THE ROLE OF LEATHER SCIENCE

AND TECHNOLOGY IN HERITAGE CONSERVATION

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Abstract

Hides and skins have been used since before the evolution of *homo sapiens* and some form of skin working technology has been employed by most human cultures throughout the world. As a result, artefacts made from the different materials that can be made from hides and skins are found in collections of artistic, cultural or historic value: the Cultural Heritage.

Before any preservation treatment is applied to an artefact, it is necessary for there to be an understanding of the materials from which it is made. Using as a basis twelve of the author's previous publications, this thesis discusses the essential knowledge and understanding of leather science and technology required before objects of leather and other materials made from skin can be treated safely and effectively.

All the author's previous publications had been appropriately peer reviewed. The papers from *Transactions of the Newcomen Society, Post Medieval Archaeology, Journal of the Society of Technologists and Chemists and The Bookbinder*, had been considered by their editorial committees and reviewed by an external referee before acceptance for publication. The book, *The Conservation of Leather and Related Materials*, was published as part of the Butterworth-Heinemann Series in Conservation and Museology, after consideration by a panel of prestigious, international Editors and Consultants. Contributions are only accepted for presentation at Conferences of the United Kingdom Institute of Conservation and the International Council of Museums-Conservation Committee after they have been scrutinised by technical committees. They are then further reviewed by international specialists before publication in the post-prints.

The study is set in context by considering briefly the nature of Cultural Heritage, preservation, restoration and conservation. The role of leather science and technology in Heritage Conservation is examined by discussing their contribution to an understanding of

- The nature and properties of the material from which the object is made (Materials Science)
- How it was manufactured (Historical Technology)
- The causes and processes of its decay (Deterioration Mechanisms)
- How this deterioration can be mitigated (Conservation Methods)

The interactions between these separate but interlinked subjects are evidenced and the fundamental nature of the core topic of Materials Science around which the other subjects can be built is demonstrated.

Points that arose during the preparation of this thesis are discussed. These include: the lack of scientific understanding of a significant minority of conservators, the paucity of literature relating the science and technology of leather to its conservation, the imprecise nature of the nomenclature employed by many Heritage professionals when discussing the manufacture of leather and skin based products and the difficulty in successfully challenging accepted orthodoxy in this field.

Published works submitted

Thomson, R. The nature and properties of leather. *In*: Marion Kite and Roy Thomson, (eds.) *The Conservation of Leather and Related Materials*. Oxford: Butterworth - Heinemann, 2006. 1-3. ISBN: 978-0-7506-4881-3 (Publication 1)

Thomson, R. Tanning - Man's first manufacturing process? *Trans. Newcomen Society,* 1981, **53**. 139-156. ISSN: 0372-0187 (Publication 2)

Thomson, R. Leather manufacture in the Post-Medieval period. *Post Medieval Archaeology,* 1981, **15**. 161-175. ISSN: 0079-4236 (Publication 3)

Thomson, R. The English leather industry 1790-1990: the case of Bevingtons of Bermondsey. Wolstenholme Memorial Lecture 1990. *J. Soc. Leather Technol. Chem.,* 1991, **75**. 85-93. ISSN: 0144-0322 (Publication 4)

Thomson, R. Bookbinding leather: yesterday, today and perhaps tomorrow. *J. Soc. Leather Technol. Chem.,* 2001, **85**. 66-71. ISSN: 0144-0322 (Publication 5)

Thomson, R. Alum in the leather industry. *J. Soc. Leather Technol. Chem.,* 2009, **93.** 125-129. ISSN: 0144-0322 (Publication 6)

Thomson, R. Chrome tanning in the nineteenth century. Atkin Memorial Lecture 1984. *J. Soc. Leather Technol. Chem.,* 1985, **69**. 93-98. ISSN: 0144-0322 (Publication 7)

Thomson, R. Pest attack on leather. *In*: *Pest Attack and Pest Control in Organic Materials*. Postprints of the UKIC Furniture Section Conference. London, 1996. 34-40. (Publication 8)

Thomson, R. The deterioration of leather. Procter Memorial Lecture 2005. *J. Soc. Leather Technol. Chem.,* 2006, **90**. 137 – 145. ISSN: 0144-0322 (Publication 9)

