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What is Conservation Science?

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Summary: 'Conservation science' or 'cultural heritage research' is defined through a discussion of research needs, training and employment patterns world-wide, and trends in published work. Parallels with mainstream polymer science are drawn throughout. Some aspects are discussed in more detail: traditional paint composites; studies in modern, synthetic, paint composites; the relevance of accelerated ageing to a range of polymer types.

Keywords: accelerated ageing; ageing; conservation science; cultural heritage research; modern paint; resins; traditional paint

Conservation Scientists Apply Research to the Preservation of Cultural Heritage

The term 'conservation science' is a relatively new one, which came into use in the 1980s. It is now widely accepted within the cultural heritage sector. It encompasses archaeometry. Recently the term has also been used in advertising for positions which involve fieldwork in nature and environmental conservation. 'Cultural heritage science' would be a better term for the subject discussed here.

Conservation scientists carry out research to further the conservation, preservation and understanding of the world's cultural heritage. They are also conservation professionals with an understanding of conservation ethics and an appreciation of the visual memory, manual dexterity and aesthetic judgement of their conservation and curatorial colleagues. They act as mediator and interpreter between eminent authorities who include academics, historians and museum curators. They have an active role within an international community of conservation professionals.

In one sense this profession applies and develops existing research. Yet conservation scientists must carry out primary research where knowledge gaps exist on the properties and identification of materials as they age. They sometimes discover new compounds in consequence. The field includes both pure and applied research. Conservation scientists apply published materials research, independently developed analytical techniques, developments in sensors, detectors and imaging techniques, studies in environmental pollutants, knowledge of historical manufacturing and production processes, and the latest developments in polymer science, among others. Their knowledge has to be extensive, interdisciplinary and multi-faceted. At present, the science that underpins a number of past and even present conservation treatments is poorly understood. Conservation scientists investigate, improve and critique conservation processes. They develop and adapt existing analytical and examination methods to aged, fragile and unique artworks and buildings. They may have to work with tiny samples, sometimes on a sub-milligram level, and often work from limited physical evidence. Increasingly they develop marketable hand-held equipment and dosimeters for use by non-scientists in the cultural heritage sector.

The Goal of Conservation Science is the Preservation of Artefacts and Materials Far Beyond their Natural Lifetime

Conservators seek to understand the long as well as short-term consequences of the treatments they carry out - or choose not to

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do – in order to ensure the survival of cultural heritage. However, artefacts are not only displayed or stored for future display. They will be re-analysed and re-interpreted in the future. It is necessary to know whether conservation treatment will modify chemical or physical properties of the artefact.

Conservation science research often begins at the point where the original artist or manufacturer ceased to research, modify and improve the product. Conservation scientists therefore characterise materials, as well as analysing them and elucidating their deterioration processes. This involves the recognition of key physical properties, as well as their measurement on model materials, then small samples from artefacts. Most artefacts and artworks are the products of little-known, ill-documented technologies and past industries. Even in the field of modern materials, which are increasingly found in both museum and library collections, and which increasingly are polymer-based, industrial research is rightly more concerned with product improvement than with product preservation for the extreme long term.

A Closer Look at Conservation Science

Fig. 1 illustrates the relationship between cultural heritage – the artefact or the monument – and different professionals in the cultural heritage sector. Conservators are the closest of all to the artefact, and they may spend many years working full-time on the treatment of one object. It is not surprising that they are perceived by other cultural heritage professionals as being too closely centred on the needs of the object, and too little aligned with the complete mission statement of their institution!

Conservation scientists take one step back from the artefact: they are investigating its properties and behaviour, as it was when it was created, as it is now, and as it will be in the future. The first and the last are extrapolations from their investigation of the actual artefact. In objects of archaeological age, their investigations help to identify original use, as well as original materials before burial. Polymer study plays a smaller part here: the majority of archaeological artefacts are inorganic, but in recent years the occasional survival of organic polymeric material has been recognised, where once it would not have been perceived or preserved.

