the lighter surface area will reduce any thermophysical stresses and, by removing the denser surface crust, a better moisture exchange between core material and surface has been achieved. It is assumed that with the general improvement of air quality, the formation of new dark gypsum crusts will diminish. Consolidation, grouting, filleting and fracture repairs have increased the cohesion within the stone structure of the alabaster and by reducing the surface area and the number of fissures, moisture ingress has been minimised. These measures, together with the improvement of the lead covering to the area above the doorway, will slow down the deterioration rate of the stonework in the future.

For the purpose of future monitoring, point-cloud data from high-resolution 3D laser scanning in conjunction with imaging technology will be utilised to provide reference points to identify changes in the condition of the object. In addition, further condition surveys are planned to evaluate the effectiveness of the treatments and monitor any subsequent changes.

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RESTORATION OF THE MONUMENT OF LUDOVICO ARIOSTO, PIAZZA ARIOSTEA, FERRARA

Benedetta Caglioti[1]

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[1] Benedetta Caglioti, Architect, Specialist in Restoration of Monuments, PhD in History of Architecture, Italy.
architettura.caglioti@gmail.com

ABSTRACT

The iconic Renaissance monument in Ferrara was requested by Duke Ercole I d'Este at the end of the 15th century for the 'Piazza Nova' of the Erculean Addition. The project comprised an equestrian statue of the Duke positioned on two monolithic columns with pedestal, capitals and a trabeated system. The project was never completed except for the 10m monolithic column, upon which were placed statues of Pope Alexander VII (1675), Napoleon (1810) and finally Ludovico Ariosto (1833), the symbolic Ferrarese poet. The project involved the removal of recent interventions which were structurally and aesthetically invasive; lowering of the statue using a specially designed engineering technique; disassembling of the eleven stone components of the capital due to oxidisation of the metal connectors; replacing the oxidised parts with new connectors; controlled cleaning of the surfaces and integrating with mortars made on-site with natural and sustainable materials. The purpose of this project is to restore the cleaner and safer Monument of Ludovico Ariosto to the community through a 'critical restoration', based on historical knowledge.

Keywords:
conservation of stone, structural consolidation, history of architecture

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Figure 1: Monument of Ludovico Ariosto in Piazza Ariostea, before the restoration works.

INTRODUCTION

The Monument of Ludovico Ariosto, located in the centre of Piazza Ariostea in Ferrara, is composed of two large steps, a pedestal, a monolithic column and the statue of the poet placed on top, with a total height of 21.2m (Figure 1). The restoration project of this monument, commissioned by the Municipality of Ferrara, involved the conservation of various stone surfaces and structural consolidation, granted by the scientific advice of the engineer Claudio Modena, Emeritus Professor at the University of Padua.

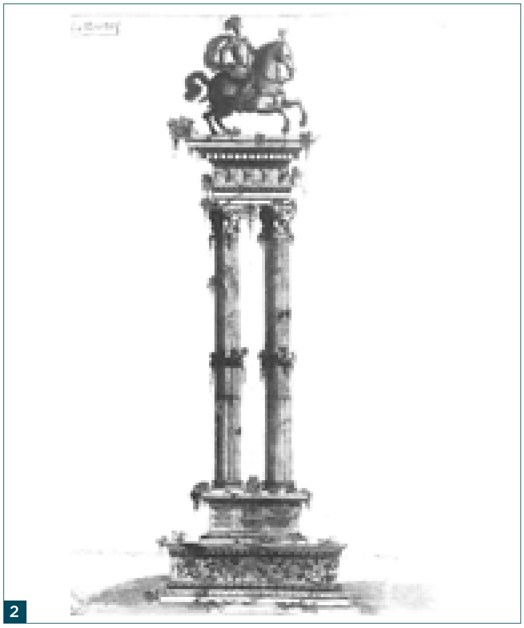

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Figure 2: Anonymous designer, Monumento equestre di Ercole I d'Este, 1603, Vatican Apostolic Library, manuscript. lat. 2774, c. 125r.

HISTORY OF THE MONUMENT OF LUDOVICO ARIOSTO

Today's Piazza Ariostea was known as 'Piazza Nova' of the Erculean Addition where the Duke Ercole I d'Este (1471–1505), at the end of 15th century, envisaged the creation of a monument composed of two large columns on which an architrave would be placed to support an equestrian statue of himself (Figure 2).

Only one of the two columns arrived in the piazza *(Cittadella, 1868, p. 23).*

In a notarial deed of 10 January 1499 *(Franceschini, 1997, p. 350),* master stonemason Antonio Di Gregorio undertook to bring the large column positioned by the River Po to 'Piazza Nova' and to arrange all necessary marble works within the year, following painter Ercole De Roberti's design, including the capital, architrave, frieze and cornice.

In a letter dated 19 September 1501, the Duke approached Cardinal Roano in Milan to request a design from Leonardo da Vinci *(Campori, 1865, p. 46)* for the execution of the equestrian statue.

A document from 28 August 1503 clarifies that marble works were carried out around the column of 'Piazza Nova' in


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Figure 3:
G. B. Aleotti, Pianta come andrebbe fatta la Fortezza se ritornasse il Po navigabile, 1605, Ariostea Municipal Library, Crispi Cartographic Collection, series XIV-5.

part by master Antonio Di Gregorio, who died the same year. This document sets out the report signed by Biagio Rossetti, the Duke's engineer, regarding the stone works carried out on the column in 1503, and defines the sum that the heirs of the deceased master Antonio Di Gregorio should demand for the works that had been completed.

The inventory present in the workshop confirms these stone works; it was drawn up by Antonio Di Gregorio's son and reports that 'unus capitellus magnus pro colona existente super platea nova' *(Franceschini, 1997, p. 635)*.

With the death of Duke Ercole I d'Este in 1505 and the rise into power of his son Alfonso I d'Este (1505–34), the works were stopped, as testified by the historical maps (Figure 3) from the end of the 16th and 17th centuries, where a rectangular pedestal with a column shaft lying at its feet was depicted in 'Piazza Nova' *(M. Florimi, 1598, 'Ferrara', Crispi Collection, Series XIV–4; G. B. Aleotti, 1605, 'Pianta come andrebbe fatta la fortezza se ritornasse il Po navigabile', Fondo Crispi, Series XIV–5).*

From the documents found at the Municipal Historical Archive *(Municipal Historical Archive of Ferrara, 'Serie Patrimoniale', Piazza Nuova, book 41, sheet 2)*, we learn that in 1604 the column was to be raised, together with its capital, and a bronze statue of Clement VIII (1592–1605) placed on top. This project did not materialise either and it was not until 1675 that the decision was recorded in the documents *(Municipal Historical Archive of Ferrara, 'Serie Patrimoniale', Piazza Nuova, book 175, sheet 46; book 185, sheet 71, book 188, sheets 11, 51, 56, 73)* to reduce the 16th century pedestal from a rectangular shape to a square, to modify its incisions and to define it proportionately with the erected column, on which would be placed the statue of Alessandro VII (1655–1667), Vice Legate in Ferrara from 1627 to 1632. It was also decided to alter the column shaft, where sculptor Cesare Mezzogori sculpted an oak branch to hide chips in the stone, while work was continued on the capital of the column by engraver Giovanni Comini *(Municipal Historical Archive of Ferrara, 'Serie Patrimoniale', Piazza Nuova, book 188, sheet 58).*

The French invasion of 1796 led to the statue of the pope being removed from the top of the column in October of the same year and it was replaced by the Statue of Liberty, which was later removed following the Austrian invasion only three years later (1799). When the


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**Figure 4:
Historical photograph, Municipal Historical Archive of Ferrara, Carteggio XIX secolo, roads and buildings, b.17, 1935.**

French regained possession of Ferrara, a statue of Napoleon was placed on top of the column on 31 May 1810 (statue sculpted in stone by the Bolognese sculptor Demaria). This was removed following the Austrian conquest of May 1814, and on that occasion it was decided to change the name of the piazza, which had previously been named after the French emperor, to Piazza Ariostea. This decision was taken with the intention of dedicating the piazza to a Ferrarese personality distinguished in the arts and literature, who was separate from the political tensions and thus appreciated by the different governments that would follow over time.

In 1833, after extensive debate, brothers Francesco and Mansueto Vidoni, stonemasons, were commissioned to create the statue of Ludovico Ariosto following Francesco Saraceni's design. The statue was erected on 25 November 1833.

When the left arm fell to the ground after a violent storm in June 1879, the Municipality sought to promote works on the statue and decided that the upper section should be reconstructed. They were carried out by sculptor Ambrogio Zuffi in 1881 *(Municipal Historical Archive of Ferrara, 19th century correspondence, 'Potenze – Monumenti', B31, file 2, sheet of 7 May 1881)*.

In April 1935, with the aim of adapting the piazza to the racing events of the Palio, the central part was dug out into a slight slope which uncovered part of the foundations of the Monument (Figure 4). The foundations were clad with white Verona stone slabs to form the first two high steps that are still visible today *(Municipal Historical Archive of Ferrara, 20th century correspondence, 'Strade e Fabbricati', B17, 'Lavori di sistemazione di P.zza Ariostea 1935', sheet 31 January 1935)*.

Analysis of the documents found at the Municipal Historical Archive testifies to the numerous restoration works carried out on the whole of the monument, from the pedestal to the statue, from 1830 to 1881 *(Municipal Historical Archive of Ferrara, 19th-century correspondence, 'Potenze – Monumenti', B31, file 2-3-1B, sheet from June 1830 to June 1881)*.

THE ‘CRITICAL RESTORATION’ PROJECT

The historical/critical knowledge of the Monument of Ludovico Ariosto was the starting point for the restoration project. For the conservation project, critically evaluated, the professionals involved considered the critical judgement behind the project choices from both a historical/aesthetic and structural point of view (Carbonara 2012).

The first phase of the restoration project included analysis of documentary research and site investigations simultaneously. Firstly, historical research was carried out both by reading the published bibliography, cartography and iconography, and through archival research at the State, Municipal and Italian Heritage Office Archives.

The following were performed before proceeding with the works: site analysis using a drone and laser scanning to provide a 3D record; optical microscopy to define the various types of stone; diagnostic investigations using video-endoscopy, geo-radar and ultrasound to understand the structure of the monument; and accelerometer measurements for dynamic characterisation due to external forces (wind and vibrations caused by traffic). Direct analysis led to the drafting of the architectural metric survey, photomaps, and cognitive and diagnostic analysis of the materials and structural parts. This allowed the drafting of the relief of the cracking pattern and analysis of the deterioration, both structurally and superficially.

The results of the documentary research and site investigations were compared and considered not only as a cognitive instrument but also as a reading of the character and specific values of the architecture. This aided the decision-making processes, taking into consideration the current ‘culture of restoration’.

The site investigations were carried out during the planning phase and revealed that the metal parts had suffered the greatest deterioration. In particular, two types of metal were used for reinforcement: normal steel, adopted in the past, and stainless steel, used in more recent interventions. The connection between these steels caused a cathodic oxidation effect which had accelerated and amplified the erosion of the traditional steel, resulting in the expansion of the steel inside the stone and movement of the stone parts in contact with it. These damaging


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Figure 5: Statue of Ariosto disconnected at the base.

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Figure 6: Podium of the statue. The external metal support ring in stainless steel has been welded to the damaged parts, accelerating oxidation.

mechanisms, triggered by metal oxidation, constitute, from a structural point of view, the most significant problem encountered in the whole monument, with the most compromised parts being in the podium of the statue and in the capital.

The statue of Ludovico Ariosto had particularly detached at the base due to the forward positioning of the bust. This problem had probably already been observed in the past, considering the metal reinforcement to support the statue. However, today it appears to be ineffective and not well-consolidated (Figure 5).