Thomson, R. The effect of the Thermo Lignum pest eradication treatment on leather and other skin products. *In*: *The Treatment of and Research into Leather*. Postprints of ICOM-CC Leathercraft Group Interim Meeting. Amsterdam, 1995. 67-76. (Publication 10)

Thomson, R. Towards a longer lasting leather: a summary of the CRAFT Leather Project. *The Bookbinder*, 2003, **17**. 65-70. ISSN: 0950-7094 (Publication 11)

Thomson, R. The CRAFT Leather Project: artificial ageing studies. *In: Recent Preoccupations Concerning Textiles, Leather, Legislation*. Postprints of ICOM- CC Leathercraft Group Meeting. Athens, 2004. 46-49. (Publication 12)

Contents

1. Introduction

The unique properties of leather and other skin based products have been exploited in human cultures across time and throughout the world [1]. It is not surprising, therefore, that artefacts made partly or wholly of leather feature widely in collections of objects of artistic, cultural and historic value: the Cultural Heritage.

As with objects produced from other materials, particularly organic materials, artefacts made from leather and other skin based products are subject to agents of decay. It is the primary purpose of the Heritage Conservation profession to slow or even halt this decay, thus winning, albeit temporarily, what Ward in his influential book *The Nature of Conservation* [2] has termed "the race against time." In this way, the objects are preserved so that they can be studied, interpreted and enjoyed by present and future generations.

Before undertaking any treatments of an artefact, whether passive or interventive, it is necessary for the conservator to have an understanding of the nature and properties of the materials from which the object is made [3], how it was manufactured [4], the causes and mechanisms of its deterioration [5] and how this deterioration can be mitigated [6].

With many materials, such as metals, ceramics, textiles and paper, this knowledge is provided by specific education programmes and specialist groups within professional bodies. Despite their overwhelming presence in heritage collections, this is not the case with skin based products. There is a distinct lack of understanding of these different materials and little appreciation of their widely differing properties. This is exacerbated by the fact that, until the recent publication of the book *The Conservation of Leather and Related Materials* [7], co-edited by the author, there has been a paucity of relevant literature, as evidenced by the fact that only six significant books have been published on leather conservation during the last sixty-five years [8 - 13]. Papers have been published both in conservation journals and in the proceedings of specialist conferences but the majority are descriptive, detailing the practical techniques employed in the conservation of individual objects. What is lacking is a body of literature on the properties of this important group of substrates and how these properties are achieved.

It is essential that conservators achieve a holistic view of the materials they are dealing with, in this case leather and skin based materials. It is the aim of this study to review, analyse and, where appropriate, re-examine in the light of more recent work, twelve of the author's peer reviewed published works, selected from the wider range of publications shown in the Appendix in such a way as to determine the concepts within leather science and technology which will enable this to be attained. The knowledge and understanding acquired during the course of this research will be employed to present a coherent picture of the role of leather science and technology in Heritage Conservation. This will lead to a greater understanding among conservators, archaeologists, curators and others whose role is to care for the Cultural Heritage of the unique nature and properties of the variety of leathers and other skin based materials which they are required to treat.

1.1 The Context

1.1.1 Cultural Heritage

As stated above, all objects, whether natural or manufactured, are subject to agents of change: physical, chemical or biological. In the case of manufactured items, these changes are usually considered undesirable and are termed deterioration or decay. In the majority of cases, this damage is considered to be an inevitable part of the object's lifecycle and, when the level of dilapidation becomes unacceptable to its owner (a subjective assessment), it is disposed of.

Some artefacts, however, as diverse as paintings, sculpture, buildings, clothing worn by known historic individuals, decorated leather bookbindings, family photographs or simply objects which are old and rare, are deemed to be too important to be discarded in this manner. As a result, efforts are made to preserve them as part of the Cultural Heritage.

Attempts have been made for millennia to determine which objects are worthy of such attention. Jokilehtio [14] has listed sixty-three definitions of Cultural Heritage, ranging in date from that given by Theoderic the Great in the sixth century to that agreed by the International Council for Monuments and Sites in 2005. Michalski [15] has categorised objects worthy of such attention into

- Those which have an impersonal narrative value, i.e. those with a social, hi-cult, symbolic importance.
- Those which contain within them useful ethno-historic evidence which, potentially, could be revealed scientifically, now or in the future.
- Those with sentimental, symbolic meanings (including ritualistic and religious) for groups, large or small, or even individuals.

