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# Science, value and material decay in the conservation of historic environments

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**Abstract**

The historic environment undergoes cycles of material deterioration, and these processes have a powerful impact on the meanings and values associated with it. In particular, decay informs the experience of authenticity, as a tangible mark of age and 'the real'. This article examines the intersection between material transformation, scientific intervention and cultural value. Drawing on qualitative social research at three Scottish historic buildings, we show that there are a complex range of cultural values and qualities associated with material transformation. Furthermore, we highlight how the use of science-based conservation to characterize, and intervene in, processes of material transformation can affect these values and qualities. We argue that it is necessary and important to consider the cultural ramifications of such interventions alongside their material effects. This requires a case-by-case approach, because the cultural values and qualities associated with material transformation are context-specific and vary with different kinds of monuments and materials. We conclude with a series of recommendations aimed at integrating humanities and science-based approaches to transformation in the historic environment.

**Keywords: value / qualitative research / science and technology / authenticity / decay**

## 1. Introduction

Stone, brick and mortar are the most widespread materials making up the historic built environment throughout Europe, and to varying degrees in other parts of the world. In this article, we look at the vulnerabilities of such masonry materials to deterioration and decay, and the ways in which heritage science interventions intersect with the range of cultural values and qualities associated with such material transformation. The core of our argument is that the assessment of values associated with material transformation—and the scope and potential effects of scientific intervention—requires a case-by-case approach. The specific values and qualities associated with material transformation are complex, situated and contextual. Consequently it is not possible to identify simple rules or models that can be applied universally across different heritage sites, even in cases where the same processes of material transformation are at work. Instead, qualitative social research should be used to explore how material transformation is involved in the creation and negotiation of values at specific historic buildings and monuments. Our arguments are based on research carried out at three case study sites in Scotland, during 2013-14. This research shows that material transformation is associated with a wide range of overlapping attitudes and values amongst both heritage professionals and visiting publics. Furthermore, there is no basis for *a priori* distinctions between forms of decay that are positively valued and those that are considered undesirable. Our analysis reveals that values associated with material transformation are informed by complex relations between materials, decay processes, types of monument, visitor expectations, forms of expertise and demands on use. In our conclusions, we examine the implications of the research project, and provide recommendations for practitioners in navigating the changing face of value-oriented conservation.

Collaboration between the sciences and the humanities is central to the AHRC Science and Heritage research project underpinning this article (www.uws.ac.uk/mavproject/). The research team has expertise in heritage science (Hughes, PI), cultural heritage (Jones) and social anthropology (Douglas-Jones and Yarrow). Working in partnership with the National Trust for Scotland and Historic Scotland, our case studies extend the range of this interdisciplinary dialogue, incorporating heritage professionals with backgrounds in architecture, conservation, heritage management, engineering and a range of different kinds of heritage science. A stakeholder workshop also proved a fruitful context for interdisciplinary discussion and debate. Previous ethnographic research carried out with Historic Scotland between 2010 and 2013 [1] also informs the arguments presented in this article.

In advancing interdisciplinary understandings of the values attached to material transformation in the historic environment, we pay specific attention to how these inform, and are informed by scientific interventions. We define heritage science broadly as anything involving the application of scientific methods to measuring change, analyzing materials, protecting them from decay, and consolidating vulnerable components [2] [3]. This encompasses a common distinction between applications of science to advancing understanding (of both material change and heritage environments), and intervening to modify, manage, or arrest material change [3]. The latter area is sometimes referred to as 'conservation science' [4] and  includes both preventive conservation based on scientific understandings of agencies and processes of deterioration (sometimes referred to as 'environmental conservation'), as well as remedial conservation, which may include adding or removing materials using techniques originally developed through scientific research.

## 2. Research context

Masonry materials are vulnerable to deterioration and decay under the influence of a variety of physical and chemical agencies. 'Weathering' encapsulates a range of processes driven by moisture movement, driving rain, freeze-thaw cycles, salt crystallisation and chemical attack from pollutants [5] [6]. Biofilms can have a significant impact on historic masonry, including staining, moisture movement and physical stresses [7]. Climatic variability also brings about change to physical environmental conditions, for instance increased rainfall exacerbates water ingress and increased biological growth [8] [9].

In conservation contexts, responses to these forms of material degradation often result in steps to measure, record, protect, and/or repair historic buildings and monuments. There is a long and continuing tradition of regular repair and maintenance using traditional craft techniques and materials. However, the development of heritage science during the twentieth century has led to the introduction of new techniques for measuring change, analysing materials, protecting them from decay and consolidating vulnerable components [10] [2] [3]. For instance, petrographic analysis is used for characterisation and the determination of provenance. Biocides have been developed for the management of biofilms. More recently, the potential of self-cleaning surface treatments and water repellants is being explored [11]. Nanotechnological consolidants even promise the possibility of consolidation and restoration through the creation of new fabric [12]. As a result of these techniques, the nature of historic buildings and monuments, and their dynamic relations with their physical environments is altered to some degree, whether directly or indirectly. For instance, rates of weathering can be modified and signs of wear and age removed. Historic fabric can also be removed and new material introduced. But what of the impact of such science-based interventions on how heritage sites are experienced and valued?