The area of the podium, between the statue and the capital, is composed of several elements that constitute a wall of square stone elements which, following the deterioration of the connectors, have gradually become disconnected. Probably with the aim of reinforcing the various elements, a modern external metal support ring in stainless steel had been inserted and welded to the internal metal elements, causing accelerated oxidisation (Figure 6). By analysing the cracks in the podium, it was possible to observe the area of the corroded metal that has broken causing its upper part and the statue itself to incline. This phenomenon can be traced back to the jacking effect of the internally oxidised metal, particularly at the internal anchorage, which has caused the discontinuity between the connectors to open up.

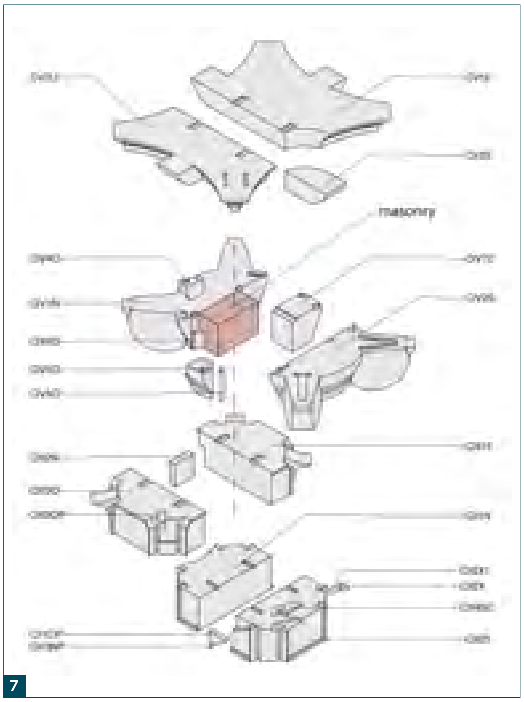

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Figure 7: Exploded axonometric view of the capital drawn up following the dismantling of the various elements and preparation for their repositioning.

The capital of the Ariostea column is made up of a series of four elements placed on top of each other, each of which constitutes various stone elements, positioned on the monolithic shaft (Figure 7). Each stone element had detached with cracks a few centimetres

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Figure 8: Capital of the column before the restoration works and the dismantling of each stone element.

wide (Figure 8) due to the stone jacking caused by the expanding metal inside (Figure 9).

In light of these observations, all the internal metal elements were replaced with new duplex stainless steel connectors of the same dimensions as the existing ones and placed in the same positions (Figure 10). To be able to carry out this operation, it was necessary to lift the statue together with each stone element comprising the podium and the capital.

Metal rope was used as a solution to prevent the column shaft from falling which was inserted along existing grooves, replacing a previous intervention carried out in stainless steel externally.

The metal cramps uniting the stone cladding on the cymatium of the pedestal of the column had suffered significant deterioration. As well as the restoration of the stone and its superficial treatment, the oxidised metal cramps were replaced with new ones in stainless steel, set and secured in molten lead.

The architectural surfaces were cleaned using biocides, clay poultices and manual techniques to remove superficial deposits, incrustations and the presence of biological staining (Figure 11). The incompatible elements were also removed (metal cramps and cement mortars) and the cracks and gaps were filled using special natural mortars mixed up on the site. They were then treated superficially with a thin coating

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Figure 9: Oxidation of the internal fixtures between the parts which define the individual stone elements of the capital.


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Figure 10: New cramps in duplex stainless steel connecting the various elements of the capital.

(Figure 12). As a final operation, the whole surface of the monument (from the statue to the steps) was treated with protective products. In particular, a protective product against vandalism was used to treat the large steps.

The monument presented widespread superficial deterioration caused by exposure to weather conditions and pollution. In particular, rainwater running from the top of the statue to the pedestal of the column had caused erosion, favouring the formation of biological patinas and the accretion of superficial deposits. There was a protective lead covering on the top of the capital, which was in such a poor condition that it had allowed rainwater to collect instead of letting it flow off the statue. In addition, the metal element, now oxidised and irregular, had altered the appearance of the top of the capital. The project involved removing the oxidised sheets and creating a more compatible system to allow rainwater to drain off the monument. A screed of breathable mortar was applied across the whole of the top of the capital with a slight inclination to help the rainwater run off, and it was applied as thinly as possible so as not to alter the perception of the top of the capital. This was then covered in a sheet of lead.

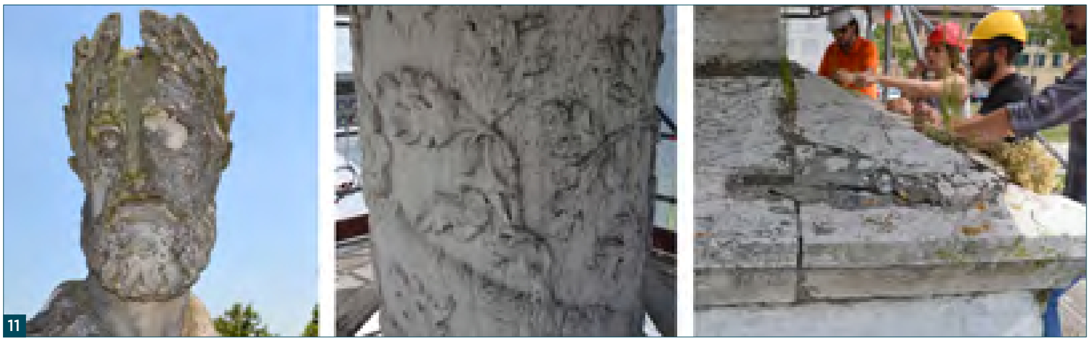
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Figure 11: Deterioration of the surfaces of the statue, shaft and pedestal.


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Figure 12: Operations to clean the surfaces of the statue, shaft and pedestal.

CONCLUSION

The restoration project of the Monument of Ludovico Ariosto was configured and realised with a multi-disciplinary approach involving study, analysis and comparison between the professionals involved, municipal officials and officials from the Ministry of Cultural Heritage.

The objective of returning the monument to the community, which required both structural and superficial restoration, was pursued through a circular process of understanding and conservation, and was fulfilled based on critically evaluated choices to recuperate the monument's visual unity and consequent capacity to reveal itself in each and every one of its elements: 'la esigibilità del monumento'.

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CHANGING APPROACHES TO CHURCH MONUMENT CONSERVATION FROM THE 19TH CENTURY TO THE PRESENT DAY

David Carrington

Dr David Carrington ACR FSA, Director, Skillington Workshop Ltd, UK.
skillwork@aol.com

ABSTRACT

The paper illustrates how the treatment of church monuments in Britain changed from a typical high-end craftsman-led activity during the Victorian period through various significant changes in direction in the 20th century to present-day conservation approaches.

Edward Richardson's restoration of the alabaster effigies at Elford and Gilbert Scott's treatment of the Westminster Abbey monuments illustrate a broad spectrum of 19th-century interventions, driven in part by the restoration of churches. The still widespread restoration approach is tempered in the early 20th century by a preservation philosophy practised by Fred Crossley on wooden effigies and in the damp-proofing methods applied at Swine Church in the 1930s. Whereas the Great War had led to the loss of craft skills, the Second World War resulted in the temporary removal of many works of art, including monuments, from some of our great churches. Post-war reconstruction and reinstatement led to both restoration in the tradition of Richardson (as at Temple Church in London) and also the birth of the museum-based approach.

By the 1970s, attempts to isolate church monuments from the building environment were starting to become the norm and were prevalent in the 1980s and 90s. However, it was becoming apparent that such an approach involved a very high degree of intervention and was not necessarily sustainable. Far more emphasis began to be placed on the treatment of the architectural context as well as the 'object' itself. The practice of church monument conservation today places far more emphasis on the investigation phase of work, understanding the relationship of monuments to the building fabric and envelope in a more scientific and holistic way to better inform treatment than in the past. This is resulting in a less standardised approach to monuments themselves, and one that will also benefit from continuing developments in investigative technology.

Keywords:
church monuments, historic conservation, Edward Richardson, F. H. Crossley, Swine Church

1. INTRODUCTION

It is a well-accepted mantra of conservation that an understanding of what is being conserved is a critical factor in determining how it should be conserved (McCaig 2013). Part of this understanding is knowledge, as far as possible, of previous interventions. This contextual approach is now commonplace in church monument conservation in the UK, but the broader study of how conservation practice in this field has developed historically has been widely neglected. This paper attempts to address that, at least from the 19th century to the present day.

2. EDWARD RICHARDSON

Edward Richardson (1812–69) was a London-based sculptor whose work can be found in places as far apart as Chichester, Canterbury, York and Chennai (Madras) Cathedrals (Roscoe et al. 2009). His original work by no means met with universal acclaim and it was perhaps for this reason, as well as because of an interest in medieval sculpture, that he dedicated so much energy to the restoration of old monuments.

His career as a restorer of monuments started in 1842 when he was commissioned to work on the nine medieval effigies of Temple Church in London as part of Sydney Smirke's restoration (Lankester 2010). Richardson's published account illustrates and describes the effigies before restoration, noting details such as any traces of colour found. However, it fails to describe the work that he carried out beyond re-ordering the effigies. The document implies that works included piecing in of new work, removal of earlier plaster of Paris repairs, re-cutting of weathered surfaces and repairs to breaks.

All but one of the effigies were severely bomb-damaged in 1941, and they have since been restored again. We are left with evidence of his restoration in the 1853 plaster casts in the Victoria and Albert Museum, numerous photographs and Esdaile's description of them as being 'so much re-cut that they can scarcely be described as medieval' (Esdaile 1933). Richardson's approach to historical detail is exemplified by his attempt to stain the 'Roche Abbey' stone of one of them to make it resemble Purbeck marble (I'Anson 1927).

Figure 1:
Detail of a knight of c. 1410 from Elford (Staffordshire), showing intricately carved alabaster indent restoration by Richardson. The inscription is an addition probably of c. 1540, when the monument was 're-used'. The monument was most recently conserved in 1996.

Such an approach, although not unusual at the time, was not universally endorsed, and reaction to this work was immediate and strong. He was refused admission to the Society of Antiquaries; Augustus Hare called him 'a charlatan who has planed down the effigies' (Gunnis 1968) and his request to carry out further work to monuments in the Temple Church in 1853 appears to have been turned down (Esdaile 1933).

Richardson's most ambitious and proudly published (Richardson 1852) restoration programme was to the medieval effigies at Elford church (Staffordshire) between 1848 and 1849. The monuments were re-ordered, missing or damaged parts replaced (often by indenting) or re-cut and the sculpture 'cleansed' (Figure 1). It is not clear as to what extent this cleaning involved the removal of surface limewash or original polychromy, but today only minute traces remain.

Cleaning seems to have involved the abrasive rubbing down of stone (especially alabaster) surfaces to remove etched graffiti and scratches as well as surface dirt (Richardson 1852). To Richardson's credit he took plaster casts of all areas that he worked on and his published account of the work is, despite a lack of detail about some of the processes he employed, exemplary in its thoroughness of recording at this date. It is, however, quite likely that the account was published in the hope that it would justify the extensive restoration in the face of criticism which by then must have been anticipated.

3. GILBERT SCOTT AND THE ROYAL TOMBS AT WESTMINSTER ABBEY

Sir George Gilbert Scott (1811–78), Surveyor of the Fabric to Westminster Abbey, was an architect who made many advances in the treatment of church monuments. It is possible that this reflects rather than leads that of his contemporaries but, because of his stature and because his work is relatively well documented, it is easy to give much of the credit to him. The fact that he was not alone is exemplified by William Burges' chapter in Scott's 'Gleanings from Westminster Abbey', where the utmost of respect for the historic patina is described (Scott 1863).

Clearly Burges had recent restoration work by the likes of Richardson very much in mind. In Scott's own words, his objectives concerning the treatment of the royal monuments were to preserve them from further decay rather than to attempt any restoration (Scott 1854).