These reasons for preservation are not mutually exclusive. A sixteenth century, polychrome, moulded leather figure of the Madonna and Child, created by a known artist craftsman would, for example, contain elements of all three categories. Similar attempts at defining which objects contribute to the Cultural Heritage and are thus worthy of being considered for preservation have been made by Caple [16] and Muñoz Viñas [17].

Possibly the most straightforward (and, therefore, over-simplified) definition was agreed by UNESCO in 1972 in its Convention Concerning the Protection of World Cultural and Natural Heritage [18]. To paraphrase, this states that monuments, groups of buildings, works of man or the combined works of man and nature which are of universal value from an historic, artistic, scientific, aesthetic, ethnological or anthropological point of view shall be considered as Cultural Heritage.

1.1.2 Preservation, Restoration and Conservation

Archaeological evidence has shown that regular maintenance and routine repairs have been carried out since earliest times and Pliny discussed the treatment of ancient objects and monuments [19]. This tradition continued through to the nineteenth century with specialist craftsmen working with the normal tools and materials of their trades to treat particularly appreciated artefacts, such as paintings, furniture, leather wall hangings and tapestries. Keck [20] details examples of such interventions dating from Roman through to the Renaissance periods and comments that the overpainting and relining of damaged paintings was an established procedure well before the end of the seventeenth century.

These interventions could not, however, be considered as what would today be termed conservation or restoration. As Muñoz Viñas [21] points out, it would be more historically accurate to call them 'servicing', 'cleaning', 'maintenance' or 'repairing'. Bookbinders still use the term 'furbishing'. Daly Hartin [22], discusses the use of the term 'reflowering' used from the sixteenth to the eighteenth centuries by restorers, often recognised artists in their own right, who were employed to bring damaged or darkened paintings "back to life".

The end of the eighteenth century saw the Age of Enlightenment, accompanied by the concept of High Art within western European society and the development of the philosophy of aesthetics [23]. As the nineteenth century progressed, the enthusiasm for Romanticism enhanced the position of the artist in society. This, together with a rise in patriotic feeling, exalted the beauty of monuments surviving from previous periods of perceived national greatness (especially if they were in a picturesque, ruinous state). These survivals, however, were often in a parlous condition and required some form of active treatment if they were to endure. It was in this context that the concept began to emerge that the preservation of what was to become known as the 'Cultural Heritage' required different techniques to those employed in a domestic setting and the seeds of the conflict between conservation and restoration were sown. This conflict expressed itself first and most eloquently in the field of architectural preservation, possibly because, unlike the treatment of small private possessions, restoration work on buildings is more likely to be exposed to public scrutiny.

Early nineteenth century France contained many historic buildings surviving in a more or less ruined condition. Following the Revolution, these became the property of the State and national sentiment demanded that they be preserved. The architect, Viollet-le-Duc, an acknowledged scholar of medieval architecture, was appointed to oversee the repair of such monuments as La Madeleine de Vézelay, Notre Dame de Paris, Amiens Cathedral and the city of Carcassonne. He expressed the philosophy behind his approach to such works in the statement: "To restore an edifice means neither to maintain it nor to repair it nor to rebuild it; it means to re-establish it in a completed state which may in fact never have actually existed in any given time [24]."

At the same time in England, the influential John Ruskin, was taking the opposite view, possibly in reaction to the wave of 'improvements' being undertaken by the Church of England to hundreds of parish churches up and down the country. For him, nothing present should disturb the original remnants of the past. He declared: "Do not let us talk then of restoration. The thing is a lie from beginning to end. [By restoration] the old building is destroyed and that more totally and mercilessly than if it had sunk into a heap of dust." He went on to say: "It is again no question of expediency of feeling whether we shall preserve the buildings of past times or not. We have no right whatever to touch them [25]."

It is possibly because of this and similar strongly worded statements that the Royal Institute of British Architects entitled their 1865 monograph *Conservation of Ancient Monuments and Remains*, avoiding the term 'restoration' [26]. This appears to be the first use of the term conservation differentiating it from that of restoration.