Heritage conservation and management is a complex process involving not only physical fabric, but also cultural, aesthetic, spiritual, social and economic values [13] [14] [15]. Indeed, a recent report from the Getty Conservation Institute asserts that, "the ultimate aim of conservation is not to conserve material *for its own sake* but, rather, to maintain (and shape) the values embodied by that heritage" ([16]: 7, our emphasis). Furthermore, understandings of authenticity and significance in conservation philosophy have undergone radical change over the last three decades, with increasing emphasis on the intangible aspects of heritage places [17] [18]. Nevertheless, the materials making up historic buildings and monuments, and the transformations they undergo over time, are integral to the values produced in relation to them. Stone is valued for its aesthetic properties, being characterised by an outstanding range of colours, textures, and state of finish, whilst its bulk lends itself to elaborate moulding and carving. Its durability is valued, but equally weathering and wear often contribute to perceived 'character'. In the European conservation movement such material transformation has been seen as important testimony to the passage of time and the authenticity of a monument. The value of transformation in this sense was epitomised by the Romantic ideal of the medieval ruin created at the hand of nature [19], and formalised by Alois Riegl [20] in the concept of 'age value' wherein visible decay and disintegration of material fabric embodied the passage of time, the age of the material affected, and was immediately and aesthetically accessible. Decay and disintegration are also central to the concept of patina and its associated aesthetic qualities of harmony and beauty ([21]: 435-437; [19]: 148-182; [22]). Patina therefore has come to refer not only to physical changes – dents, chips, oxidization – but also qualitative experiences of these changes within an aesthetic register. Mortars, renders and plasters, whilst often less durable than stone itself, and intentionally subject to greater renewal over time, can also enhance or detract from assessments of age value and authenticity.

Despite long-standing recognition of the values surrounding aging, decay, patina and ruination, there has been relatively little research in this specific area [21] [23] [24]. Conservation approaches increasingly emphasize the need to conserve the values embodied in heritage, as much as historic material itself [16]. This requires greater attention to the way in which these values enter into conservation decision-making. Conservators are often acutely aware of the value of patina, although Clifford [25] has nevertheless called for more investigation into its cultural significance. In contrast, the nature of experimental investigation means that heritage scientists often extract materials, properties and processes from their physical and social context. While there are wide-ranging and detailed studies of the impact of scientific techniques on the material fabric itself, there has been little investigation into their impact on cultural meanings and values. Indeed, it could be argued that much applied research has been driven by specific scientific frameworks, with limited consideration of possible impacts on issues of authenticity and historic value. As Cassar [26: 9] emphasises, we need to understand how values are affected by material change. Yet, we also need to ask how science-based approaches to measuring, analysing and modifying material transformation impact on the values of heritage? Furthermore, how do the values associated with material transformation, and the wider cultural significance of heritage, impact on the use of heritage science? To answer these questions it is necessary to draw on humanities-based methodologies.

## 3. Methods

Qualitative social research methods are increasingly used in heritage management to provide evidence for value-based conservation and significance assessment [17] [1] [27] [28]. These methods, including semi-structured interviews and participant observation, are particularly suited for examining the complex meanings and values that surround historic buildings and monuments [29]. However, they are rarely employed to understand the values and qualities specifically associated with the scientific management of material transformation. In our research we used participant observation and interviewing to gain insight into the values associated with material transformation and the use of heritage science at three heritage sites. Research of this kind is necessarily contextual. Our methodology is underpinned by the assumption that the ways people seek to understand and give meaning to the world have to be understood in relation to the contexts in which they come into play. This contextual approach necessarily involves an inductive methodology: while we established a set of research questions at the outset, the form and shape of subsequent investigations was also informed (and modified) through ongoing consultations with research partners and participants.

The three case studies we focus on in this article were provided by our research partners, Historic Scotland (HS) and the National Trust for Scotland (NTS): Dryburgh Abbey; Skelmorlie Aisle; and Charles Rennie Mackintosh's Hill House. Each of these sites was selected because it has significant conservation issues resulting from material transformation, with associated scientific research and/or intervention. They also allow us to explore the interactions of a range of variables, including: (i) different building types and materials; (ii) site-specific conservation problems, approaches and interventions (including different scientific approaches); (iii) varying constellations of stakeholder interests, values and opinions.

Field research was conducted between March and July 2013, and consisted of interviews with heritage professionals and visitors. The anthropological method of ‘participant observation’ was also employed, involving sustained systematic observation of relevant contexts, to ascertain how social values and practices are drawn into everyday interactions. This technique was used in a range of situations including laboratories and workshops, during conservation meetings, site inspections, and guided tours for visitors. Initial discussions and conversations at the case study sites formed the basis for subsequent in-depth interviews, which explored conservation practices, decision-making, and attitudes to material transformation. A range of heritage professionals were interviewed, including heritage scientists (mainly with geo-materials expertise), applied stone conservators, preventative conservators, managers, stonemasons, and architects. Interviews were transcribed and analysed using qualitative data analysis software, NVivo. Shorter informal interviews were also conducted with visitors, and visitor books consulted, to explore their expectations associated with each site, their perceptions of how the material fabric of buildings was changing, and how they felt about forms of scientific intervention. For each of the case study sites, a systematic literature review was also undertaken, focusing on key conservation and management documents, as well as associated scientific reports.

## 4. Material transformation and the production of value

The research results provide evidence for a broad range of responses to material transformation and views on how it could, and should, be managed. Many of our interviewees over the course of the study expressed positive values associated with aging, weathering and decay. For most visitors to the case study sites, marks of age, weathering and decay played an important role in establishing the authenticity, significance and aesthetic appeal of buildings and monuments, as identified by Riegl and Ruskin over a century ago. As one German visitor to Dryburgh put it, “I wouldn’t want any new things. They should try to keep it as it is. We like ruins, there is a mystification and respect for the projects of our ancestors.” Similarly, a Canadian tourist stressed, “we like to see some decay, to see the age of a building.” Some visitors, when asked in more detail about material transformation, focused particularly on surface wear, which they sometimes referred to as ‘patina’. The impact of human activity, such as wear on the tread of a stair or a banister, might also be particularly valued as an indicator of authenticity, the passage of time and a sense of connection to generations past [21] [17].