The curator, owner or collector work another step further from the object: they are concerned with its context and meaning as well as its aesthetic appearance or monetary value. Since curators are interpreting the artefact and its meaning for a non-specialist audience, they are concerned with its function, its meaning to earlier societies, the purposes for which it was collected and has been displayed, and the cultural and/or spiritual values once associated with it. Art historians, historians of technology, experimental archaeologists and material historians also work two steps back from the artefact, as do educators, docents and guides. They rely on primary information provided by conservation scientists and conservators, in order to relate the story of the past.

Museum and site directors and administrators, and fund-raisers, are even less closely involved with the artefact *per se*, and would never cite preservation of the collection as their sole *raison d'etre*, as might conservation scientists as well as conservators.

The range of materials which conservation scientists study could not be wider. It includes both the immovable heritage, comprising buildings and sites, and the moveable heritage. The latter consists of all the materials types found in museums, galleries, libraries and archives, and historic houses, and all industrial products of today, which will be in the museums of the future. This includes both natural and man-made materials, from ancient and forgotten technologies as well as from current ones.

Conservation scientists can often be found working closely with collections in museums, galleries, libraries and archives (albeit in far smaller numbers here than in museums, and with a shorter history of

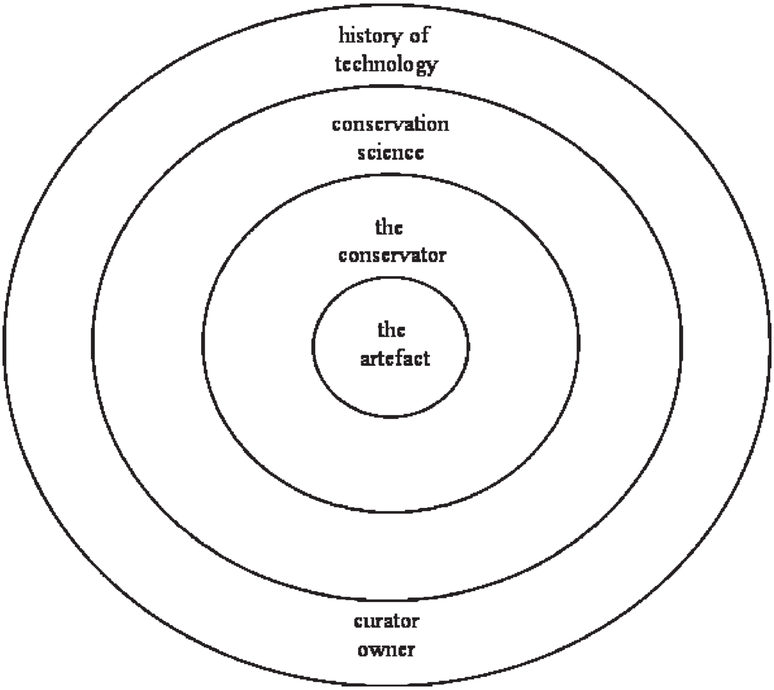

Figure 1.
Relationship between the artefact and different heritage professionals.

employment, at least in the UK), historic monuments and sites and as lecturers in universities which offer post-graduate conservation courses. In several countries with government-funded national conservation institutes, such as Italy, the Netherlands, Belgium and Canada, the majority of conservation scientists are civil servants working for an institute with client museums but no collection. Such countries tend to have few or no conservation scientists in museums etc.

Occasionally, academic scientists who have a long-term association with conservators and conservation scientists begin to share and understand full professional knowledge of the latter groups. This is always a slow process, characterised by an initial lack of understanding of the complexity and variety of historic materials by those who have never had to think about it previously. The lack of shared understanding comes into sharp focus when the academic researcher requests, for example, a sample of 'historic paint' or 'historic metal' which s/he thinks can be reproduced for all cultures and all periods, in one sample!

Recent years have seen successful data-sharing world-wide, in the cultural heritage sector, for techniques such as FTIR, and proposals for similar sharing of mass spectrometry and Raman data. This will increase in importance in the future.

Training for Conservation Scientists

Conservation scientists have an initial training in one of the sciences. In the past they have been trained almost exclusively in a physical science: physics was a common background in the past, chemistry is an increasingly prevalent background today, with an emphasis on organic or organometallic chemistry, and smaller numbers have studied materials science, colour science, mechanical engineering or geology. Rather few have ever come into the profession from the biological sciences, though this small number is increasing slowly. Approximately 50% of working conservation scientists in the UK began in chemistry, over 40% in physics, with the other sciences accounting for the remaining 10%.