The schools of thought represented by Ruskin and Viollet-le-Duc were clearly irreconcilable. Nevertheless, they both contained valid arguments, albeit in a less extreme form than expressed in the above quotations. These were taken into consideration by

Camillo Bioto [27], the Milanese architect and engineer, in the development of his theory of *restauro scientifico* in the late nineteenth century. These include minimum intervention, the reversibility of any treatment deemed necessary, the need for original and restored parts to be clearly discernable to the trained eye and the recording of any treatments undertaken. In this he established some of the principles which are currently accepted as basic tenets of Heritage Conservation ethics in fields other than architecture to this day, including leather.

The development of the preservation of leather artefacts followed a similar pattern, described as 'servicing' by Muñoz Viñas above, with numerous modifications and repairs being found on shoes and other leather objects uncovered by archaeologists dating from pre-Roman times to the present day. As early as the seventeenth century, methods and materials for the preservation of leather are described in some of the first British Patents. These include those of John Wolfen, *A new invenĉon for the making of and ppreparing of ĉtaine stuffs and skynns to hould out wett and rayne and preserve them* [28], William Sutton, *A new and extraordinary art and invention of all sorts of lynnen ... and leather, soe as to hold out water and also for the preventing of ... mill dewe* [29] and George Sylvanus, *A new and extraordinary mixture of wax and other ingredients known by the name of German balls ... for beautifying and preserving any sort of leather* [30].

Throughout Europe, the seventeenth century also saw a rise in the fashion for decorating walls in castles and country houses with gilt leather hangings [31]. In a contemporary dissertation on the subject, published as part of the Académie Royale's *Descriptions des Arts et Métiers*, Fougeroux de Bondaroy discusses the preservation of this sumptuous material. He indicates that "the hangings are best preserved in slightly humid rooms ... and those which are not exposed to bright sunlight." He continues "...when the hangings are blackened, ... the simplest method to clean them is to wipe them over ... with a moist sponge which will remove anything which tarnishes them, and which will give the leather a certain suppleness necessary for its preservation [32]."

These comments show that what are understood today to be the major causes of deterioration of leather and other organic artefacts (heat, light, inappropriate relative humidity and surface dirt) were fully appreciated three hundred years ago. The suggested treatments would, however, not be acceptable to the modern conservator.

As with other classes of artefact, the mid-nineteenth century saw the beginnings of the application of science to the preservation of leather objects when a committee of chemists and leather specialists, chaired by Michael Faraday, was asked to investigate the sudden deterioration of the leather upholstery and bookbindings in the Athenaeum. This was shown to result from the effects of acidic vapours produced by the newly installed gas lighting. Studies into the acid deterioration of leather and the methods of mitigating its effects continue to this day. (See Sections 4 Deterioration Mechanisms and 5 Conservation Methods.)

Traditionally, restorers of objects such as paintings and furniture kept their methods and materials secret. The first third of the twentieth century, however, saw a gradual change, with a realisation, particularly by specialists working within national museums, that the aim of any treatment should be to protect the integrity of the object, including evidence of its history, rather than just to restore it to a bright, clean, 'as new' condition for maximum impact on display. It was within this ethos that books such as Rathgen's [33] *The Preservation of Antiquities: a curator's handbook*, Scott's [34] *The Cleaning and Restoration of Museum Exhibits* and Plenderleith's [35] *The Preservation of Antiquities* were published. At the same time, conservation laboratories and scientific research departments were set up in major galleries and museums across the world to investigate the nature and properties of the artefacts within their care and the effects of preservation treatments on them [36]. In this way, what has been termed scientific conservation was slowly established. An early development was the organisation of an international conference under the auspices of the League of Nations in Rome in 1930 to discuss the treatment of paintings. The proceedings were published in 1939 [37]. These confirmed the increasing necessity for an understanding of the chemistry and physics of the materials employed both to produce the artefact and to treat it. They also reinforced the fact that activities undertaken within a museum environment to conserve artefacts (in this case paintings) were often distinct from, though closely related to, those employed by commercially based paintings restorers.