Scott's report of 1854 provoked a reaction from the Society of Antiquaries and the Royal Archaeological Institute, again probably mindful of Richardson, protesting that the monuments should not be touched.

The work that was actually carried out on the royal tombs started after drawings and photographs were taken. It involved the cleaning of the bronzes using 'acids of oxides' and the cleaning and 'induration' of stone surfaces.

Induration was Scott's attempt at what would now be called consolidation. He saw this as a means of stabilising deteriorating stone surfaces, especially powdering and flaking Purbeck marble. All the royal tombs in the sanctuary were treated in 1856 by applying a solution of shellac in alcohol to their surfaces. Where deeper penetration was required, a gardener's syringe was used to apply more dilute solutions, increasing the concentration as one worked towards the surface. The aim was to find a method of indurating stone throughout the entire building. The significance here is threefold. Firstly, the method was apparently first used on the royal tombs. Secondly, such practices were likely to have been employed by Scott and his contemporaries for some time to come in undocumented cases. Finally, the introduction of the concept of consolidation marks a significant development in the treatment of monuments, being at least in part a reaction to the restoration work carried out by Richardson and others in the preceding decades. However we might today regard the actual methods used, the principle of preservation over restoration has at least been established.


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Figure 2:
The oak effigy of a lady, mid-14th century, at Paulerspury (Northamptonshire), conserved by Crossley in about 1920. No attempt was made to restore missing features such as the hands.

4. FRED CROSSLEY

Frederick Herbert Crossley (1868–1955) is well known as a woodcarver, an author and a photographer. He was, however, also a pioneering conservator, particularly for wooden effigies. He was responsible, for example, for the repair and stabilisation of the two mid-14th-century wooden effigies at Paulerspury, Northamptonshire (Figure 2). This work was instigated in about 1915 and carried out during or shortly before 1920 (evidence of these dates can be found in unpublished archive letters to Rev. Cam). In 1916, George Sheddon writes a letter explaining that fundraising had begun for the project, and the invoice was sent by Crossley in May 1920. Crossley's work followed that advocated in a report from the Society or the Protection of Ancient Buildings. This advocated cleaning, treatment with Formaline, filling of holes with paraffin wax and consolidation of the back with canvas glued in place. Breaks were to be repaired by dowelling through hidden surfaces and gluing. Limewash was brushed off but allowed to remain in the grain, and the oak left otherwise in its natural state with no applied oil (Powys, undated).

The success of this treatment is evidenced by the good condition of the effigies today. The materials used might be altered, but the philosophy of his approach is familiar 100 years on.

5. G. W. MILBURN AND SONS

The next reference point comes in the early 1930s with the York sculptors G. W. Milburn and Sons' treatment of the alabaster monuments at Swine Church in East Yorkshire under the direction of the architect Colin Rowntree. This is best described in Mr. Rowntree's words:

> *. . . very considerable damage had been, and still was being, caused by dampness, which had disintegrated some of the alabaster mouldings and carving and caused them to crumble and to powder. Similar damage had been caused by the heat from a stove which had been set up in close proximity to one of the tombs.*
>
> *The tombs were taken down, any loose alabaster was brushed off, and the backs of the panels were coated with bitumen where necessary. In rebuilding, lead damp-proof courses were fixed under all the panels to prevent any damp rising from the bases, the slabs were held together with copper cramps, and broken limbs or other portions of the effigies were dowelled and the joints carefully pointed up.*
>
> *No attempt was made to restore any of the old work, but a narrow wooden strip and a corner of a panel which had been filled in with cement were replaced by pieces of alabaster. (Crossley 1939)*

The treatment of these three tombs is exceptional for four reasons:

- The publication of such a full description of the work undertaken, albeit quite briefly. The condition before, causes of decay, philosophy towards repair and restoration, method of rebuilding and problems encountered are all covered.
- The principle of isolating the monument from damp is a very early example of such an approach.
- The Swine tombs are very similar in form to the alabaster tombs restored by Richardson at Elford, yet the treatment to damaged areas was far more conservative.
- The choice of bedding, pointing and fixing materials is noteworthy. Cement was totally avoided, using plaster of Paris instead, and copper cramps were chosen to replace existing (presumably) iron ones.
- Two of the three tombs have had no further treatment, enabling the relative success of Rowntree's approach to be assessed (Figure 3). Unfortunately the damp-proof course can now be seen to have failed, allowing the alabaster to continue to deteriorate as it had before.

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Figure 3: Alabaster tomb chest with effigies of a knight and lady of c. 1410 at Swine (East Yorkshire), conserved in the 1930s with an early attempt at isolating from damp with a membrane.

6. FROM THE SECOND WORLD WAR TO TODAY

The Second World War formed a watershed for the treatment of church monuments. The impact of the war itself was concurrent with legislative developments in Anglican churches at least. In particular, Diocesan Advisory Committees were statutory from 1938, and the 1955 Inspection of Churches Measure. The long-established practice of repainting monuments ceased during the 1960s, as more emphasis was placed on preservation rather than restoration of colour. Such a conservation approach occurred in parallel to an increased involvement with museums in the post-war restoration of monuments. The Victoria and Albert Museum, for example, was involved with the reinstatement in 1945 of the ten or so effigies removed from Westminster Abbey in 1939.

It seems to be from this influence, spread through a new legislative framework, that monuments were increasingly treated as objects in isolation of the churches in which they were housed. Indeed, all their problems were deemed to stem from their building environment, and through the influence of a generation of conservators grounded with this approach, the almost universal course of action for monuments in poor condition from the later 1970s to the mid-1990s was to make every effort to isolate them from the building – taking the Swine approach to its ultimate conclusion (Larson 1978). This approach is the dry method.

Present-day approaches tend to be less prescriptive, and treatments are typically underpinned by scientific analysis of the building context and the causes and rate of deterioration, resulting in a more holistic approach. Treatments applied to monuments themselves do on occasion require complete dismantling and rebuilding, sometimes with a view to isolating from direct contact with the building environment. This has been driven to a large part by requirements of the faculty process. In Church of England churches permission is required from the Diocese for any works to go ahead. This process has contributed to the improvement in standards. The contemporary investigative and reporting process is normally built up in two or more phases as a result of this (Carrington 2006).

New challenges continue to arise. Damage from bat urine and droppings has become a greater concern in parallel with changes in bat habitats and increased levels of protection for bat colonies. More and more churches are under threat of redundancy, challenging our estimation of the value of the context in which monuments were built if moving them gives a better chance of preservation, and challenging how works are funded.

Science constantly provides new tools for non-destructive investigation, such as hand-held XRF machines. This method has recently been used, for example, to examine the Chapter House carvings at Southwell Minster for traces of paint and of metal leaf.

Climate change is starting to affect how we look at building performance, including how temperature increases or changes in rainfall patterns might affect the moisture content of the building fabric and the internal environment.

7. CONCLUSIONS

19th-century approaches including scraping (‘denudating’) and re-ordering continued to be the norm at the beginning of the 20th century. As exemplified at Paulerspury, a break occurred with the Great War (1914–18) – not only during the years of fighting, but for several years afterwards, as the country started to recover from the loss of a generation of skilled craftsmen and a lack of finance for such endeavours. Much of the energy of stone carvers during the immediate post-war years went into the production of war memorials.

Lack of documentation hampers a study of the development of conservation practices as applied to church monuments until the later 20th century, but a few key reference points chart the early stages of a revolution that was to come to fruition some forty or fifty years later. Sir George Gilbert Scott’s experiments with ‘induration’ during the 1850s and 60s are the earliest documented attempts to ‘conserve’ deteriorating monuments – although he would have considered it to be an aspect of ‘restoration’. Crossley’s philosophy was closer to what we might consider as conservation today, and the work at Swine was a precursor of the museum-based approach that had developed by the 1970s.

Present-day conservation starts with far more rigorous investigation before making any physical intervention and results in a far wider range of treatments being applied, always with greater regard for the building environment. However, things do not stand still and there will be more chapters to this story in the future, not least of all driven by challenges that none of us would have foreseen thirty or forty years ago.

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REVEALED BY FIRE: HISTORIC GRAFFITI AT BIRKHILL HOUSE, COALBURN

Paul Barham

Paul Barham ARB RIBA RIAS FRSA, Director and RIAS Accredited
Conservation Architect, Barham Glen Architects, Scotland.
paul@barhamglenarchitects.co.uk

ABSTRACT

When fire devastated Birkhill House in March 2016, owners Talamh Housing Co-operative engaged conservation architect Paul Barham of Barham Glen Architects to help save what remained of the house and manage its repair and restoration. The interior and roof of the house had been badly damaged and the panelled rooms referenced in its statutory list description were lost. Repairs were carried out in 2017 by W. H. Kirkwood Ltd and included a new slated roof, timber floors, stone repairs and new windows and doors. The removal of fire-damaged panelling revealed red ochre drawings showing armed figures wearing garb estimated by Historic Environment Scotland to date from of the 1600s. The Co-op remains in touch with the family that farmed Birkhill for two hundred years, who have shared documents going back to the confiscation of the house following the death of its Covenanter owner at the Battle of Bothwell Bridge. The final phase of repairs is now under way, incorporating the figures revealed by the fire as interpretive exhibits, along with sword-sharpening marks and witches' marks, all on the same lintel, salt and bible boxes and lintel inscriptions uncovered elsewhere in the building.

Keywords:
Birkhill, historic graffiti, Covenanters, interpretation, fire, Talamh

Figure 1:
Fire – the immediate aftermath.

1. INTRODUCTION

Since 1993, Birkhill House in Coalburn, South Lanarkshire has been home to Talamh Housing Co-op, a diverse group of people working towards sustainability and low-impact living. On 14 March 2016, a catastrophic fire all but destroyed the B-listed farmhouse, and everything in it. Fortunately no-one was seriously hurt, but the fire was a serious blow to Co-op members and put at risk more than three hundred years of local heritage.

Repair works started in the spring of 2017, and by mid-2018 a new slate roof, stone repairs, timber floors and new timber windows had been installed. Since then the Co-op has been using self-build skills to complete the internal finishes.

While the main repair works were under way, the removal of some fire-damaged wall linings revealed what appeared to be painted figures on the wall surface underneath. An astute site manager brought the historical graffiti to the attention of the architect, who alerted HES. HES took an immediate interest in its possible historical significance. It is the story of these figures, what they might mean and how they might be conserved and made accessible that is the subject of this paper.

Figure 2:
Birkill House in the year 2000.

2. THE FIRE

The author had been working with the Co-op and its sister charity, Talamh Life Centre, on a funding bid for craft workspaces and on hearing news of the fire overnight drove to Coalburn to see what could be done to save the building. The fire was still ‘live’ and the area around the farmhouse cordoned off by the emergency services. Fortunately no-one had been seriously injured.

The collapsed roof and floors were pushing out on the water-drenched three hundred-year-old walls, and it was impossible to tell how stable the remaining structures were. By the time the fire and rescue services were ready to hand over what remained of the farmhouse to building control, a project management team had been assembled, consisting of a conservation-accredited architect and structural engineer. The author had an ongoing involvement with repair and maintenance issues at Birkhill and was able explain this to the South Lanarkshire Council’s BCO, who was willing to accept a monitoring role in the knowledge that a competent design team was in place and ready to make an assessment of the structure.

Figure 3:
Extent of fire damage, March 2016.

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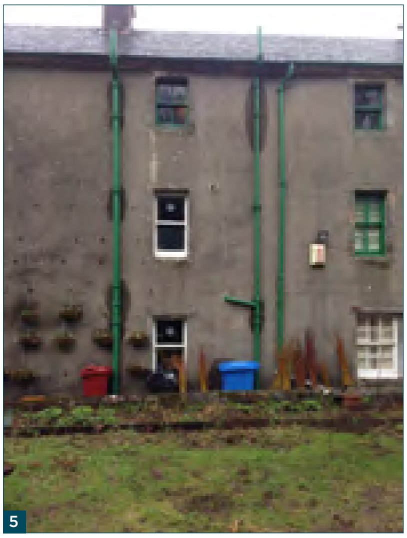

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Figure 4: Beneath the debris, some of the panelling still appeared to be salvageable.