Most conservation scientists recruited today are either in possession of a doctorate in the physical sciences, or would expect to obtain one during their initial contract or position. Some who are now in mid-career earned their post-graduate degree in the physical science they first studied, though analytical chemistry, applied optics, environmental chemistry and forensic science are inter-disciplinary subjects which often directed their first steps towards the multi-faceted profession of conservation science. Forensic science in particular shares common features with conservation science: small samples, too few samples for good statistics, a lack of comparative evidence, and the need to modify published analytical protocols to suit the limited samples. For some who earn a doctorate in mid-career, the subject might be more closely allied with artefacts or artworks, and could be described as technical art history, materials history, or archaeometry, depending on the type of artefacts involved, rather than as a pure science.

The professional accreditation of conservation scientists is a hotly-debated issue in the UK and to a lesser degree in the US. It has closely followed, but always lagged, the attempts of conservators to achieve professional accreditation and recognition of their profession. These ongoing attempts have achieved more success in the UK and the US than in continental Europe.

The mature conservation scientist has knowledge and understanding of conservation objectives, ethics and philosophy, art or cultural history, and the histories of technology and materials. As Fig. 2 illustrates, rounded conservation scientists develop an expanding knowledge base, but always from the starting-point of a pure science. Understanding and application of the scientific method, the critical evaluation of evidence, and the presentation of evidence to audiences with different levels of knowledge, remain key skills at every stage in their careers.

Where do Conservation Scientists Publish?

The conservation literature is generally their first choice. Conservators represent an eager, motivated and well-informed audience for their publications. The majority of delegates at intentionally 'inter-disciplinary' conferences in cultural heritage are frequently conservators. There is a perception among some conservation scientists that there are too few publishing opportunities for in-depth conservation science. At the same time, there is a growing perception among conservators that too much of the conservation literature is devoted to research into materials, and too little to their conservation. It is certainly true that many papers are written by conservation scientists, and that most conservation scientists publish far more regularly than do conservators. Today, the number of conservation scientists who are journal and book editors is also high, disproportionately so in relation to their overall numbers. Of all museum professionals, conservation scientists have had the greatest commitment to publishing and disseminating the results of their research.

Conservation scientists do publish in the scientific literature too, but generally at the beginning of their careers, when their next full-time position might turn out to be in mainstream science rather than the cultural heritage sector. It has to be said that the scientific literature is rarely consulted by conservators and never by other museum professionals, except in the course of literature searches for major research projects. Purely scientific papers would be perceived by most cultural heritage professionals as entirely lacking in context, and therefore of limited use. In the pure sciences, much more emphasis is given to the development of a new, unique method, or to its first application to cultural heritage material, than to the new light it could shed on large groups of artefacts.

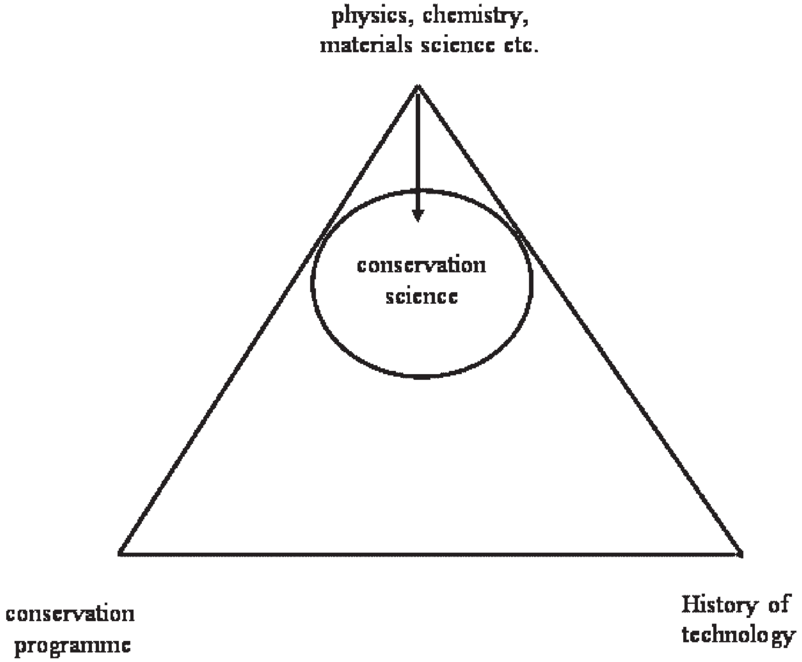

Figure 2.
Training and knowledge bases for conservation science.