In the aftermath of the Second World War, this concept of scientific conservation developed further with the formation of both the International Institute for Conservation of Historic and Artistic Works (IIC) and the Conservation Committee of the International Council of Museums (ICOM-CC). Conservation was moving from a craft based trade to a profession which aims to combine connoisseurship, art historical techniques, analytical chemistry and materials science with the hand skills required to treat artefacts of historic, artistic or cultural value. Through the second half of the twentieth century, these bodies developed codes of ethics and defined minimum standards of education for members of the developing profession. It was within this context that Waterer [38] published his textbook *A*

Guide to the Conservation and Restoration of Objects Made Partly or Wholly of Leather, for which he was elected a Fellow of the IIC.

It was also during this period that attempts to differentiate between conservation and restoration became a contentious issue [39]. These terms were considered in the author's J. Arthur Wilson Memorial Lecture [40] *Conserving Historic Leathers: saving our past for the future* (not one of the publications submitted). This was delivered at the invitation of the American Leather Chemists' Association in Pennsylvania in 2002. As part of a comprehensive review of the subject, it drew attention to the fact that the terms have varied over time and can still vary from country to country, culture to culture and even from speciality to speciality. It was stated that: "What has been routine practice in the restoration of antique furniture for a dealer would not be considered acceptable in an ethnographic museum environment" and that "For this reason, guidelines and codes of practice have been drawn up by such bodies as the American Institute for Conservation of Historic and Artistic Works (AIC) [41, 42] and the United Kingdom Institute for Conservation of Historic and Artistic Works (UKIC) [43]. It is interesting to note that even these two closely related institutions, using a nominally similar language, vary somewhat in their approaches."

In the lecture, in order to explain the differences between conservation and restoration to a general audience, a hypothetical situation was examined. It was imagined that:

"... an old chair is discovered in an attic ... It has one leg missing and another is full of woodworm. The leather upholstery is torn and discoloured and has pieces missing ... The chair is taken to the local museum and the owner is surprised to be told that it is ... probably the missing chair from a famous set on display at a local historic house. ... As such it is a very valuable piece. However, it requires immediate treatment if it is not to fall apart completely. What should be done?"

Three levels of treatment were described in some detail. If the chair were to be placed in the museum as a study piece, minimum interventive techniques would be employed. This represents conservation in its most pure form which aims to leave the object in such a state that the maximum amount of scientific, technological and art historical evidence could be retrieved by present and future generations.

A more interventive treatment would be carried out if the chair were to be placed alongside the rest of the set on display in the historic house. This is still conservation and there is a rule of thumb in the profession which states that conservation treatments should not be visible from six feet away but should be immediately apparent to an expert from six inches.

Should the family in the historic house wish to use the chair on a regular basis, an even more interventive treatment would be required. This is restoration and, provided no attempt is made to pass the chair off as completely original, this is completely ethical.

The paper went on to state that the essential difference between conservation and restoration lies in the primary objective of the practitioner. The restorer aims to return cultural property to a known or assumed state. This can involve the removal of significant quantities of deteriorated original material and the addition of new elements. It is often the aesthetic appearance of the restored object and its ability to be used for its original purpose which is paramount. The conservator on the other hand is aiming to minimise chemical and physical deterioration of the object with a view to retaining the maximum amount of scientific and historical information

The fact that the definition of the terms 'conservation' and 'restoration' were such a contentious issue was highlighted by the fact that two leading conservation academics felt it necessary to write to the Editor of the Journal where the lecture was published [44]. They stated that the definitions put forward were outdated since ICOM-CC had ratified an alternative definition of the profession and that this had been accepted and developed by the European Confederation of Conservators' Organisations (ECCO). The author's response was that the situation is not as straightforward as they suggested and that as the paper had been delivered in the USA to an audience of leather chemists, not conservators, the discussion was based on the guidelines of the AIC [45]. By definition, the AIC cannot be a member of ECCO. It should also be noted that neither the UKIC, nor its successor, the Institute of Conservation, is a member of ECCO so conservators in Britain, like those of the USA, are not bound by their definitions.

It should be recognised, however, that, in practice, a balance has often to be sought between the two approaches depending on the object, the context in which it is to be held and the wishes of the owner. Since the publication of the paper, the concept of the Accredited Conservator-Restorer controlled by ethical guidelines developed by the professional bodies, has been developed [46].