Figure 5: Condition survey, February 2016: the cracks that pre-dated the fire.

The engineer and architect revisited the scene the following day. The 700mm thick walls were holding up well, with some displacement of wallheads and skews. Inside, however, the house was a charred and sodden mess.

The structural engineer issued his report on the building structure within a week, and was able to suggest a contractor with experience of stabilising fire-damaged buildings. Building Control were kept informed and the cordon maintained around the damaged building.

It took two months before the insurers settled the claim and work could be instructed, and all that could be done meantime was to monitor the condition of the building. It proved useful that the author had carried out a building survey less than a month before the fire. From the photographic record it was clear that cracks in the walls had been there before the fire, and that there were no signs of subsequent deterioration.

At the end of May 2016, the design team was able to progress immediately with the stabilisation works and prepare repair proposals. Meanwhile, housing co-op members showed their resilience by utilising the farm courtyard as an outdoor living space.

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Figure 6: Temporary field kitchen – life goes on at the housing co-op.


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Figure 7:
Inspecting the damage from the 'man-basket'.

Figure 8:
Assessing the requirements for the strip-out and stabilisation.

3. STABILISATION WORKS

Stabilisation works started in July 2016. The first priority was to clear the inside of debris, then to install a temporary support system for the walls.

An aerial survey was carried out to establish the condition of wallheads, remnants of roof structure and damaged wall linings. Close examination showed all wall panelling to be damaged beyond repair.

The first requirement of the stabilisation works was to relieve pressure from debris on the external walls. Working from the man-basket, fire-damaged material was dropped through what remained of the floors onto the solid flags of the old farm kitchen. A mini-excavator was craned in and the debris craned out by the mini-skipload. Whilst none of the interior finishes were salvageable, the remains of a number of fireplaces were removed for safe-keeping.

Following the strip-out, all that remained within the walls were the stone turnpike stair (including its roof), the central chimney, and four steel beams at first-floor level.

Access was now easier, and it was possible to carry out more detailed survey work. It was at this time that one of the two sisters who grew up in the house paid one of her periodic visits, her first since the fire. The Smith family


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Figure 9:
Aerial inspection – the housing co-op were still able to use the courtyard.

Figure 10:
Soft-strip nearing completion.


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Figure 11:
Main fireplace wall – figures remain hidden behind plaster.

had lived at Birkhill House for nearly two hundred years and had shared records going back a further century. Isobel Prowse was able to point out features long since covered up but now once more exposed to view: recesses which according to family history had originally served as salt or bible boxes (one beside the kitchen fireplace to keep valuable salt dry, another near the centre of the house which may have kept the family bible from prying eyes during the religious persecutions of late 17th century Scotland). Other erstwhile hidden features included the remains of built-up doorways, complete with remnant ironmongery, and the steel beams inserted into an excessively bouncy drawing room floor almost seventy years previously.

The stabilisation works involved an internal scaffolding support and flying shores tied through window openings. Exposed wallheads were capped temporarily with lime mortar.

The survey drawings were now updated to include detailed dilapidation and repair proposals so that the full repair works could be tendered.


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Figure 12:
Temporary works in progress.

Figure 13:
Temporary works completed.

Figure 14:
East gable dilapidations – surviving parging concealing the hidden figures.

Figure 15:
East gable section repairs – the reinstatement of panelling was taken out as a saving.

Figure 16:
Mid gable dilapidations.


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Figure 17:
Mid gable section repairs.


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Figure 18:
North wall dilapidations.


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Figure 19:
North wall section repairs.


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Figure 20:
Progress on site.

4. MAIN REPAIRS CONTRACT

The main repair works were tendered in September 2016 on the basis of a detailed schedule of works, full repairs drawings and NBS specification. The detailed schedule became an essential tool to establish the extent of work which could be afforded, once the insurance pay-out was known.

After negotiations with contractor W. H. Kirkwood Ltd, in February 2017 a substantially reduced tender sum was agreed to carry out the full repairs, minus services and internal finishes. Work started in March 2017, exactly a year after the fire.

The approach was to make the shell watertight as quickly as possible, to protect the still vulnerable wallheads and so that the saturated walls could begin to dry out. This allowed the roof to be rebuilt before the temporary supports were removed.

Where historical detail had been exposed at the ground floor level, the stonework was left exposed and repointed. Elsewhere the stonework was parged or pointed, depending on its condition.

It was in May 2017 that a curious and observant site manager called the architect to come and see the red ochre drawings on the newly exposed lintel to the drawing-room fireplace.


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Figure 21:
Replacing the roof was the first priority.

Figure 22:
The figures on the fireplace lintel, revealed when the plaster was stripped.

5. THE FIGURES ON THE LINTEL

The figures must be older than the panelling that covered them up for two centuries, and possibly pre-date the ownership of the Smith family. The first people to tell would therefore be Isobel Prowse and Janet Telfer, the sisters who knew so much about the history of their old home. At the same time, arrangements were made for HES to visit and take detailed photographs. After the visit, HES forwarded the following advice from the curator at the National Museum of Scotland:

'I think the image could date from the early 17th century and therefore be contemporary with the house – based partly on the way the figures are drawn, and partly on the hats. The hats have a close crown, a broad brim that curves upwards, and the one on the right seems to have a feather in it. It is hard to know exactly what kind of hat is being represented, but the drawing conforms to a broad type current from c. 1620s–1650s in Western Europe.

'The long hair of the men would also fit with an early to mid 17th century date – the drawing seems to suggest natural hair, and wigs became the norm in the second half of the 17th century.'

This seemed particularly interesting, especially considering that the date on the lintel over the main door into the turnpike stair is 1692. How could the figures be earlier?

Since 2003 Isobel Prowse has shared details of the farm going back some three centuries, from the Lockharts of Birkhill to her own family, the Smiths. The information is taken from the Smith family *Book of Memorandums*, written at Birkhill by John Smith (the purchaser in 1792) and the *Annals of the Parish of Lesmahagow*, by J. B. Greenshields, Advocate (1864), and these documents may provide the key.


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Figure 23:
The two armed men.


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Figure 24:
The drawings in the centre of the lintel.


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Figure 25:
The drawings at the right-hand end of the lintel.


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Figure 26:
Wall linings stop short of the fireplace to display the graffiti.

Figure 27:
Detail from old plan (c. 1800) – Birkhill House is accurately drawn.

Robert Lockhart of Birkhill was a Covenanter who fought and died at Bothwell Bridge (1679). The property was then forfeited, but returned to the family after the accession of William and Mary. The date carved on the main door lintel in the turnpike stair is 1692. It appears that the restoration of the estate to Robert's widow and son was celebrated by the building of a new house or by extending the house built in the 1660s. That the new enlarged house may have incorporated the earlier dwelling house is supported by a letter from Andrew Smith (10 August 1896, *Book of Memorandums*), which suggests that the earlier house probably consisted of only two storeys, of a kitchen and store room on the ground flat and an apartment above divided by a wooden partition. The fire of 2016 also revealed solid stone lintels running the full depth of the wall to the first-floor windows, whereas ground- and second-floor windows had timber safe lintels behind the stone of the façade.

The remains of an old doorway in the middle of the house provide evidence of extensive alterations (the old low doorway may have been a cattle door) and it appears probable that lower two storeys to the east of the turnpike stair pre-date the inscription over the door lintel, and likewise the ochre drawings on the upstairs fireplace lintel. The *Book of Memorandums* also records that ochre was excavated on site.

The drawing on the lintel depicts a scene of violence. The two men on the left are armed, and are clearly depicted. Which side they are on, and who or what they are attacking, is less clear, but it is hard not to surmise that the events relate to the 'Killing Times' of the late 17th century.

We are fortunate to have a record of the history of Birkhill House since the 17th century. The house was subsequently enlarged and extensive alterations were carried out in 1737. Birkhill was purchased by John Smith in 1792 and old plans (the original in the safe-keeping of Janet Telfer, but a charming copy lost in the fire of 2016) appear to date from around this time. The stylised image of the house shows the characteristic three-bay building with three chimneys, the central one offset to the left.

The *Book of Memorandums* goes on to describe various changes during the 1800s; however, it is interesting now to note that the figures on the lintel remained hidden from view throughout the two whole centuries of the Smith family's tenure.

Figure 28: The other old plan – reconstructed from photos taken during framing, some years prior to its loss in the fire.

6. COMPLETION

The figures on the lintel were left in the state in which they had been uncovered, and temporary protection was put in place. No other drawings or marks were found in the house.

Since handover of the building as a wind and watertight floored shell in late 2017 the Co-op has progressed with the installation of services, insulation and finishes on a self-build basis. The area of wall around the fireplace and lintel has been left untouched, with wall linings stopping at either side.

Some sooty handprints were successfully removed from the lintel, using small sponges dipped alternately in buckets of mildly soapy and pure water to dab away the soot.

Talamh Housing Co-op remains intent on protecting the figures and using them as an educational resource.

7. LESSONS LEARNED

It should not be a surprise that a catastrophic fire should uncover hitherto unknown aspects of a building's history, nor that these might point to other historical events with wider cultural resonance. Nevertheless, when one is engaged in a demanding project with the specific focus on building repairs, such considerations may too easily be overlooked.

As far as concerns the discovery and protection of the figures Birkhill House, the key lessons learned have been:

- The importance of responding quickly to a building at risk
- Putting together the right team for the job
- Client engagement and focus throughout the project
- Maintaining good client-contractor relations
- The benefit of knowing something about the building's history
- To be prepared for surprise discoveries in the course of repair work
- To respond positively to the challenges to conservation in a lived-in environment.

Figure 29:
Birkhill House restored.

8. CONCLUSIONS

Further research needs to be carried out into how best to conserve the figures, and what their precise meaning is. What environmental factors could affect the figures now they are exposed to view? Should the figures be enclosed or kept open to view? How are the figures to be protected from day-to-day damage? What are the options for conservation and display of other historic features, such as the knife-sharpening scars and possible witches' mark identified by HES?

Have similar figures have been uncovered elsewhere? Can more be found out from the drawings themselves? Apart from the armed figures, the other faces and symbols have still to be explained. It has been assumed that the drawings are red ochre, possibly dug on site, but can this be established?

The Co-op plans to utilise the wall drawings along with other embedded historical features as a means of illustrating graphically the history of the farm in relation to important events in local and national history.

Current plans for Birkhill include exploring funding routes to develop the site as a centre for environmental education and traditional skills. As more information comes to light concerning the origins of the farm and its place in local history, so the opportunities increase for the conservation and development of the farmhouse and outbuildings as a collection of self-interpretive artefacts.

It is to be hoped that historians may shed more light on the meanings and motivations behind the figures, and that a well-researched interpretation of the figures can be provided for visitors. The second half of the 17th century saw violent upheavals which still resonate in Scotland today, so perhaps the least we can do now is establish who the figures on the lintel were and make the connection between them and the fortunes of successive incumbents of Birkhill House.

ACKNOWLEDGEMENTS

The following people and organisations have all had a hand in saving Birkhill House and uncovering its historical graffiti: Talamh Housing Co-op; Isobel Prowse; Janet Telfer; W. H. Kirkwood Ltd; Burnfield Builders & Demolishers Ltd; Stewart Mackie (The Structural Partnership); HES.