All scientists become skilled in report-writing through their training, and, by a logical extension, many are more skilled in writing successful applications for funding than other heritage professionals. Thus, they have occasion to produce project reports aimed at a wide target audience: grant-awarding bodies, trustees, and the general public, as well as the conservation profession. In consequence, their skills in 'translating' scientific concepts into other fields, and in explaining the relevant of their work, become highly honed.

They often contribute substantially, even disproportionately, to the development of policy and protocols within the public institution where they work. In the past, the number of heads of conservation departments who began as conservation scientists was disproportionately high. Today conservators, no longer the educational inferiors of conservation scientists, complete successfully in this area.

Increasingly, conservation scientists make major contributions to initiatives on the public understanding of cultural heritage and the public understanding of science. Those in the public sector have to learn to communicate with people with a wide range of knowledge levels and experience on matters scientific. This skill, after all, is used by them on a daily basis. In most cultural institutions, (art) historians are more prevalent than scientists, and they do not share a common language with science.

Conservation scientists have yet to make an adequate contribution to national policy and resource for cultural heritage, but they have begun the process. The trend in their research has moved from an understanding of basic principles to the concept of risk assessment, and the literature in preventive conservation illustrates this trend.

Preventive Conservation and Risk Assessment

Russell and Abney, authors of the 1888 UK government-commissioned report on the *Action of Light on Water Colours*,[1] could very reasonably be called the first conservation scientists, though they would not themselves have used or understood that term. In that publication, they identified all the major causes of deterioration of organic materials – which are polymers in many cases, carried out practical experiments in the fading of water-based paint, and laid the foundation for an enormous number of studies throughout the 20th century. Many of their ideas have been 're-discovered' and re-published in recent decades. Their work was thorough, and explored the subject in depth. No earlier 19th-century scientists (or 'men of science' as they would have styled themselves) made such a comprehensive contribution, though many in several countries had brief associations with field archaeology or studies of painting materials.

Conservation scientists (in today's understanding of the term) worked in the largest national museums and galleries in the UK and Germany from the 1930s, and in other northern European countries too, but publishing did not gain momentum until the 1970s. One of the seminal texts was Thomson's 1978 *The Museum Environment*.[2] Interesting, it was written in two parts, one for scientists and the other for conservators and curators. This unique division would not happen today, though Thomson in his preface foresaw that future publications in this area would not be so targeted. This book gave ideas for the preservation of whole collections.

Ashley-Smith's 1999 *Risk Assessment for Object Conservation*[3] represents another step forward in conceptual thinking. Recent conference proceedings have focussed very much on risk assessment for entire collections, with papers being produced on easy-to use light dosimeters,[4] sensors for pollutants alone,[5] or pollutants and light combined.[6] National risk maps have been developed for the monuments to be found in regions, and whole countries, for example Italy.[7] Policy guidelines have been produced for the maintenance of historic buildings in the face of predicted climate change.[8]

Polymer Analysis: Traditional Oil-Based Paint

Historic paint formulation seems very simple at first sight: artists have always mixed white and coloured pigments, the majority of them inorganic compounds, into a binder. The earliest ones consisted of water, which evaporated off. In western easel painting, egg tempera was superseded by drying oils, typically linseed or walnut. The paint was applied in layers over a preparatory ground, and artists soon began to add other plant-and animal-based materials to modify the rheology of their paint. Linseed oil is made by extraction from the seeds of the flax plant, so it is a variable product, whose drying chemistry is dependent on the method of extraction and the impurities remaining in the oil. Fifty years ago, paint analysis of suitably small samples from unique artworks was challenging, and the analysis of the pigment[9] was carried out entirely separately from the analysis of the medium, which developed later.[10] The presence of added materials compromised the analysis, sometimes fatally. 'Suitably small' might have been 1mg a few decades ago, but may be 100–250 μg today.