Professionals involved in managing and conserving historic buildings and monuments expressed similar views on the positive value of certain kinds of material transformation. As one property manager put it, “I think of the surface of an object, or a material, that’s been laid down over time.… It’s important, for most of us, in the pleasure of looking at this thing.” Age was also valued as a mark of authenticity by our professional interviewees, as expressed by this architect:

> I went to Abbotsford* recently, and they hadn’t cleaned all the lichen off the stonework and that patina I thought added a lot to the appreciation of the building as being one of the early 19th century. It had been there for that

length of time. *(*19$^{th}$C dwelling of the author Walter Scott, near to Dryburgh)*

For most heritage professionals, their approach to the management of material transformation was also framed by their anticipation of the value visitors might attach to it. Thus, in considering conservation strategies and reaching decisions with their colleagues, heritage professionals frequently considered how their work would be seen and what kind of 'public' reactions they would encounter, although visitors were rarely directly consulted.

Material transformation certainly produces qualities that are valued in positive ways, but it is also associated with the prospective loss of the historic building or monument itself. Most heritage professionals recognize a version of the dilemma articulated by Lowenthal ([19]:126): while decay undermines authenticity through destruction of fabric, conservation can also undermine authenticity through artificially arresting valued forms of material transformation associated with aging. Here a moral duty and accompanying responsibility is placed firmly in the hands of those who look after heritage sites: 'if they don't get it right', commented one visitor 'the thing is going to go, and it's gone forever, for future generations'. In turn heritage professionals internalized this moral duty, as one put it: 'If we don't stop the decay, we'll lose the monument'. Those interviewees who discussed 'decay' and 'patina' directly often placed the two terms on a spectrum of material transformations, distinguished by the speed and depth of the process, as well as the degree of threat associated with it. As one property manager explained, patina can be managed from a state of being 'aged' and aesthetically attractive, to “a point where suddenly you go, but now it’s detrimental to the fabric.” However, there is considerable variation in terms of how material transformation is valued and when it is deemed harmful. Moreover, different perspectives often relate to different kinds of expertise, and the forms of skilled vision and practice associated with them [1].

For most professionals, heritage science is recognised as having a very important role in terms of investigating and understanding material transformation. As one preventative conservator put it, ‘science is already doing a lot, with thermography, x-ray diffraction, environmental monitoring, petrographic studies. It is building up the picture of what you have’. Scientific evidence research was considered important in meeting the obligation for a evidence-based approach: ‘we can justify our decisions because they are based on observation, and research’. At the same time, our interviews revealed a widely held view, amongst architects and heritage managers in particular, that scientific research should not be the only means by which a building is understood or valued. Furthermore, new kinds of intervention based on heritage science, such as consolidants and coatings, aroused greater ambivalence. For many heritage professionals, the unknown consequences of new treatments are a source of concern, and laboratory testing is not seen as a substitute for ‘real-world’ conditions. The concern expressed relates ultimately to the issue of authenticity, and the perceived negative impact of materials that are regarded as ‘artificial’.

In turn, visitors’ perceptions of sites, are mediated in more or less direct ways by scientifically-based understandings of them. Information conveying the findings of scientific investigations is often positively valued, being taken as a sign of 'care'. These findings also directly mediate understandings of the authenticity, both through positive identification of original fabric, but also through results that can sometimes undermine the visitor experience of what is genuine. For visitors, scientifically derived and industrially produced materials were often equated with 'artificiality', the erosion of the valued 'naturalness' of monuments. As one American religious tourist put it, 'There is something powerful in knowing that the stone mason's work of 800 years ago is still here on its own merits. It would be… <he grimaces> to know it's been propped up artificially, or by chemistry'.

The research thus confirms that material transformation is associated with a range of positive values, but that it is also associated in a negative sense with the ultimate loss of both the historic object itself and the values associated with it. For the subjects of our research, the use of science for prevention and understanding was associated with a different set of meanings, compared to the more interventionist use of science in remedial techniques. In relation to the former science can be seen as contributing to the understanding of what is 'real' and hence 'authentic'. By contrast, scientifically based interventions are often regarded more ambivalently, having the potential to uphold but also to undermine authenticity, for example through the introduction of new materials and techniques that may be seen as 'unnatural' and whose long-term consequences are unknown. However, such generalizations have their limitations. In what follows, we demonstrate how values associated with material transformation emerge at specific case study sites, and how these are informed by the nature of those sites and the material transformation they exhibit. It will be shown that these values, and the notions of authenticity associated with them, are highly contextual, depending on the materials involved, the transformation processes at work, the wider significance of the site, and the forms of expertise applied.

## 5 Case Studies Analysis

### *5.1 Dryburgh Abbey, Scottish Borders*

Our first case study focuses on Dryburgh Abbey, a site that has been actively curated as a romantic ruin, intimately associated with ideas of 'natural decay'. Although this dates back to eighteenth century interventions, it remains an important aspect of the cultural significance of the monument and its conservation. As we show, romantic ideas about decay and ruination thus frame the kinds of scientific research being undertaken, and competing understandings of 'appropriate' interventions arising from these findings.

Dryburgh Abbey (Fig. 1) was founded in the 1150s by the Premonstratensians on a bend in the River Tweed, approximately 60km south west of Edinburgh. It is a typical medieval, European religious complex, built in the gothic style using locally sourced sandstone. Its walls are >1m thick, composed of coursed ashlar on the exteriors, and filled with lime and rubble. Internal surfaces would typically have been lime plastered, but most of this is lost now. Its post-Reformation biography was strongly influenced by David Erskine, founder of the Society of Antiquaries of Scotland, who curated it in the image of a romantic ruin in the late eighteenth century. It is a scheduled ancient monument in the care of Historic Scotland (HS) and it is open to the public throughout the year.

The partially subterranean Chapter House is one of the few surviving roofed parts of the Abbey, although it has a doorless entrance and unglazed windows. This structure has national significance because it contains the largest area of medieval polychromatic wall decoration in Scotland, painted with tempera onto lime plaster (Fig 2). However, it has been at risk for some time from water ingress from above and high air humidity. Interventions to date have included re-roofing and waterproofing, as well as the construction of a French drain to ameliorate rising damp. The decorations and the internal walls suffer nonetheless from colonisation by algae and lichens. The ceiling and walls are currently cleaned using a weak chemical biocidal treatment. This intervention is regarded by HS as an acceptable temporary measure to control the biocolonisation, which returns requiring biannual reapplication. Other interventions such as UV irradiation of the walls have proven to be ineffective [30].