1.1.3 Scientific Conservation

The development of conservation as a profession in the decades after the Second World War led to discussion of the knowledge and understanding required by a conservator. Francis Rawlings [47], Scientific Advisor to the National Gallery, writing to George Stout, Head of Conservation at the Fogg Art Gallery stated that: "Conservators should not only be good practitioners but scholars as well, knowing not only what they do but why they do it and prepared to discuss fundamental questions with their opposite numbers [i.e. curators] in aesthetics, art history and so forth." He goes on to suggest that: "Embedded in this matrix should be an intensive *ad hoc* course in physics and chemistry – brief and circumscribed, but entirely scientific and objective in nature, given by scientists sensitive to art of course."

Professionalisation also led to the institution of tertiary level courses where such concepts could be developed in practice. Initially in the UK, these programmes were run as part of archaeology degree programmes but, in 1947, a specialist Department of Conservation was founded at University College London's Institute of Archaeology whose remit was to expand the range of specialities beyond archaeology [48]. A grounding of science was considered an essential element of the teaching and the archaeological scientist, Henry Hodges, was appointed to cover this aspect [49]. He had written widely on the history of technology and this also became a core subject on the syllabus [50, 51]. Visiting lecturers were invited to teach on specialist topics such as artists' materials, paper and wall paintings. Leather and other skin products were also covered but this was limited to a single one hour lecture per year on leather, given by Claude Spiers or, later, Peter Ellement, from the National Leathersellers' College. Over the following decades, further diploma, graduate and post-graduate courses were developed in Colleges and Universities across the country, many specialising in specific disciplines, such as textiles, books and paper, paintings, furniture and stained glass. Others gave a more general training. Significantly, in relation to this thesis, none specialised in leather. This resulted in many graduate conservators being required to treat leather objects without having a sufficient understanding of the material.

Today, there are about fifteen centres for conservation training at graduate or post-graduate level within the UK. While there are inevitable differences in the range of subjects covered and in the methods of tuition employed by the different institutions, there appears to be a central core of skills and knowledge expected to be gained by students before they can be considered as trained conservators. In addition to an ability to carry out practical, manual treatments in a sensitive manner and an awareness of ethical standards to be observed, all institutions expect their students to gain an understanding in such subjects as the history of art and decorative styles, microscopy, chemistry, physics, materials science, the history and technology of manufactured objects and the mechanisms of their deterioration [52, 53]. These requirements were incorporated into the ICOM-CC Code of Ethics in 1984 [54].

As the great majority of students of conservation, whether graduate or post-graduate, have a limited science background, it is appreciated that a particular emphasis needs to be placed not only on what science is taught but how this is done. As Lodewijks[55] points out, it is not necessary for a conservator to become a fully trained scientist. The teacher should therefore be able to distinguish between which parts of the sciences are indispensable for conservator, which parts are useful and which superfluous. It is also necessary to distinguish between which scientific (and by inference, technological) knowledge is required by all conservators and which is necessary or useful for those who wish to specialise in a particular discipline. It would appear that an adequate knowledge of leather science and technology has not been considered necessary for all conservators.

It was in an attempt to decide into which categories the different elements of the sciences fall, that a conference *The Role of Science in Conservation Training* was organised in 1986. This was attended by delegates from fifteen countries. The proceedings give details of a range of syllabi. It is depressing to note that, apart from brief mentions in programmes designed specifically for book and archive conservation, of the seventeen courses mentioned, only one includes the conservation of leather objects. This, run by the National Centre of Museums in Budapest, gave six hours of lectures and twenty-four hours practical workshops on the topic [56]. This is equivalent to the amount of time they spent teaching the treatment of wooden or textile objects. In the writer's experience, the situation has not changed significantly and the conservation of leather is, unsatisfactorily, still under-represented in undergraduate and post-graduate courses.

1.2 Leather Science and Technology

This thesis will argue that it is essential that conservators achieve a holistic view of the substrate they are dealing with. In view of the above, however, it is not surprising that despite the overwhelming presence of objects made of leather and other skin products in Heritage Collections, the author has experienced a distinct lack of understanding of these different materials and little appreciation of their widely differing properties. It is the objective of this study to create a coherent picture of the concepts within leather science and technology which will add to the literature of the subject, thereby enabling this understanding and appreciation to be attained.