The last ten years have seen research into possible interactions between polymer and pigments.[11,12] Pigments based on lead, zinc (from the nineteenth century), mercury, aluminium and cobalt (also from the nineteenth century) might be expected to have a great impact on the drying chemistry of the oil: all these elements except mercury have been used in twentieth-century paint driers. This research is analogous to present-day industrial research into polymer composites - except that the paint film on a historic artefact may consist wholly of degradation products, with barely any starter components surviving after hundreds of years. The MOLART[13] and de Mayerne[14–16] projects (1995–2002 and 2001–2005 respectively) in the Netherlands have contributed enormously to this new understanding of polymer behaviour in paintings. Parallel research in the same projects by conservators, materials historians and art historians into traditional paint making has made it possible to re-create traditional paint recipes with a high degree of accuracy,[17] thus providing high-quality experimental material for the future development of analytical techniques, the measurement and comparison of physical properties, and for assessments of conservation treatments.

Polymer Analysis: Modern Paint Media

Modern paints are highly complex industrial products, designed for very specific end-uses. Traditional linseed- and walnut-based paints for indoor and outdoor decorative use, as well as for artists' paints, were joined by poppyseed oil and safflower oil products for artists' use in the nineteenth century. In the twentieth century, other oils were used as well, and alkyd-based paints were developed for decorative use. Today, the most significant synthetic paint medium used in artists' paints is acrylic-based.[18] Acrylics are also the major polymer type used in US outdoor housepaints, while alkyds and polyvinyl acetates dominate the European market for both indoor and outdoor decorative paints. Acrylics have therefore been the focus for artefact-based, documentary[19] and analytical[20] studies of such materials occurring in paintings and sculpture.

A typical acrylic paint includes: polymer(s) for the medium; pigments (most of which are organic today); extenders (inorganic materials); water; surfactants; anti-foam agents; thickeners; biocides; coalescing solvent; pigment dispersant; and wetting agent,[18] most of which are organic. This carefully-formulated combination of materials, used as recommended, gives a durable paint with an expected lifetime of 5–10 years. However, artists do not tend to use paint in the recommended manner. Their additives, thinners, use of thick layers and non-optimum drying time before more paint is applied, in combination with all the industrial products already present in the paint, can combine to make an alarmingly non-durable paint from a very stable polymer. It is also the case that components present at 1–5% by volume may critically affect ageing properties, so identification of minor components presents analytical challenges that have to be met. The paint surface of a modern artwork may be water-sensitive, solvent-sensitive, prone to excessive dirt retention due to a glass transition temperature too close to room temperature, brittle on minor impact, or sensitive to temperatures below 10 °C. It may also be underbound, that is, it has too little medium present to form a good paint film, and is therefore liable to absorb extraneous material such as spilt liquid or grease from fingerprints deep into its structure. Any such accidents necessitate interventive conservation treatments such as surface cleaning. Cleaning presents peculiar difficulties on colour field paintings, for example, which include large expenses of easily-disrupted uniform texture and colour.

Recent research at Tate has focussed on paint film softness, solvent and water sensitivity, pigment removal, extraction of soluble components, changes to surface finish, re-soiling, and long-term effects. This has involved chemical analysis (mainly by methods such as PY-GC-MS, GC-MS and FTIR microscopy), thermal analytical methods to determine changes in paint properties such as glass transition temperature, and sensitive surface characterisation techniques, the most useful of which is AFM.[21] These have been carried out initially on paint samples made from products still on the market, with the aim of detecting small changes in properties brought about by applying different, typical, cleaning treatments to the samples. To ensure the treatments are realistic, all the conservation scientists in the research group have also trained and mostly been employed as conservators, and they maintain a regular dialogue with conservator colleagues in several countries.