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COLOURS IN ROMANESQUE SCULPTURE: POLYCHROMY FOUND IN A 12TH CENTURY BAS RELIEF IN PAVIA, ITALY

Alessandro Cini

Alessandro Cini, Restauro E Arte.
restauroearte@gmail.com

ABSTRACT

The Basilica of St Michelle Maggiore in Pavia, Northern Italy has over 900 years of history and is one of the best examples of Romanesque architecture in Italy. It is famous for its rich and complex sandstone sculptures, both on the façade and interior. The Basilica has also been known as 'the King's Basilica' since Federico Barbarossa, a king of the Italian Kingdom, was crowned at it in the 12th century.

The initial project included the conservation, cleaning and consolidation, of a bas-relief set on one of the entrances of the Crypt of St Michelle. The sculpture was carved in a local sandstone named arenaria. Analysis showed that the stone was once painted in polychromy, which was covered by dust. After finding the remains of polychromy, the approach to the conservation of the statue was re-assessed to ensure the preservation of the different colours that were found under a hard layer of smoke and biological dust. As the colours are fragile, the standard cleaning and consolidation would have been too harsh and a more sensitive way of cleaning was applied. Using a laser cleaning technique applied by a specialist resulted in the colours becoming visible to everyone.

The positive collaboration between the church (administration), the university (survey) and the restorers resulted in a new perception of how the Basilica would have looked in the past and the potential to continue the work and uncover more polychromy on the building.

Keywords:
Pavia, sandstone, romanesque, polychromy, sculptures, Basilica


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Figure 1: Basilica of St. Michele Maggiore, Pavia, Northern Italy.

INTRODUCTION

Pavia, in Northern Italy, is located 30km south of Milan. Nowadays it is a small city of nearly 100,000 inhabitants, famous for its university. It is a quiet town on the outskirts of the city, a green place on the river Ticino where one can study and enjoy the tranquil surroundings, far from the crowded roads of Milan. But the town has a glorious past. From 572 to 774 it was the capital of Longbards, then under the Frankish Empire, capital of the Italian Kingdom until the end of the 12th century. The city lost its importance due to the rise of Milan after the defeat of Frederick Barbarossa in the battle of Legnano (29 May 1176).

A church devoted to St Michael Archangel was established by the Ticino in ancient times, and is mentioned by Paolo Diacono at the time of the Longobard King Grimoaldo in the 7th century. In that time the church was near the royal palace, used as palatine chapel for the court during Longbards kingdom and later, until its destruction by fire in 1004. We don’t know the exact year of the new construction, but it is supposed to be in the late 11th century (crypt, choir and transept). We do know for sure that the construction was completed in 1155 (Figure 1), the year of the coronation of Frederick Barbarossa, thanks to the reporting of this historical event in local coeval chronicles. The location where the king was crowned is still today marked on the floor by a white marble stone, carved with the sign of the Iron Crown. This symbol is considered one of the oldest royal insignias of Christendom, which tradition holds to be made of iron beaten out of a nail of the True Cross (Mondadori 1995).

What makes this church unique (from a national viewpoint) is not only the importance of its royal hosts, but the particularly rich decoration which adorns its façades and interiors. Carved from local sandstone, this ornate display includes both religious and profane themes. Traditionally, religious and private monuments in Pavia were built using brick. The use of this construction material was determined by the nature of the surrounding flat landscape, being located far from the mountains. Brick was considered a poor material for a royal building, considering the imperial cathedrals of the transalpine countries were all built in stone. For this reason it was decided to use this same material to provide continuity. A local sandstone, Arenaria, with golden glares was selected.


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Figure 2:
Portal bordered with carved arches and sculpted parallel friezes.

Figure 3:
Example of detailed carvings on the portal.

This stone was excavated in the hills of Oltrepò, and the mountains south of Pavia, not far from the sea.

The church façade is extremely rich in decoration. Portals are bordered by carved arched lintels while the façade surface was decorated with sculptured parallel friezes (Figure 2). Displayed within are scenes of ordinary life, such as the harvest in autumn, mixed with biblical images and medieval monsters (Figure 3). The figure of St Michael Archangel (Figure 4) rises above the front entrance and dominates the entire façade, while at his feet the beaten devil is shaped like a dragon. The other two sculptures on the side portals represent Ennodio and Eleucadio, two sainted bishops, whose relics are housed inside the church. Inside the building, the decoration is mainly found on the capitols of the Crypt (Figure 5) and nave, of which these are considered among the best surviving examples from the medieval period in Northern Italy. The presbytery and transept display many bas-reliefs with representations of scenes of the Old and New Testament.

Contrastingly, decorations inside the church were found to be in a good condition today, whereas exterior decorations are ‘corrupted’ and most of them unrecognisable (Figure 6). The exposure to external agents – in particular to ambient atmospheric pollutants, which are significantly prevelant in this area – is responsible for the decay of the stone. Being sandstone, it is not particularly resistant even in a pollution-free area.


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Figure 4:
St Michael Archangel.

Figure 5:
Inside decorations are mainly in the Crypt capitols.

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Figure 6: **Exterior carving showing signs of deterioration.**

Throughout the last fifteen years the author has studied the results of analysis and surveys, both on the interior and exterior of the building, undertaken by several academic institutions, namely: University of Milan, Consiglio Nazionale Ricerche (Italian national research centre) of Milan and University of Pavia during the last thirty years. External surface examinations focused on determining a method to strengthen the weak stone and in the interior to clean and protect the stone, frescoes and wall surfaces. It could never have been imagined that a simple conservative restoration work, on a sandstone bas-relief, could completely change the idea of how the church appeared in medieval times.

BACKGROUND TO THE PROJECT

The inspirational element for this reinterpretation of the church's appearance is a bas-relief set above one of the two entrances to the Crypt (Figure 7). The relief is carved in the same local sandstone as the interiors and façades and measures 110 x 45cm. Depicted within the panel are two angels which support a central round frame. A typical carved representation of the Agnus Dei symbol, Lamb of God, is found inside this roundel. The whole scene is inserted into an S-shaped framework with inserted foliate decorations.

The restoration was offered free of charge to the Church, a present to the priest, who had a particular devotion to this masterpiece. This gift was based on the assumption that the work was a straightforward project.

A conservation work proposal was submitted to the Soprintendenza of Milano, Italian office for the conservation of art and architecture. The project was approved by architect Paolo Savio, inspector responsible for the area of Pavia. A laser scanning survey was offered by architects Peverelli and Colombo (Figure 8). Diagnostics were offered by the Università di Pavia and Laboratorio Arkedos s.r.l., under the supervision of Dr Pia Riccardi. This research included both cross-section anlaysis and X-ray diffraction.

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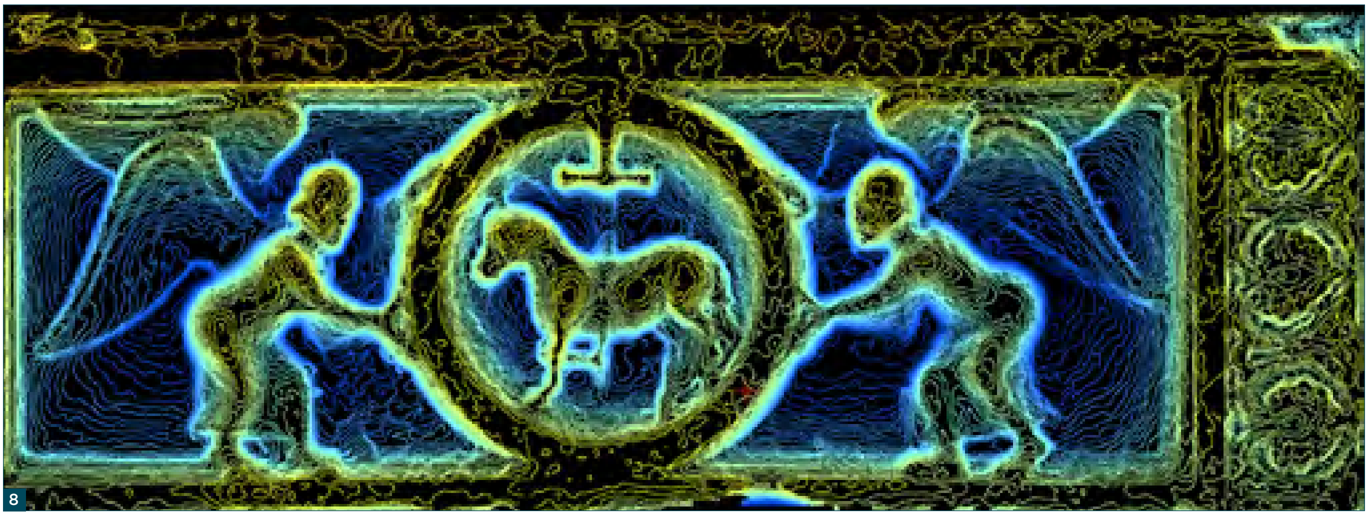
Figure 7: **Bass relief set above entrance of the Crypt.**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On receiving the results we discovered the most surprising revelation. Amazingly, under the dust, the surveys clearly revealed the presence of a painted layer which had been impossible to see before (Figure 9). It was therefore decided to undertake further analysis. Extremely small samples, dimensions (<2mmq), were taken from what was considered the red colour for cross-section analysis. These samples were observed under both a stereomicroscope and scanning electron microscope (SEM). Characterisation of materials was also done using EDS spectrophotometry for inorganic materials, and FTIR spectrophotometry for organic materials. Investigations confirmed there were no organic materials within the pigmented layer, which was actually identified as a coating with a calcium-magnesium binder, painted directly onto the sandstone. Later, during restoration, other samples will be taken of the different colours present. It is expected results will be approximately the same.

Figure 8:
Point cloud of laser scanning carried out by architects Peverelli and Colombo.


9

Figure 9:
Survey revealed the presence of a painted layer.


10

Figure 10: Conservators removing dust on the pigmented layer.

CLEANING STRATEGIES

As a result of these findings, the project had to be completely changed. It was clear there were different colours on the carved stone, under a hard layer of candle smoke and biological dust. At the same time we knew the colours were extremely fragile and easily damaged, so we needed an appropriate consolidation and cleaning to prevent any colour loss.

We decided to use a laser cleaning technique and involved a professional in this kind of specific cleaning: Dr Ignazio Tombini. Dr Tombini planned to use two different machines: Thunder Art (SQS-1064) and EOS 1000 (SFR – 1064), and to operate with laser ablation to remove the dust on the pigmented layer (Figure 10).

The first laser SQS was used with fluence values included between 0.7–1 J/cmq to remove the dust on the part of the bas relief both with and without polychromy. In the areas with no polychromy the stone appeared clean, while on the others, once the dust was removed, the resultant colour was generally a dark white (Figures 11, 12). During the laser ablation the support was continuously sprayed with demineralised water. The removal of the dark white layer to get the final colour was completed with the second laser machine, the SFR. This machine, offering different characteristics, allowed removal of the thin layer above the colour using a more precise selection to obtain the clean final colour without any risk of damage. At some points the process was helped with support of the medical lancet.


11


12

Figure 11 and 12: Resultant colour after removing dust was dark white.


13

Figure 13: **Bas-relief after restoration.**

CONSOLIDATION

Once the bas relief was completely cleaned, we needed to stabilise the polychromy, which was so weak that any attempt of touching with a hand would have destroyed it. The method was agreed in accordance with a restorer from the Italian Centre Opificio delle Pietre Dure OPD of Florence, Mariposa Lanfranchi and the architect Paolo Savio, from the Soprintendenza of Milano.

Due to the composition of the polychromy itself it was decided to exclude any method which included organic materials and to use inorganic materials. Also, considering the silicate nature of the stone, any stabilisation with calcium-based material was excluded. Ultimately, barium hydroxide was chosen and concentrations tested before interventing. The final concentration selected was 2%, with a supporting paper of 2/3mm thickness, left in situ until the water had evaporated. This operation was repeated two times and, at the end, the surfaces had to be cleaned of by-products from the reaction.