The ICOM-CC Code of Ethics for conservators cited above requires that they must receive "artistic, technical and scientific training" [54]. Included in the areas specifically mentioned are "a knowledge of technology and materials" and the "chemistry, biology and physics of deterioration processes and conservation methods". It is clear that these requirements are not being met in the field of leather conservation.

In order to determine the role of leather science and technology in Heritage Conservation, twelve of the author's published works, all of which had been peer reviewed, will be examined and, where necessary, updated in order to:

- identify the nature and properties of the material from which the object is made (Material Science)
- demonstrate how it was manufactured (Historical Technology)
- determine the causes and mechanisms of its deterioration (Deterioration Mechanisms)
- assess how this deterioration can be mitigated (Treatment Methods)

The Publications were selected from a much wider body of work (see Appendix) to give an insight into each of these elements. They were chosen because, individually, at the time of writing, each presented new information. Together, they now demonstrate new approaches to the subject made possible by a synthesis not previously undertaken. They include a number of the named Memorial Lectures that the author has been invited to present. In addition to being particularly apposite to the development of this thesis, by tradition, such Lectures are longer, allowing time for the complexities of the arguments to be developed. This thesis will argue that these apparently individual subjects are inherently coherent. Only in synthesis will they inform the processes of leather conservation.

1.3 Structure of thesis

The thesis will be organised in five Sections:

Following an introduction explaining the context within which the study was undertaken, the Materials Science of leather and other skin based products, as put forward in Publication 1, will be appraised. This outlines the properties required for a material made from hides and skins to be considered as a true leather and summarises how these are attained. It will be argued that it is a recognition of these basic tenets of leather science that is necessary for a full understanding of the following Sections.

The next Section gives an overview of the Historical Technology of the different leather manufacturing industries, with Publications 2-5 addressing different aspects of the vegetable tanning process, Publication 6 describing the various applications of alum to skin processing and Publication 7 reviewing the introduction of the now predominant chrome tanning process. The concepts presented in these publications together contribute to a recognition of how the material used to make a particular object was manufactured and provide the essential understanding required for safe and effective preservation treatments.

In Section 4, Publications 8 and 9 examine the causes and mechanisms of the deterioration of the materials under discussion and how a knowledge of leather science underpins an appreciation of how such deterioration can be delayed or even halted. Deterioration resulting from biological, physical and chemical factors will be addressed.

The Publications in Section 5, 10-12, exemplify how an understanding of the manner in which basic concepts of leather science have enabled the development of successful new conservation treatments, both interventive, as in the case of a pest eradication technique, and preventive, in the case of the development of deterioration resistant bookbinding leathers.

The Discussion, Section 6, analyses the interactions between these different but interdependent topics, demonstrating that it is only with a coherent knowledge and understanding of both leather science and leather technology that objects made from skin based materials can be cared for with confidence.

Perhaps with a greater knowledge and understanding of skin based products, puff ball fungi excavated from a Romano-British site would not have been conserved and exhibited as leather purses [57], an eighteenth century painted parchment fan would have not have been destroyed by treating it as if it were made from paper [58], early medieval felt insoles mistaken for buff leather [59] and no one would have applied an inappropriate, commercial 'leather cleaning and feeding' product which ruined a seventeenth century gilt leather altar frontal in the Mesquita in Cordoba.

Redacted content:

Thomson, R., 2006. The nature and properties of leather. In Conservation of leather and related materials (pp. 23-25). Routledge. https://www.taylorfrancis.com/books/e/9781136415234/chapters/10.4324/9780080454665-8

Thomson, R.S., 1981. Tanning Man's First Manufacturing Process?. Transactions of the Newcomen Society, 53(1), pp.139-156. https://doi.org/10.1179/tns.1981.008

Thomson, R., 1981. Leather manufacture in the post-medieval period with special reference to Northamptonshire. Post-Medieval Archaeology, 15(1), pp.161-175. https://doi.org/10.1179/pma.1981.003