More recent scientific research and intervention has focused on preventative conservation. Data-loggers have been used to monitor the RH (>90%) and the movement of condensing air. Based on this data, the introduction of a door and window glazing, has been proposed, allowing active control of humidity to discourage biological growths. To explore the possible effects of environmental modification, HS conducted an experimental trial during 2012-13 in a small room adjoining the Chapter House. The trial demonstrated that relative humidity (RH) could successfully be controlled through this method, but painting conservators, architects and site staff have expressed concerns regarding the wider impact of the intervention. These range from the potential risk of promoting salt efflorescence on the plaster itself, to compromising the atmosphere and authenticity of the Chapter House and the Abbey. At the time of our research, HS was still considering the best course of action.

Our research consisted of participant observation at the site and interviews with visitors, HS site staff, a conservation architect, painting conservators, and the consultant preventive conservator who was commissioned to look at environmental conditions. Different perspectives on the conservation problem emerged. From the point of view of the preventive conservator 'incorrect relative humidity is probably the biggest way of accelerating decay', a perspective gained from studying for university degrees in Heritage Conservation (Bournemouth) and Sustainable Heritage (UCL). To his mind, the 'uniqueness' of the plaster justifies the significant architectural interventions proposed to achieve environmental control. His 'solution' focuses on the specific problem of biocolonisation, and the environmental data he had gathered. Wider concerns including the aesthetics, energy, and costs of the architectural interventions, were emphasised by other conservation professionals involved.

The painting conservators knew the case well, visiting regularly for biocidal treatment, which they regard as a tried and tested approach. In contrast, the potential unforeseen impact of the preventative measures proposed, in particular the possibility of increased salt formation due to dehumidification, made them uneasy. As one conservator put it: 'I don't want to have it all on my head, doing something so major on such a precious thing'. This caution, 'a conservative' approach in her terms, reflected her interest in the paintings themselves: 'I feel like it's a bit too precious a place just to do an experiment with, in a way' she reflected. 'Often we go looking for answers', she commented, 'we tend to think that "if science has told you" then it must be right. And in some cases it is, but not always.'

The HS architect responsible for coordinating decision-making at the site also considered the scientific results as one of many factors: 'I think the architect's role', he said 'is to give the wider picture and see whether it fits in with all the other parameters one has on that space'. Within this frame of reference, the interventions required for dehumidification of the Chapter House have widespread ramifications for the values associated with it, and indeed its authenticity. An enclosed staircase would have to be added, but this, he pointed out, would need to be based on 'conjecture'. Furthermore, in his view the scientific data on environmental conditions is a 'snapshot' of 'absolute conditions that are perceived at one time', but 'the trouble is they may not be typical of the other uses that the spaces get…so I think they always have to be put in context'. He envisaged that a 'clean and modern' glass box would need to be built, an architectural intervention clearly differentiating the intervention from the original fabric. 'But some people would hate that', he reflected, demonstrating the way in which various perspectives are weighed during deliberation: 'A lot of people use that space for weddings and they like the wholeness of [it] I think; the fact that it has hardly had any intervention at all since the 19$^{th}$ century'. As a result, regular use of biocides was seen as likely to do less ‘harm’ than dehumidification, because as a form of intervention it is much more contained and has far fewer ramifications for other aspects of the building.

Site staff and managers are perhaps most familiar with day-today use of the Chapter House. They are also closely involved in its use as a wedding venue, meeting couples and making bookings. They too emphasised the space as a whole and stressed that it look as ‘natural’ as possible. They entered into long conversations with the MAV project ethnographer about the implications of the architectural solution proposed to control the environmental conditions; what *kind* of door would be ‘appropriate’ and ‘authentic’, would it have had metal hinges, if so what kind? They were concerned about how conservation efforts focused in on the painted plaster might affect the revenue gained through wedding bookings, and thereby the future of the site as a whole. ‘You can’t put in a glass door’, commented one seasonal worker, ‘unless you have a very good reason. If you closed off the Chapter House, you’d be taking something away from the Abbey – the freedom to just go in.’ For him, this ‘freedom’ allowed visitors to experience ‘how it might have been’, and also gave him job satisfaction: ‘It’s the best bit of my job, going in first thing in the morning’.

Informal interviews with visitors themselves gathered a range of views on the possible intervention, the majority of which referenced the ruin’s mature wooded setting and the ‘romantic’ aesthetic of the site. Tourists moving between the Abbeys of the border region expressed positive orientations to decay as ‘natural’, sometimes connecting this to biological understandings of life. One expressed a desire for Dryburgh to ‘have death in beauty’; another for it to ‘be able to decay slowly, without us preventing it’. Biological growth in most areas of the Abbey was appreciated aesthetically: pointing to growth on the ruin’s walls, one couple pointed out that ‘it [the wall and foliage] has been there for hundreds of years and I think […] we should keep that’.

The Dryburgh case study reveals a wide range of concerns about the proposed science-based interventions and their impact on wider values. It shows that different forms of expertise and the frames of reference associated with them produce different kinds of valuation, which relate to different ideas about what is ‘real’ or ‘authentic’, and hence important, about the site. In the scientific measurement of environmental conditions associated with the biocolonisation of the painted plaster, the environmental conservator extracts certain materials and variables from the wider concerns of other heritage professionals. Attempting to reinstate wider relationships, monument staff, architects and painting conservators work through the wider ramifications of the proposed architectural interventions for the authenticity and value of the painted plaster itself, but also the Chapter House and the Abbey as a whole. In assembling these wider relationships they draw on different forms of skilled vision, but they also invoke visitor perspectives and experiences associated with the notion of a romantic ruin and its aesthetic value, particularly as this appeals to the wedding market.