CONCLUSIONS

After restoration, the bas-relief had all the original polychromy perfectly visible and in good condition (Figure 13). All colours that lay under the dust were saved and no material was lost. Most of the polychromy had already gone many years before we decided to carry out the restoration work. But the portions we revealed completely changed the idea of the interior decoration of the church (Figure 14).

We are accustomed to seeing medieval decoration on ‘naked’ stone and seldom think that originally it was indeed refined with colours. This tradition was documented on the Classical monuments of ancient Greece and Rome. In Northern Italy, on medieval decorations, we have some examples of colours on stone decoration documented in recent research on the sculptures of Parma Duomo (Pinna 2009). Here colour is applied on stone after a preparation of ‘Colla Animale’, glue made with animal bones. This technique is well described by Cennino Cennini in his medieval manual for gilding. In San Michele there is no Colla Animale preparation, as demonstrated by the survey investigations. Another recent discovery of painted stone of the medieval period comes from the Cathedral of Ferrara.


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Figure 14: The newly discovered polychromatic layer changed the perception of the interior decoration of the church.

This is something completely new for St Michael, and for Pavia. Over the last fifteen years I have followed directly the main restoration on the Tiburio (polygonal lantern atop of the dome), where there are several capitols carved in sandstone. I have never seen a trace of colour here, probably because of their decay due to infiltration from the ceilings.

After what we have discovered thanks to the bas relief restoration, in collaboration with members of the University of Pavia history department, we have inspected many stone decorations inside the basilica and found out that in some areas we can suppose the presence of polychromy. Some restoration still needs to be undertaken in parts. In other areas of the same decoration there are traces on the sandstone which led us to suppose that a dramatic removal of something, maybe colour, has occurred. Traces are particularly visible on the wide stone columns which divide the naves of the basilica. One possible theory is that at some point, during one of the many renovation works which take place in every church, due to the change of sensibility, the colours have been considered of no significance and have been removed. Alternatively, the decision could have been taken for economic reasons: it was cheaper to remove surviving polychromy than restoring. This would have been a typical approach until a few years ago in Italy.

What is interesting is that what was supposed to be a straightforward piece of conservation work was revealed to be a milestone in the knowledge of the basilica's history. Furthermore, this project involved several different professionals and institutions who have worked together with a high standard of professionalism, giving their time and expertise for free.

There was a rare synchrony between the hosts (the church), the academics and researchers (university) and the professionals (private restorers). At the end, a symposium was hosted in the basilica, with good participation from researchers and the public. Articles were published in papers and conservation magazines. But there remains a lot of work to be done, and many colours to be discovered – a story still to be written.

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LAYERS OF COMMEMORATION IN MOUNT AUBURN CEMETERY’S GARDNER TOMB

Ariana McSweeney[1*] and **Gus Fraser**[2]

[1*] Ariana McSweeney, Preservation Craftsperson, Mount Auburn Cemetery, United States of America. amcsweeney@mountauburn.org

[2] Gus Fraser, Vice President of Preservation and Facilities, Mount Auburn Cemetery, United States of America. gfraser@mountauburn.org

* Corresponding author

ABSTRACT

Mount Auburn Cemetery in Cambridge, Massachusetts became the first rural cemetery in the United States upon its consecration in 1831. The Cemetery's founders envisioned a picturesque landscape, inspired by English gardens and Paris's Père Lachaise cemetery, where mourners could find peace in proximity to nature and artistically exceptional monuments. Today the Cemetery continues its mission to inspire, comfort, and commemorate in a landscape of beauty, and it was designated a National Historic Landmark in 2003. In 1924 Mount Auburn became the final resting place of Isabella Stewart Gardner, a well-known local patron of the arts, whose family tomb is visited by thousands every year. Mount Auburn's sidehill tombs are often small historic buildings in themselves, and that of the Gardners is no exception. It houses a bust of a young girl and an oval bas-relief profile of a boy, both carved in marble. Recently it became apparent that the tomb's envelope was not sufficiently protecting the monuments from moisture. Water was damaging the stone by dripping onto the marble and generally increasing the level of the interior's latent moisture. Significant work has already been undertaken to address this issue, but the tomb requires additional repairs. For example, action must be taken to mitigate the effects of the water that will inevitably make its way inside. In addition, conservation needs to be carried out on the sculptures themselves. One of the more urgent problems is the fact that water dripping from the copper chimney has stained the marble bust green. With the complex relationship between its exterior and interior, its historic significance, and its popularity with visitors, the Gardner tomb raises unique conservation challenges about immobile monuments in larger structures.

Keywords:
cemetery, funerary art, sculpture, tomb, stone conservation

Figure 1: Mount Auburn Cemetery's Consecration Dell, 1860. The image on the left is an engraving made by James Smillie in 1847, and the engraving on the right was made in 1860. Courtesy of Mount Auburn Cemetery Historical Collections

1. BACKGROUND

1.1 Mount Auburn Cemetery

The 1831 consecration of Mount Auburn Cemetery, a National Historic Landmark located in Cambridge, Massachusetts, represented a major shift in the design of American burying grounds (Banta 2015). In contrast to earlier graveyards, which tended to be urban, unsanitary, and full of slate monuments arranged starkly in rows, Mount Auburn was designed to be a place where our mortal selves could connect with the natural world through a balance of art and nature. The harmonious combination of sculpture and horticulture was one of the major principles that guided the creation of the Cemetery as a whole, and for this reason the landscape is a monument in itself (Banta 2015). The Cemetery's staff is often required to conserve the monuments, tombs, fences and other structures not as independent works of art, but as part of an evolving landscape that has and will continue to change over time (Figure 1). Mount Auburn has been popular with visitors and mourners since its consecration, and today it is both an active burying ground and an open-air museum of history, sculpture, and horticulture.

1.2 Tombs at Mount Auburn

There are now approximately 45,000 monuments in Mount Auburn Cemetery, ranging from elaborate sculptures representing angels and classical architecture to small granite markers almost flush with the ground. The Cemetery also contains freestanding mausolea and several hundred tombs, including those situated on the sides of hills. Former Mount Auburn president Oakes Ames noted that 'during the first ten years of the Cemetery, a total of 190 tombs were erected in contrast to only 164 monuments' (Ames 1954). After a few decades most tombs were built into the hillsides (these were eventually termed 'sidehill' tombs), and the vertical façades facing their brick vaults became more elaborate. Features that were frequently added to more prominent and substantial sidehill tombs included interior monuments memorialising individual people, which could often be admired through openings in doors. In this way lot proprietors recognised specific people while also making a bold statement about their entire family. The proliferation of sidehill tombs, along with the popularity of


2


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Figure 2:
Gardner family tomb.

Figure 3:
Niche housing a marble bust with marble relief below.

the cast iron fences and the granite curbing that defined the boundaries of individual lots, was part of the evolution of the Cemetery's early landscape.

1.3 Isabella Stewart Gardner and the Gardner tomb

The Gardner family tomb (Figure 2) is representative of these important trends in the Cemetery's development. John Lowell Gardner purchased lots 2900 and 2901 in 1859, and subsequently commissioned the construction of a sidehill tomb that has since become one of the most visited monuments in Mount Auburn. While the Gardner family had long been wealthy and influential in the Boston area, the tomb owes its popularity to famed patron of the arts Isabella Stewart Gardner, who was interred there after her death in 1924. Isabella Stewart married John Lowell Gardner's son in 1860 and acquired an extensive art collection over the course of her life (Isabella Stewart Gardner Museum). The collection eventually became the contents of the Isabella Stewart Gardner Museum, one of modern Boston's most important hubs for art and history. The Gardner tomb's high visitation rate means that its conservation is of special importance.

The tomb is also significant in that it is an excellent example of the way sidehill tombs were built at the Cemetery in the second half of the 19th century. It was constructed with brick and clad with a façade of granite quarried regionally in Concord, New Hampshire (unpublished archival document, Mount Auburn Cemetery, 1886). The tomb is situated in the side of a steep hill and topped with soil and grass, and it has a large oak door with an opening covered by a bronze grille. The floor plan consists of banks of catacombs on either side of a central aisle (pers. comm.). There is a niche housing a marble bust opposite the door, and a marble relief is mounted on the wall below the niche (Figure 3). The sculptures represent Catherine Elizabeth Gardner and Samuel Pickering Gardner, respectively. These children –

4

Cemetery of Mount Auburn.

5

Cost of Perpetual Repair.

Care of Lot.	20.00
Plants.	
Shrubs.	
Myrtle.	
Top-dressing.	10.00
Sodding.	40.00
Cleaning Stone.	30.00
Leading	
Painting.	
Annual expense. (average.)	100.00
ENDOWMENT necessary to provide for annual expense (Interest 4 per ct.)	2500.00
Additional for INSURANCE of Monuments and Headstones.	
Total.	2500.00

$2500 — pd April 23/16

Figures 4 and 5: Historical records of the perpetual care contract.

likely Isabella Stewart Gardner's niece and nephew – died within days of each other in October 1865 (unpublished e-mail, Winslow, 2008). The sculptures are valuable because they are indicative of the fact that disease and illness often claimed the lives of the young during much of Mount Auburn's history. They also have artistic significance; they were carved by French artist Jules Clément Chaplain, who earned the prestigious Prix de Rome for engraving in 1863 and the Légion d'Honneur in 1877 (Benezit Dictionary of Artists).

1.4 Cemetery care obligations

Mount Auburn is committed to preserving the tomb as an important component of its landscape and history. The Cemetery also has an obligation to care for the tomb, stemming from an agreement known as a perpetual care contract (Figures 4 and 5). Perpetual care contracts were intended to guarantee that the monuments and the landscape would have a source of funds for maintenance in perpetuity (unpublished archival document, C. P. and B. R. Curtis, 1844). Work orders and correspondence from the Cemetery's archives show that the staff has performed basic maintenance on the lot over the years, including repointing the joints of the façade, waterproofing the roof, applying varnish to the oak door, and periodically washing the exterior and cleaning the interior (unpublished database, accessed 2019). These efforts, however, were not enough to prevent recurring moisture issues and leaks, which have affected the condition of the interior sculptures as well as the structure of the tomb itself. Within the last several years a concerted effort has been made to stabilise the tomb's condition and to establish a regular schedule of maintenance.

2. MONITORING AND REPAIRS

2.1 Early repairs

As a small building partially engaged with the hillside, the Gardner tomb has always been subject to a variety of moisture-related problems. Over the years, surveyors have cited several ways in which the condition of the tomb's exterior might be contributing to its excessive interior dampness. The copper ventilator above the bust and the relief appears to have been leaking as early as 1933; a work order instructs Cemetery staff to caulk the appliance with a plastic compound (unpublished work order). Further archival evidence indicates that failing masonry joints were another reoccurring problem. The first work order that included repointing was written in 1876 (unpublished work order). Repointing was then repeated in 1884, when George P. Gardner gave orders to 're-lead [the] tomb in [the] best manner[,] taking out all loose lead' from both the exterior and the interior (unpublished work order). In 1932 pointing was necessary again, but this time the work order specified that loose joints should be repaired with a caulking compound rather than lead (unpublished work order).

2.2 Documentation of stone conditions

Mount Auburn made a major effort to bolster its cemetery-wide conservation efforts in the 1990s, and in 2000 students from Boston University's Preservation Studies graduate program surveyed most of the Cemetery's sidehill tombs and mausolea (pers. comm.). The following year Erica Glanz, one of the students, selected the Gardner tomb as the subject of a much more detailed survey. The resulting report suggests that the problems that plagued the structure in its early years had not abated by 2001. Not only was water pooling on the floor near the door at this time, but efflorescence and green algae were also noted on the marble catacomb panels (unpublished report, Glanz 2001). Further water damage could be found on the ceiling, which was missing chunks of plaster (unpublished scope of work, 2001) and was generally cracked, soiled, and in need of repainting (unpublished scope of work, 2001). While the wet environment wasn't posing an immediate threat to the sculptural monuments, the slow, steady dripping of condensation and the gradual saturation of the marble made moisture a significant long-term problem.