Accelerated Ageing of Polymers and Colorants

Since conservation scientists are always constrained to work with very small samples from artefacts, they all resort regularly to accelerated ageing of model materials, to provide expendable 'historical' material for analytical and treatment methods development. Museum exposure of polymers and other light-sensitive materials is of course benign, when compared to the outdoor weathering performance demanded of industrial products. However, museum artefacts are required to have very long lives, and to maintain texture and colour characteristics for as long as possible. Even mild exposure leads to cumulative and significant damage in the long term. Thus, there have been many studies carried out by conservation scientists, to compare museum-aged and artificially-aged materials, for example varnishes.[22] Other objectives of accelerated ageing include the selection of stable conservation materials, to eliminate the poor performers, and to identify the worst aspects of ageing.

The conservation literature[23] shows that many methods have been used for accelerated ageing: visible light alone; visible light plus UV; UV alone; dark, i.e. thermal ageing; concentrated atmospheric pollutants, and acid hydrolysis to pre-age one component of a composite, such as a canvas support later used for paint application. All are appropriate in the context of the research programme. Other ageing methods which would be appropriate in some circumstances include aggressive cleaning with alkali or solvents to mimic past conservation treatments, application of more recent conservation treatments such as lining of canvas paintings, or exposure to corrosive breakdown products from the degradation of some cellulosic polymers, such as acetic and nitric acid from degrading cellulose acetate and cellulose nitrate respectively.

Thermal ageing is not always a realistic option: for polymer samples it is necessary to use temperatures below the melting point, and also lower than the glass transition temperature by about 10 °C. For some formulations of acrylic artists' paints, the upper limit for thermal ageing might be 30 °C – which is also the highest limit of acceptable indoor temperature for a museum or gallery.

Where thermal ageing is appropriate, cycled light and thermal ageing would offer a more realistic simulation of 'natural' ageing. Cycled temperature and relative humidity changes would also be realistic, particularly for multi-layer samples. In studies on paper (cellulose and lignin polymers), folding endurance tests have been used to simulate the use of a book or newspaper. Exposure to a low or moderate level of typical outdoor pollutants would also mimic the service conditions of some paints and coatings – especially those on outdoor sculptures. Such accelerated methods become more expensive, and might require the same level of investment as the artificial weathering machines used by the automotive industry, for example.

Whichever method is selected, the ageing is usually carried out until one property of the model material has decreased, to match that of the naturally-aged material. This might be fading for colorants, ultimate tensile strength for paper or canvas, yellowing for polymer degradation, or solubility changes for coatings and paints. The prediction of solubility changes is very important when a polymer is being assessed for use as a coating, consolidant or adhesive. Ageing studies would include the elucidation of its photo-degradation mechanism,[24] and its tendency to cross-link (become less soluble in the solvent used to apply it) or undergo chain scission (which creates more mobile, extractable components). It is rare to discover that more than one property can be matched by accelerated ageing – only natural ageing seems to achieve a serious decline in several properties at the same time. It follows that one standard ageing method will never be found to suit all sample types.

The best conservation science studies involving accelerated ageing programmes are holistic, and take account of more factors than seem important initially. Aspects to consider include: reciprocity (the concept that a dose of light exposure would have the same effect, whether delivered at high or low intensity, and/or continuously or not); the concept of a threshold for damage, such that numerous exposures below the threshold would not induce cumulative damage – which is probably valid only in living systems which can repair damage; the more realistic but related concept that materials show an induction period before cumulative damage leads to a measurable change in properties; effects of post-exposure oxidation, especially photo-oxidation. The greatest unsolved – and insoluble – problems are how to treat control samples, and how to store all samples after ageing. For different materials, the controls might best be kept in the dark, kept at a lower temperature, or kept free of dust or atmospheric pollutants. The same applies to the aged samples.

Key Points

- Today's research by conservation scientists evolves into tomorrow's conservation practice, knowledge and protocol.
- Cultural heritage research includes the study of every natural and man-made material.
- Heritage professionals seek to preserve artefacts and artworks far beyond the lifetime intended by their manufacturer or creator. Higher-order interactions may be as important to artefact survival as the more obvious agents and modes of deterioration, which we would aim to control so as to minimise ageing effects, as soon as they are well understood.
- The development of standardised protocols for accelerated ageing is unlikely in conservation science.

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