The preservation of Dryburgh Abbey as a romantic ruin is associated by conservation professionals and visitors with distinct but overlapping understandings of aesthetic value, historic significance and authenticity. These are associated with a range of context specific assessments of how heritage science is applied and whether the solutions associated with it are implemented. Furthermore, the case shows how specific forms of valuation are negotiated through the lens of different kinds of expertise. The attitudes, values and expectations of 'the public' are also important in this process; frequently projected by professionals as part of their valuations and debates. Scientific evidence is valued in itself as a justification for action, but the tendency to extract data in relation to a specific problem, a kind of 'snapshot' in the words of the conservation architect, is viewed with caution. Finally, it is evident from the data presented that while the professionals involved bring their own expertise and evaluations to the case, decision making takes place in an institutional context, where the different authorities of the participants shape the evaluations involved.

### *5.2 Skelmorlie Aisle, Largs, North Ayrshire*

Our second case study focuses on Skelmorlie Aisle, where stone decay is attributed little value in terms of patina and the authenticity of age. Instead it is seen as a malign if poorly understood influence to be arrested. Yet, as we show, material authenticity is still privileged and heritage science is being deployed to try to understand the material processes at work and the environmental conditions informing them. The case allows us to explore the distinct, yet relational, values associated with different kinds of heritage science.

Skelmorlie Aisle (Fig. 3) in Largs, North Ayrshire, was built in the 1630s by Sir Robert Montgomerie of Skelmorlie to provide a place for private worship and burial. Originally the north transept of Largs old church, it remained as a free-standing mausoleum structure in the historic graveyard after the rest of the church was demolished in 1802. The loft of the Montgomerie tomb within the Aisle comprises a richly carved renaissance style canopy, in dense pale gold sandstone, which is raised over a partially sunk burial vault and approached by steps with a balustraded parapet (Fig. 4). The Aisle itself has a wooden barrel-vaulted ceiling, painted with quotes from the Geneva Bible and rich allegorical landscapes by James Stalker, dating from 1638 ([31]: Fig 5). Together the carved stone tomb canopy and the painted wooden ceiling represent perhaps the most outstanding examples of such work in Scotland. The Aisle is both a scheduled ancient monument and an Historic Scotland (HS) Property in Care. Nevertheless, visitor numbers are considerably lower than Dryburgh, in part because access is more restricted. Keys for the graveyard and the Aisle must be obtained from Largs Museum (open 2-5pm between May and September).

The ceiling paintings are in a good state of preservation. The tomb canopy is faring less well. Although the upper stonework is crisp, the lower parts appear badly decayed. Granular disintegration and exfoliation (Fig 5) has been evident since the mid 20$^{th}$ century, manifesting as craters, flaking and powdering on the surface. Indeed, records show that in 1940 powdered surfaces were treated with Magnesium Fluorosilicate with little evident success. In places, a thin crust has formed, with disintegration continuing beneath. So far, the decay has been attributed to high moisture levels and possible salt contamination. There are also damp patches and salt efflorescence on the walls of the Aisle, which are constructed from course ashlar. The south wall is a particular concern, because it originally consisted of an internal wall with a pointed arch that was blocked and rendered (‘harled’ in Scotland) externally after the rest of the church was demolished.

At the time of this project, HS had been investigating the stone decay for five years, drawing on the expertise of two conservators (one stone conservator and one preventative conservator) and two heritage scientists (both with geological training). Moisture mapping of the tomb and its canopy using microwave sensors and thermography showed no clear pattern related to rising damp. Petrographic analysis of the stone revealed it to be very dense—confounding expectations that decay might be associated with high porosity and low strength. XRD analysis was applied to salt efflorescence to explore pollutants and the presence of different salt types. Based on these results, it is apparent that the stone decay is not directly related to the effects of moisture or salts. The heritage scientists involved have also considered the possibility that condensation events are destabilizing pyritic inclusions, producing sulphuric acid, which is then dissolving calcium and iron carbonate in the stone. As part of the current research, temperature and humidity in the Aisle have been monitored using data loggers.

The root cause of the stone decay on the surface of the tomb structure remains a puzzle. The isolated character of the decay, and the manner in which it eludes a clear diagnosis, places conservators in long-term dialogue with material scientists, geologists and preventive conservators. Efforts to find out what has been causing the flaking of the stone demonstrate how different professionals engage with material transformation in different ways.

The materials scientists focus directly on the process of material transformation taking place, extracting the problem from its wider historic context and associated values. One of them explains: "If you can find out what's causing the decay and stop it happening, that's not going to change its current value, it's going to prevent loss of value in the future." The pursuit of knowledge and understanding also privileges certain kinds of analytical technique related to the material itself; in this case whilst the decayed powdered stone is useful, core samples are preferred. However, such destructive sampling would require consent from heritage managers within HS and arouses anxieties. As the stone conservator put it: 'if you don't know what material you're dealing with you don't know how you're going to treat it', but sampling is 'destructive', and has limits. 'It will tell us something about the petrography of the material and the structure of it and its contents', she noted, 'but it doesn't necessarily tell us an awful lot about the behavioural properties', which are particularly relevant to understanding the process of decay. Furthermore, mobilizing values surrounding the authentic historic material in contrast to scientific values; you could end up with monuments that 'look like wasps nets; you've got no stone left, you're doing far more damage than you can possibly do good'.

The issue of sampling highlights the values associated with heritage science itself, as well as with material transformation. There are also concerns about the unknown consequences of science-based interventions especially those associated with new materials, as the stone conservator commented:

> We are very reluctant to do things involving applying chemicals unnecessarily. Especially things that are irreversible, if we don't understand the long term effects well enough. There are so many examples in the past that have turned out badly that were well intentioned at the time.

Yet the role of heritage science in the UK has increased. The stone conservator again highlighting the complex interplay between experience, judgement and evidence: 'In the past, [we had the attitude], it's always worked before why wouldn't it work now? Now it's much more "Well, have you got the scientific evidence, and what does that tell us"?' The problem is that the evidence, in this and many other cases, is far from incontrovertible.