Glanz noted that erosion of the hillside had exposed the tomb's foundation, which she identified as a possible source of water penetration (unpublished report, Glanz 2001). In addition, she wrote that the exterior masonry joints were loose again. Her main concern associated with this issue seems to have been the possibility that the joints would allow water inside the tomb while the exterior was being cleaned (unpublished report, Glanz 2001).

However, she also noticed that an open joint above the door and the surrounding area was slightly wet on rainy days (unpublished report, Glanz 2001). This suggests that the joints may have been allowing water to infiltrate the tomb more frequently than Glanz initially supposed, and that they may have been contributing more significantly to the moist atmosphere of the tomb's interior.

Like other surveyors before her, Glanz recognised that the ventilator was a major source of water ingress. In 2000 the vent pipe cap was found completely detached, allowing rainwater to fall onto the bust below (unpublished survey report, 2000). Although the existing cap was re-secured, leaks around the cap and dripping condensation continued to cause wear on the marble, and the bust was stained blue-green with residue from the corroding copper (unpublished report, Glanz 2001). To prevent the damage from worsening before conservation work could be carried out, Mount Auburn staff closed the interior ventilator hole in 2018 (pers. comm.). However, this was not an adequate long-term solution to the problem because the lack of ventilation within the tomb would cause interior moisture to linger even longer than it had in the past. Meanwhile, the bust was still stained and some of its sculptural definition had been lost.

In contrast, the ventilator had done little damage to the marble relief below the bust. In fact, the relief is generally in good condition today. The most serious recorded threat to its preservation was brought to the attention of Mr G. Peabody Gardner in 1938. The Cemetery informed him that the slate slab upon which the relief was mounted was ‘very badly cracked so that it is liable to fall on to the floor of the tomb and be destroyed’ (unpublished letter, 1938). Mount Auburn staff informed Gardner that they would be happy to obtain an estimate for the replacement of the slab (unpublished letter, 1938). There is no record of such treatment being carried out, but Glanz noted that repaired and inpainted cracks were visible on the slate slab at the time of her survey (unpublished report, Glanz 2001). It is unclear whether the original slate had been repaired rather than replaced, or whether the replacement piece had broken in subsequent years and then been repaired in turn. In any case, the relief serves as an example of the connection between the interior monuments and the surrounding tomb. While the sculpture itself still looks relatively crisp and clean today, more damage to the slate upon which it is mounted has again put it in danger of being ‘destroyed’ should the slate support fail.

3. RECENT INTERVENTIONS

3.1 Waterproofing

The observations of Erica Glanz and the other Boston University students, as well as the results of other surveys that have been carried out in the past twenty years, indicate that the water problems in the Gardner tomb were the result of two conditions. One of these is condensation, which can be found in many of the Cemetery’s structures that are open to the outside air and have minimal ventilation. Because the Gardner tomb is partly below grade, the temperature of the interior masonry surfaces remains well below the dew point even during the warm and humid summer months. Condensation can also persist in winter, taking the form of ice crystals and resulting in the freezing of saturated stones.

The other condition is related more directly to the exterior envelope, which allowed water to enter the tomb during heavy rains for many years before recent repairs were undertaken. Evidence of water infiltration could be seen on the interior of the south wall, around the door, and at the niche. Failing paint and minor damage to the plaster ceiling indicated that there was moisture in the vaulted brick structure above, and significant rainfall or snow melt resulted in pooling water on the floor of the tomb. Exploratory removal of soil on the roof revealed that the joint between the granite façade and the masonry structure had failed at several locations above the front wall, resulting in gaps ranging from 1/8” to 1/2”. Cracks were also noted in the tar and pitch roof, which had been applied in the 1930s. Examination of the ventilation pipe above the niche revealed failure of the sealant used beneath the pipe’s bronze flange, as well as gaps in waterproofing above the niche wall.

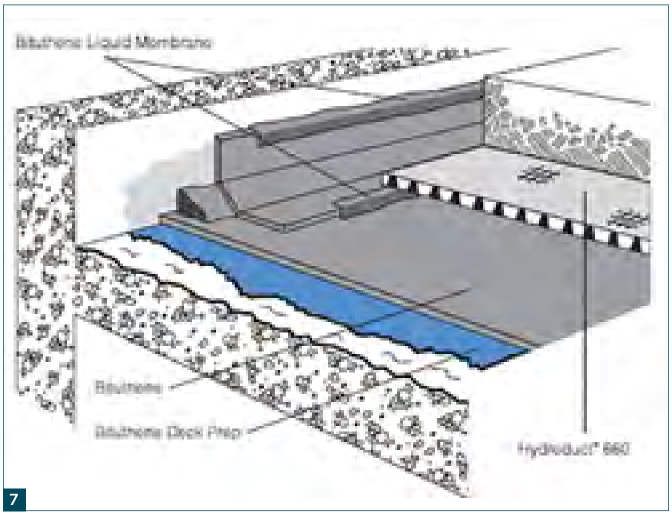

Figure 6:
Ventilator pipe cap after repairs.

Figure 7:
Drawing of water proofing membrane.

The ventilator pipe cap had also come off, but it was replaced quickly (Figure 6).

Preservation efforts that took place after 2001 have addressed maintenance of the exterior envelope, including pointing of the exterior walls. Prior to recent repairs the walls were pointed primarily with lead, and less frequently with cementitious mortar and masonry sealants. Although it is difficult to confirm the original pointing material, Cemetery work orders indicate that lead was being used in the 1870s (unpublished work order, 1876). Despite this evidence, Cemetery staff elected to repoint the exterior granite and the joint between the stone façade and the brick structure with a Type N mortar (1 part Portland Cement: 1 part hydrated lime: 6 parts sand) in 2006 (unpublished database). Within five years the joints were again compromised, and in 2017 the mortar was removed (unpublished database, 2017). The masonry joints were back-pointed with new mortar to within approximately ½” of the stones’ faces, and lead wool was tamped into the rest of the joint. Cemetery staff also filled some joints by pouring molten lead, and then removing the excess material and tamping the surface. Vulnerable upward-facing joints were filled with urethane sealant, with lead ‘T’s installed over the sealant for visual effect.

It was apparent that waterproofing the roof was another necessary step in the repairs of the tomb’s exterior, and that this task would require additional expertise and funding. Thanks to generous family donations, the work was carried out in 2018. Cemetery staff removed the topsoil that covered the roof, and a waterproofing contractor adhered a bituthene membrane directly to the structure below (Figure 7, Grace Construction, 2008). The membrane was lapped up onto the perimeter granite curb, where it was terminated at grade. A drainage board was installed over the membrane for protection before the topsoil was replaced. Finally, a perforated pipe was buried in a shallow sand- and gravel-filled trench at the rear of the tomb in an attempt to catch and drain water washing down the hillside.

With repairs to the exterior complete, Mount Auburn now must address the condensation inside the tomb. Methods tested in similar tombs have included increasing ventilation to draw more air through the interiors, and placing a pan of desiccants inside the structures. These attempts have been maintenance-intensive and only partially successful, so alternative strategies are currently being sought for future testing as time and budget allow.

3.2 Sculpture conservation

Now that the exterior envelope of the tomb has been sealed, the Cemetery can give more attention to the condition of the sculptures themselves. A conditions survey was completed in April 2019 by Joshua Craine of Daedalus, a local sculpture and fine art conservation firm. Craine's findings were similar to those of Glanz. The bust is still badly discoloured by water from the ventilator leaks (Figure 8), but early assessments indicate that the stains are relatively superficial (pers. comm.). While the relief is in excellent condition, the slate slab behind it is delaminating in the same way that it did almost 100 years ago. It is also cracking in areas that appear to be either sites of previous repairs or natural weak points in the stone (pers. comm.). Craine's assessment of potential solutions to these problems will be guided by Mount Auburn's general preservation philosophy; the least invasive methods will be tested first, and more intensive approaches – such as aggressive cleaners for the marble and replacement of the slate – will only be attempted if required. It is important to note that while the damage and wear to the exterior envelope of the tomb has threatened the interior monuments, Chaplain's sculptures have remained extremely crisp in comparison with other marble sculptures that have been in the open air of the Cemetery for 150 years or more.


8

Figure 8:
Close up of bust in situ.

4. CONCLUSION

While forward-thinking lot owners and cemetery managers set aside funds for the basic maintenance of selected monuments many years ago, underlying issues often require new and specialised techniques and materials. Thanks to the interest and additional funding of the Gardner family, Mount Auburn has been able to address the permeability of the Gardner tomb's exterior envelope. However, more challenging condensation issues intrinsic to the sidehill tomb's construction still threaten the sculptures within the structure, which in turn require work themselves. The Cemetery will continue to work with conservators to identify creative and cost-effective solutions to these problems. The appropriate techniques can then be applied to other tombs that are threatened by similar issues.

The layers of history and types of monuments within Mount Auburn Cemetery make it an exceptionally interesting and complicated site to preserve. The conservation of the Gardner tomb is important not only due to its popularity with visitors, but also because it provides a visible representation of these layers in one place. By preserving the tomb, Mount Auburn is also preserving a physical representation of the concepts that inspired the creation of America's first rural cemetery.

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HOLDING LOSS AT ITS CENTRE:
LOOK OF AGE AT MISSIONS CONCEPCIÓN AND SAN JOSÉ

Meghan King

Meghan King, MS Historic Preservation 2019,
The University of Texas at Austin.
kingmeghanelizabeth@gmail.com

ABSTRACT

Mission Concepción and Mission San José in San Antonio, Texas belong to the larger collection of five 18th-century Spanish Colonial Missions founded along the San Antonio River. This paper considers the state of the exterior stucco of both buildings as the means by which to contemplate the value preservation places on loss as a determining factor in practice. Both churches display considerable loss to their historic stucco, but the ideological constrictions of the Secretary of the Interior's Standards inhibit substantial intervention. This paper investigates the 'why' of this preservation scenario – why do we prefigure loss so centrally in our approach to preservation? And from where does this value emerge? In investigating the particulars of the histories and current states of plaster and stone preservation at the Missions, this paper probes the broader field of American preservation and interrogates the value system imbued throughout practice that often goes unexamined.

Keywords:
preservation theory, loss, age value, American preservation, Spanish Colonial

1. INTRODUCTION

In 2003 the Canadian poet and classicist Anne Carson published *If Not, Winter*, her translation of poetic fragments by the fifth-century Greek lyric poetess Sappho. The trouble in the task for Carson, as with all translators of Sappho who came before her, was the problem of loss. Not only do very few of the original papyri scrolls that recorded Sappho's words survive, but among those that have, only one poem remains with its scroll physically intact enough for it to be read completely (Carson 2013). In translating, Carson made the poetic decision to visually inscribe her translations with signifiers of the material loss that so determines the experience of reading the original. She deployed square brackets to signify this loss. For instance, Poem 6 in *If Not, Winter* appears as follows:

> so
>]
>
>]
>]
>]
>]
>
> Go [
> so we may see [
>]
> lady
>
> of gold arms [
>]
>]
> doom

Carson's editorial prerogative to employ square brackets expresses a near fetishistic feeling towards the fragmentariness of her primary source. In so doing, she translates for her reader not simply the text itself but the physicality of the very papyrus itself and its attendant loss.

The title of this paper derives from a line in a book belonging to preservation scholar Thordis Arrhenius (2012) in which she describes monuments which 'leave loss at the center'. This paper's title is slightly adapted semantically to serve its point – that at the heart of preservation practice is the necessity of loss, even a reverence for it. To say that preservation holds loss at its centre is to speak to the fixity of its value within practice that the inquiry of this work aims to address. Similarly to Carson's bracketed translation of Sappho, in preservation loss is often given as much space as what remains.