Hypotheses about the mechanisms of decay at work on the Mausoleum emerged from – and were disproved by – techniques such as microwave surveys, thermal surveys, or building surveys. In their turn they raised the possibility of interventions that could lead to further material transformation, as in the case of the Dryburgh Chapter House. An early hypothesis was that salts were being drawn in from the ground through the crypt walls up into the monument. The stone conservator noted that the interventions required to alleviate it would be, in her terms, 'very involved'. New drains and a damp proof membrane, possibly even 'disturbing the archaeology', would require support from the HS architect and heritage manager, something serious she associated with justifications and permissions. In her view, scientific research provided leverage with other professionals in the process who could authorise decisions and strategies. The heritage scientist working closely with her agreed: ‘it’s the core of [the] decision: otherwise you don’t have anything to discuss – a problem without a solution’.

As a result of this desire for evidence, scientific analysis was brought into the project in a range of other ways beyond sampling. One key data set was collected by the environmental data-loggers monitoring the internal environment in which the memorial stands. This was the domain of the preventive conservators, who have, as at Dryburgh, proposed environmental modification to avoid condensation events. Temporary low-level heating and a blind against solar gain have been introduced to assess the effect on the environment; essentially to investigate whether reducing the humidity and stabilizing the temperature will diminish decay. However, this in turn raises concerns for the architect about the impact on the walls of the Aisle itself; would drying out the interior simply draw more moisture in through the walls and increase salt efflorescence on them? And he asked, what of the unforeseen impact on the ceiling paintings? Relative significance based on a range of values is thus brought to bear on potential solutions to the particular area of material transformation subject to scientific research. The carved Mausoleum structure is generally given greater value, than the walls if not the ceiling painting. Yet the impact of interventions oriented to the former on the latter still requires evaluation and judgment.

Understandings of the specific significance of Skelmorlie relate to context-specific evaluations of the problems and possibilities associated with various forms of scientific understanding and intervention. In contrast to Dryburgh, a romantic ruin, the conservation team do not deem the material processes at work, in this case salt efflorescence, peeling crusts and stone decay, to possess aesthetic merit or ‘age value’, either from their own perspectives or those they project onto various publics. Instead, decay of the tomb canopy is understood as a problem in the function of the building that needs to be resolved to preserve the elaborate carving. Ideas about public values figure less prominently in negotiations at Skelmorlie, but they are still in implicated. As the current preventative conservator observed, an ‘ideal’ environment would be a museum where all environmental factors could be controlled, but this would not be an ‘ethical’ decision, since it conflicted with the values placed on public access, something that the architect and heritage manager confirmed. Finally, we observe again that conservation and material scientists work in an arena where permissions, jurisdictions and different perspectives on the nature of a conservation problem co-exist. In this case, it is the values associated with heritage science itself, and the tensions that can arise between science and conservation, which are brought into sharp focus.

### *5.3 The Hill House, Helensburgh, Argyll and Bute*

Our final case study is Hill House, an example of the kind of modernist architecture, which is an increasing concern for heritage organisations. It presents a specific set of conservation issues relating to the distinctive materials used, and the extent to which a monument-derived conservation philosophy of ‘minimum intervention’ is an appropriate response. As we show, these issues impact on the application of heritage science, in a context where ‘authenticity’ is less a matter of material originality and more commonly associated with a specific architectural vision.

The Hill House (Fig. 6) sits on an elevated, exposed, southwest facing coastal site above the town of Helensburgh, approximately 30km west of Glasgow. Designed and constructed during 1903-4 by the Glasgow-based architect Charles Rennie Mackintosh (1868-1928), it was commissioned by Scottish publisher Walter Blackie, as his family home. Mackintosh was a modern architect with a distinctive style variously associated with the Arts and Crafts, Art Nouveau and European secessionist movements. He is also known for design and furnishing of the interior of his buildings, in partnership with his wife Margaret Macdonald, as was the case at Hill House. Mackintosh’s status has increased significantly in recent decades, meaning that his surviving work now attracts the highest levels of statutory protection. The Hill House was designated a Category A Listed Building in 1971 and donated to the National Trust for Scotland (NTS) in 1982. It has a resident property manager, and is open to the public between April and October.

Mackintosh was keen to apply new materials in his buildings. Whilst the Hill House has solid masonry walls made from brick and soft red sandstone, the exterior is rendered in grey-coloured roughcast render, or “harl”, containing Portland Cement (PC). At the time, PC had gained currency and was promoted as the strongest, most waterproof material available [32]. This claim persuaded Mackintosh to use it in his pursuit of novel, modern design values, allowing him to dispense with traditional water-shedding features, such as wall copes at gables and window cills. However, the inflexibility of the PC based render, compared with a lime-based alternative, has resulted in extensive cracking (Fig. 7). PC's low water permeability and high capillary retention traps any water ingress that occurs through the cracks causing further deterioration of the render, exacerbated by freeze-thaw action. In places, moisture has penetrated the whole wall, putting the Mackintosh-Macdonald interior at risk by increasing RH and condensation, resulting in mould growth. There have also been outbreaks of dry rot. Recent scientific investigations have focused on investigating the condition of the fabric of the building using materials analysis (petrographic thin sections and XRD) and thermography, alongside traditional engineering and condition surveying. The internal environment is being monitored with Hanwell recorders documenting temperature and RH in several rooms.

The NTS are in the process of examining the history of repairs and the scope of possible future interventions ([32] ibid.). Their deliberations centre on the status of the render, particularly the extent of original fabric remaining, and the technical repair challenges posed by previous interventions. In terms of conservation philosophy, there are questions regarding authenticity and whether this lies in the original fabric, or in the other aspects such as the building's design and Mackintosh's intentions. During the 1980s, a hydrophobic silane was used with limited success; both as a surface water repellent coating and as a consolidant in conjunction with hydrocarbon rod ties in the interface between the PC harl and the degrading underlying sandstone ([32] ibid.: section 3.1). Current thinking questions the appropriateness of this former conservation strategy, since it used an irreversible experimental approach to preserve the fabric through introduction of a different manufactured material ([32] ibid.: 75). There are also concerns about whether the use of the silane consolidant has exacerbated problems with the harl, leading to further problems of water retention. Evidence now suggests that a considerable amount of the original render had in fact already been replaced during the Hill House's life cycle, perhaps as much as 80%.

These discoveries also come at time when conservation attitudes towards twentieth-century buildings and modern materials are changing, not least as a result of the *Madrid Document* [33]. As the regional Lead Surveyor on the NTS Buildings Team commented during a project interview, the kinds of problems faced by the Hill House are

> an international issue, and that's the right sort of level that these debates really need to happen….to face up to the fact that there maybe has to be a slightly different approach in some cases, when it comes to 20th Century buildings, you know, they can't all be treated like Dryburgh Abbey where every single stone has to stay in exactly the same place forever you know. […] Material has to function.

The figure of an important historic architect linked to Hill House is also a distinguishing factor, which means that material transformation is subject to a different set of valuations. 'To be consistent with the Mackintosh design intention', he remarked 'you have to try and maintain something that's looking quite crisp and sharp'. In the light of this, solutions are being sought that aim to preserve the modern silhouette and 'unity of style' in line with Mackintosh's architectural vision, even if that means sacrificing or replacing the PC render. Indeed, Wright ([32], ibid.: 94) remarks that ‘perhaps the Hill House ‘unity of style’ might be considered as the *primary* value to be preserved’ (original emphasis). Here, then, aesthetic and architectural values are privileged over authenticity of materials, with authenticity being relocated in relation to Mackintosh’s vision.

Aesthetic values and Mackintosh’s intentions also feature heavily in data on visitor experiences and guide perspectives. Volunteer guides regularly share their knowledge of the house and its history with visitors. During inteviews they reported feeling under pressure from visitors whose only experience of Mackintosh had been through glossy coffee-table books. Visitors were sometimes disappointed or angered by peeling paint, discolouration, or visible cracks in the external harl of the house. Having come with expectations regarding the ‘modernity’ of Mackintosh’s work, signs of age are considered ‘inappropriate’ by many. As one materials scientist, with extensive experience of building conservation as well as sample analysis, noted

> [visitors often] want to see what Mackintosh perceived and what he delivered, because that’s what they’ve been led to expect. So when they see decay, they see discolouration, they see the effects of water penetration, the first response is “nobody is looking after this.”

The Hill House case study provides an apt contrast to the other case studies, reinforcing our argument that values associated with material transformation are context-dependent and emerge in relation to specific buildings and monuments.

At Hill House, signs of material transformation and age value conflict with the aesthetic modernity of its design for many heritage professionals and indeed visitors. As a consequence, for many, conservation of the design of the building is deemed more important than preservation of the original PC render; material authenticity is thus displaced. Project interviews explored the contextual meanings of ‘authenticity’ and ‘truthfulness’, revealing that differing understandings of these concepts inform distinct approaches. Volunteer staff who worked at the Hill House, for example, were concerned with preserving the appearance of the building, with less concern for the ‘authentic mix’ of Portland Cement. Several staff remarked that recent painting and repair of the render compromises authenticity. In their view a full-scale replacement would better ‘serve the interests of house and the public’ by replacing a ‘failed experiment’ with a material that would withstand the driven rain of the Hill House’s exposed position.

The Hill House also highlights how the history of a building and its previous interventions, as well as historical shifts in conservation priorities, informs values and actions in the present [34] [35]. The value assigned to the material fabric of the Hill House render has shifted over time. In previous conservation campaigns, the values associated with what was thought to be the original fabric justified experimental intervention to keep it in place. Subsequently, these valuations have been questioned, and doubts raised about the originality of the fabric. Hill House also demonstrates, how conservation interventions are increasingly required to take account of previous treatments, whose behavior was not anticipated and may not be predictable [3]. This encourages caution amongst conservation professionals towards new scientifically developed products as they are exposed to the detrimental effects of well-intentioned historical interventions. Finally, the Hill House case reveals how the scope of scientific intervention—as a problem-solving activity—may be determined in advance, by other formulations of what the problem is. Priorities like “preserve the original fabric” or “preserve the artistic vision of the architect” define the parameters (and goals) of scientific research, and the likely acceptability of solutions.

## 6. Conclusions: implications and recommendations

At the outset of this article, we argued that if the aim of conservation is to sustain and shape the values associated with heritage objects, there is a need for greater attention to the relationship between material transformation, value, and heritage science. Indeed, radical changes in how significance and authenticity are conceived in conservation philosophy, with increasing attention to intangible aspects of heritage, have created a pressing need for new research on the role of materiality [18] [17] [21]. Yet, in many areas of heritage practice the conservation of material fabric and the consideration of significance, value and authenticity, proceed in a parallel, at best loosely connected, fashion. The UK House of Lords Science and Technology Committee’s Report on *Science and Heritage* [2] is a good example. The Report vociferously advocates the development and application of heritage science, but, although it defines conservation in terms of sustaining the values associated with heritage ([2]: 11-12), much of its focus is on preserving material fabric. Consequently there is little attention to the important question of how the application of science intersects with values. In recent work, Cassar ([26]: 9) has emphasized the 'symbiotic' relationship between material transformation, intervention and value, and called for a deeper understanding of what she calls the 'material/cultural' interface. We endorse this call, but we argue that attempts to quantify, categorize, or systematise this relationship (e.g.[34] [36]) are inevitably limited to generalizations that skate the surface of the complex dynamics involved.