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Figure 1:
West façade of the church of Mission Concepción.

Figure 2:
West façade of the church of Mission San José.

The impetus for this paper emerged from a set of circumstances the author became familiar with at two 18th-century Spanish Colonial churches belonging to the San Antonio Missions World Heritage Site: the churches of Missions Concepción and San José (Figure 1 and Figure 2). Among the five missions comprising the site, Concepción and San José share an analogous construction of soft, porous tufa limestone with a corresponding coat of lime plaster which once served as the means of transmission for decorative al seco paint schemes. Each displays a substantial amount of loss to its historic exterior stucco. Such loss contributes to the ingress of water into the porous substrate beneath, exacerbating its friability and jeopardising the fate of the remaining historic stucco (Figure 3). The issue as it stands, however, is that as Texas State Antiquities and components of both a National Park and a World Heritage Site, the churches are subject to heavy regulatory oversight. Despite the fact that there is a demonstrated material need, the Texas Historical Commission (the regulatory overseer of all necessary permitting for work on the Missions) will not allow permits for more radical stucco intervention to go forward.


3

Figure 3:
Fragment of stucco revealing limestone substrate, church of Mission Concepción, south belfry.

This raised a series of practical and philosophical questions – why would a decision-maker in this instance decide to prioritise loss over demonstrated material need? What frameworks facilitate and steward a decision-making of this logic, and with what values are these frameworks imbued? The logical place to turn was the Secretary of the Interior's Standards of 1977, an edict by which preservation in America lives and dies. It is the thing to which all governmentally regulated preservation activity is beholden. Investigating the Standards rather quickly gives way to its progenitor, the Venice Charter, and all its attendant modernist thinking. In so breaking down these frameworks and their values against the case of Missions Concepción and San José, this study reveals an inherent flaw in the nature of American preservation. It is not so much that the Standards themselves are bad, or that a strong regulatory framework that stewards and underwrites preservation activity should be dispensed with. Rather it is the unique convergence of the two that gives rise to an unfortunate implacability that puts loss in the driver's seat of preservation – it holds loss at its centre. The noble endeavour of the Standards to institutionalise preservation is the very thing that inhibits a more expansive, contemporary notion of preservation and all the robust interpretive capacities it affords.

2. THE TROUBLE WITH STANDARDS

Standards occupy a position between theory and practice, and they are necessarily a place of compromise. Amid a sea of seemingly unanswerable questions about how best to execute any given preservation decision, standards provide a rough exoskeleton within which we may frame our thinking. None of this is to say that standards answer questions – they are almost always open-ended and interpretive in nature – but that they make questions more answerable.

The Venice Charter of 1964 is fundamentally understood as a post-war cultural product that responds to the unique confluence of the widespread physical devastation of Europe and the epochal zenith of modernism. One of the most characteristic tenets of modernism is the view of time as a series of temporal ruptures – what architectural historian Samir Younés (2008: 33) identifies as historicism: 'Modernist historiography . . . propagated a view of architectural history as a history of ruptures, one style or manner inexorably breaking with the preceding one, while claiming that this was the only way to interpret the development of architectural history.' In this way, modernism views itself, and each subsequent era of history, as a tabula rasa upon which relational connections to the past are severed. This ideology found root in preservation through the Venice Charter, and in America it has taken root through the SOI Standards. Unlike the Venice Charter, however, the SOI Standards have legally binding implications for preservation in the United States, and this, in effect, ossifies and promulgates their values in practice indelibly. Looking closely at both edicts, one locates analogous statements reflecting analogous values that embrace modernistic historicism:

Table 1:
Venice Charter and SOI Standards.

The Venice Charter (1964)	Secretary of the Interior's Standards for Rehabilitation (1977)
Article III. The intention in conserving and restoring monuments is to safeguard them no less as works of art than as historical evidence.	**3**. Each property shall be recognized as a physical record of its time, place, and use. Changes that create a false sense of historical development, such as adding conjectural features or architectural elements from other buildings, shall not be undertaken.
Article IX. It must stop at the point where conjecture begins, and in this case moreover any extra work which is indispensable must be distinct from the architectural composition and bear a contemporary stamp.	**9**. New additions, exterior alterations, or related new construction shall not destroy historic materials that characterize the property. New work shall be differentiated from the old [. . .]
Article XI. The valid contributions of all eras to the building of a monument must be respected, since unity of style is not the aim of a restoration.	**4**. Most properties change over time; those changes have acquired historic significance in their own right and shall be retained and preserved.

Here one finds the dimension of time having acted on a building as an inherent priority being expressed. The dimension of time, rather than physical wholeness or completeness, is being asserted as the bearer of authenticity and this is achieved through the framing of the past in diametric opposition to the present. Conceptually they can be reduced to their four essential values: monument as document, conjecture, differentiation and reversibility. These concepts function as an interdependent system of logic that transmits this overall value system in practice – interpreting the monument as a document constitutes the ideological impulse, which is then justified by a fear of conjecture and executed through the techniques of differentiation and reversibility.

One can only read a monument in this way if one sees the past as being fundamentally unknowable save for the information carried therein by the monument. This creates a kind of rhetorical double bind where the past is both seen and unseen, understood and unfathomable. This ideological fragmenting of time alters the rhetorical function of present intervention. Rather than being an act that exists within the cyclical continuum of a building's life, intervention is understood to be ahistorical and fundamentally incongruent with the historic nature of the object. This conceptual valley between past and present is the space of fear which stunts action, allowing the knowns to exist without disturbing the unknowns and demanding little of us as stewards and interpreters of the building itself.

This identified tension is one which art historian Alois Riegl elucidates in his seminal 1903 treatise 'The modern cult of monuments: its character and its origin'. Riegl points to this as the conflict between what he calls age value and historical value, wherein the impulse to restore a monument's historic wholeness begets the risk of doing harm to the thing which makes it appear historic at all: its look of age. As the logical end of the line, age value wins out. However, to adhere to age value so strictly would be to allow the building to remain untouched, succumbing to the forces of nature and time as it will. This is not what is precisely desired and neither the SOI Standards nor the Venice Charter advocate for it, but their rhetorical framing explicitly gives preference to an approach that is as near to anti-intervention as possible and heavily discourages more drastic practices.

3. THE CASE OF THE MISSIONS

The five Missions of San Antonio are sited along the north–south axis of the San Antonio River in San Antonio, Texas. All were established by Spanish Franciscans in the early 1700s, with permanent construction of churches, conventos and compounds occurring over the course of the 18th century. The function of the Spanish Colonial missions of New Spain was both evangelical and territorial, and the San Antonio Missions served as a defensive stronghold for the Spanish empire in the region now known as Central Texas. In 1824 the Mexican government formally secularised the missions, and while their histories are chequered from thereon, it's essential to note that all suffered from periods of substantial neglect that followed (Quirarte 2003).

The critical distinction between the histories of Mission Concepción and Mission San José is one of integrity. The church of San José underwent a considerable restoration in the 1930s after the collapse of its roof and dome, as well as significant portions of its north wall and bell tower (Ford, Powell and Carson, 2016). Conversely the church of Concepción has seen very little in the way of large-scale structural concerns. For this reason, much more colonial stucco remains at Concepción than at San José. However, one fact is consistent across both churches – their stucco was not routinely reapplied. More to the point, in the several-hundred-year history of each church, more of their lifetimes have been spent without stucco reapplication than with.

In considering what it would mean to reconstitute the stucco of these two churches, the predictable questions and anxieties emerge regarding conjecture. From careful attention and study by the work of conservators we can know generally what the recipe of the plaster is, its tint, how it was applied and what the decorative paint programmes looked like generally. Nonetheless, because this building typology is so rare within the United States, and because the churches are components of prestigiously designated sites, the fear of conjecture that plagues decision-making escalates considerably. Deference is given to loss out of a fear of further loss, and the deteriorated historic fabric becomes the means of transmission for authenticity.

Considering stucco as a sacrificial layer, however, offers a means of radically divergent interpretation that allows for the material to transmit authenticity not through its look of age, but through its inherent nature as a building material. The function of a sacrificial layer is just that, to be sacrificed. It serves a dual function of being both integral to the structure of the wall and fundamentally transient. This begs the question – is the act of reconstituting the stucco scheme at the missions an act of restoration or an act of maintenance? Framing this act as one of restoration prefigures material loss as its central focus and evokes the aforementioned tension between age value and historical value. To frame re-stuccoing as an act of maintenance asserts a de-prioritisation of the material, and a reprioritisation of the process. The porousness of the tufa necessitates the application of plaster in order to mitigate water ingress and prevent damage to the structure. In this way, there is intentionality to the application of plaster which necessitates the reapplication of plaster, in perpetuity, for as long as the building is extant. Through a shift in interpretive understanding, the process of maintenance and the necessity of reapplication that is inherent to the material purpose of stucco supplant the traditionally understood notion of intent.

This notion evokes the thought of an impossible alternative history wherein the missions had never experienced such neglect and were instead properly maintained over the course of their lifetime. Would there be similar anxieties if the churches had been routinely cared for with regular coats of fresh stucco and paint every couple of decades? This line of questioning teases out where the values lie within this framework – that what happened to the building and how that's manifested physically is of greater priority than the building's inherent expression of what it needs.

By interpreting the historic stucco as an archaeological artefact containing information otherwise irretrievable, the stucco itself becomes frozen in time. As a consequence, the structural system to which it is integral becomes of service and sacrifice to the preservation of the stucco. This is evidenced, for instance, on the west façade of the church of Mission Concepción, whose bottom

Figure 4:
North-west corner of the church of Concepción.

course is completely bare of plaster and has started to erode away due to water infiltration and rising damp (Figure 4). Framing the stucco as an artefact strips it of its obligation to the rest of the building and represents an interpretive framework that is normally associated with a ruin.

The fact of the matter is, however, that neither of these buildings are ruins. Today Mission Concepción and Mission San José remain as active sites of worship and cultural tradition for the Mexican, Latino and Indigenous communities of San Antonio. Not only is this framing out of step with the building's use and cultural value, the approach to the exteriors is completely mismatched in appearance and in ideology with those which have been administered on the fully restored church interiors. This may speak to the de-prioritisation of interiors within the framework of American preservation more broadly, but the difference between the interiors and exteriors of the churches is nonetheless stark. This notion that gives a longer leash to work done on the interior is suggestive that perhaps what is truly at play on the exteriors is simply a matter of taste, justified through the adherence to the standards.

4. CONCLUSION

In addition to lending her words to this paper's title, Thordis Arrhenius, a kindred spirit, posed a question in her text *The Fragile Monument* (2012: 12) that defines this inquiry. She writes:

> '. . . at what moment did the maintenance and renewal of buildings shift to a discursive practice of conservation . . . Indeed how and when has the task of maintaining buildings become a site of conflicting and contradicting desires?'

The great irony of preservation is that its reverence for and fear of loss exist in equal measure – the site of conflicting desires. Arrhenius invites us to consider a notion of preservation that no longer puts fear of loss in the driver's seat of decision-making. The ultimate question remains, however – how can this be effectively brought into practice? Certainly, a change to the Standards would be welcome, but how to bring that about or what exactly they would say is the subject of another paper. Nonetheless, an alternate discourse would be one which moves away from the deification of the historic fabric that is so much the expression of an inherently flawed, fractured notion of time. In healing this fissure, preservation itself becomes an ever-ongoing event that is inherent to the life of a building. This offers preservationists the space to listen to the building's expression of what it needs, both materially and interpretively, and to respond in kind. In so doing, a kind of preservation practice may be achieved that no longer views loss as the thing to which it is fearfully beholden, but the thing to which it must dutifully tend.

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