Our interdisciplinary research reveals that values associated with material transformation emerge in particular contexts, informed by differing constellations of materials, processes, practices, visitor expectations, use patterns, building types and forms of expertise. In some contexts (Dryburgh Abbey), weathering and decay can accrue 'age value', marking the passage of time, contributing to the experience of authenticity, and creating aesthetically pleasing 'character', 'patina' and 'ruination'. In other cases, material transformation and decay is associated with a loss of value and authenticity; either directly through loss of material itself (Skelmorlie Aisle), or because of the wider implications of deterioration in part of the historic fabric for the authenticity and value of the monument or building as a whole (The Hill House). Just as the values associated with material transformation emerge in particular contexts, so does the application of heritage science to understanding, controlling and arresting material transformation. It is not just a case of identifying pre-existing values that then inform how 'problems' are framed, and when and how heritage science is applied. Rather, the application of science in heritage contexts is embedded in dynamic modes of valuation. The use of scientific techniques to measure, understand and control material transformation is informed by these values, but these very processes also have the potential to change those values. As one materials scientist put it, "there *isn't* a generalization. Everything is unique in buildings." He was referring to combinations of materials, craftsmanship, weathering cycles, location and climate, which are always specific to particular situations. In the same way, the values associated with material transformation are not only historically specific [19], but also context-dependent, affected by – amongst other things – the nature of the monument, the materials involved, attitudes towards risk, modes of expertise, changing conservation philosophy, institutional priorities and expectations.

The implications of this research can be summarised as follows. First, material transformation, including decay, does not merely impact on heritage significance. It is an integral aspect of the values that underpin significance. Second these values are dynamic and contextual. They may vary over time, between and within sites, and between different heritage professionals and stakeholders, in ways that cannot be determined in advance. Third, the application of heritage science to measuring, understanding and modifying material transformation is embedded in these values; it both informs and is informed by them. Fourth, integrated qualitative research methods can increase our understanding of these important, site-specific conditions and processes, and thus contribute to more nuanced and productive applications of heritage science, sensitive to the values associated with heritage sites.

In light of these points we recommend that further qualitative research is conducted on the relationship between material transformation, authenticity, value and heritage science. The tendency of heritage science to focus on a specific material or environmental process and to extract data in relation to this, even setting up controlled laboratory experiments, means that Cassar's ([26]: 9) 'material/cultural interface' is always in danger of being over-looked and this requires further attention. Importantly, however, it will not be possible to identify rules or models that can be generalized, because the values and qualities associated with material transformation are complex, situated and contextual. We therefore recommend that qualitative methods, such as participant observation, interviewing and focus groups, should be routinely employed to explore the site-specific values and qualities associated with material transformation. Data from such research could then be taken into account when planning interventions and assessing their future impact. Changes in training, expertise and institutional cultures will also be necessary to effectively integrate qualitative methods in such a routine fashion. Therefore our final recommendation is that forums are created to facilitate open-ended discussion of such issues amongst heritage scientists, conservators, managers and other heritage professionals. Whilst it has long been recognized that *cross*-disciplinary collaboration is crucial in heritage management and conservation, the promotion of *inter*-disciplinary dialogue, especially across the sciences and humanities, is a less commonplace, but increasingly important measure. Combined with such events, further interdisciplinary research of the kind central to the MAV project, involving personnel with both scientific and humanities backgrounds will help build a working environment where there is a more holistic consideration of the cultural ramifications of scientific interventions alongside their material effects.


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**Science, value and material decay in the conservation of historic environments**

**Figure Captions**

Figure 1. Early Gothic (12-13$^{th}$C) rounded arch doorway at the remains of Dryburgh Abbey, Scottish Borders. This doorway is the south entrance to the Choir, adjacent to the South Transept of the main church, and the Chapter House. The complex is composed of local white sandstone, here comprising the door surround with side pillars of a dark red sandstone. (Photograph: Maureen Young, Historic Environment Scotland).

Figure 2. Part of the medieval painted ceiling in the Chapter House at Dryburgh Abbey, Scottish Borders, showing details around the east facing window. The surviving decoration is very faint. The image also clearly illustrates the greening of the stonework caused by the biological colinisation, that is the subject of periodic cleaning. The debate about the control of this surface alteration, through direct environmental control measures or cleaning, is a key conservation issue at the site. (Photograph: Maureen Young, Historic Environment Scotland).

Figure 3. Skelmorlie Aisle, Largs, East Ayrshire (1636-38), is the remaining fragment of a larger, now demolished, church. It now sits in a graveyard in the centre of Largs, enclosed by the surrounding wall and other buildings. Its highlight lies inside; the dramatically carved 17$^{th}$ C loft and mausoleum of the

Montgomerie Family. (Photograph: Maureen Young, Historic Environment Scotland).

Figure 4. The interior of the Skelmorlie Aisle. The richly carved renaissance canopy sits above the-subterranean burial vault of the Montgomeries. The canopy, or loft was the private worship space of the Montogmeries. The wooden ceiling above the loft is richly illustrated (1638) with allegorical classical, biblical and landscape scenes, including one of Largs with the full church with the Aisle itself, before demolition. (Photograph: Maureen Young, Historic Environment Scotland).

Figure 5. Decay on the top of the tomb at the Skelmorlie Aisle, Largs. Here the dense fine grained sandstone is suffering from cratering and powdering. At the centre top right of the image an environmental logging device can be seen attached to the structure, recording conditions of Temperature and Relative Humidity near to where damage is occurring. (Photograph: Maureen Young, Historic Environment Scotland).

Figure 6. The west façade and the entrance to the Hill House, Helensburgh, Argyll and Bute (C.R. Mackintosh, architect, 1904-5). This view was taken in 2013 some months after the exterior Portland Cement render had been painted to unify the appearance and improve resistance to environmental attack. The Clyde estuary can be seen in the background. (Photograph: John Hughes).

Figure 7: Example of the cracking in the Portland Cement render of the Hill House, Helensburgh. Cracking such as this allows water ingress that threatens the

historic Macintosh-Macdonald designed interior decoration and furniture

(Photograph:  John Hughes)..

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Detailed response to reviewers

Minor corrections were made to the manuscript, following the suggestions of the reviewer.