Thomson, R.S., 1991. English leather industry 1790-1990: the case of Bevingtons of Bermondsey. Wolstenholme memorial lecture. Journal of the Society of Leather Technologists and Chemists, 75, pp.85-93. http://www.sltc.org/sltc-electronic-journal/

Thomson, R.S., 2001. Bookbinding leather: yesterday, today and perhaps tomorrow. Wolstenholme Memorial Lecture 2000. Journal of the Society of Leather Technologists and Chemists, 85(2), pp.66-71. http://www.leatherconservation.org/publications/

3.1.5 Vegetable Tanning commentary

The majority of leather artefacts requiring treatment will have been produced by the vegetable tanning process. As a result, for those caring for the Cultural Heritage, this process is central to their understanding. Publications 2-5 consider this process within a range of contexts. Publication 5, in particular, considers the developments in leather manufacturing technology which occurred during the nineteenth century and how these had such profound effects on the rate of deterioration of the materials produced, effects that cause concern today.

The author was invited to deliver the paper, *Tanning Man's First Manufacturing Process?* (Publication 2) to an audience of historians of engineering and technology at the Science Museum in London. It was only the second occasion on which a paper on leather technology had been delivered to the Newcomen Society in over ninety years. Although the main body of the lecture described vegetable tanning in some detail, the introductory section discussed the development of skin processing, putting its evolution in parallel with that of *homo sapiens*. The paper put forward the, then, novel hypothesis that hides and skins were systematically exploited by mankind's hominid ancestors some two million years ago, that some crude form of leather was being produced a million years ago and that Neanderthals were producing a range of soft, flexible leathers. This hypothesis has not been challenged.

Being written thirty years ago, this paper, by stating "Certainly by the Neolithic period, vegetable tanning was a well developed process", reiterated the then accepted hypothesis and this proposal is still widely believed [110-113]. Work carried out over the intervening years, based both on reassessments of published evidence and examinations of new archaeological finds, has shown the situation to be far more complex.

The supposed widespread use of vegetable tanning in Egypt from prehistoric times onwards is based on the large number of well preserved artefacts which have been excavated throughout the region. When the paper was published, it was assumed that only a fully tanned material could survive for so long in such a good condition and that the only technology available at the time would have been vegetable tanning. This supposition was supported by the discovery of a 'Predynastic tanning laboratory' in Gebelein [114]. Samples of the materials found at the site were passed to the eminent leather chemist, Bravo, who determined them to be goatskins and *acacia arabica,* a material still widely used in North African tanneries. These findings were published [115, 116] and disseminated by, among others, the widely respected Forbes [117] and Lucas [118].

In a review of Ancient Egyptian leatherwork and skin based products, Driel-Murray has argued against this supposition. She suggests that the survival of such a wide range of skin based objects is the result of particularly favourable climatic conditions [119]. Furthermore, she cites Donadoni Roveri [120] who concluded that the remains from Gebelein were those from a Predynastic cemetery which had become intermingled with those from overlying Ptolomaic buildings which had been occupied by a Greek military garrison. The finds of goatskins and tanning materials were therefore probably from the late first millennium BC.

Apart from those from Egypt, with its arid environment, prehistoric objects made from skin products are extremely rare and their survival is a result of other exceptional conditions. These include preservation in sphagnum peat bogs [121-125], in association with oak wood [126, 127], in salt mines [128] or by glacial ice. The presence of bog acids or tannins extracted from oakwood prevents any meaningful investigation into processing methods used to prepare objects from the former categories. It is only in the cases of those preserved by salt or in ice that such examinations can be carried out.

A number of Bronze and Iron Age objects from the Hallstatt salt mines have been examined visually and were considered to have been made from rawhide or oil tanned skins [129]. Evidence for vegetable tanning was not found.

The almost intact clothing of 'Ötzi the Iceman' was recovered from the Schnalstal Glacier on the border between Austria and Italy in 1991 [130, 131]. These have been examined more thoroughly and have been dated to about 3250 BC. Until the discovery of a single shoe in Armenia [132], dated about 250 years earlier, these were the oldest skin based finds capable of undergoing investigations into their tanning methods. Groenman-van Waateringe and her team, analysed the pollen grains entrapped in the hairs from the Iceman's clothing, and compared the results with those obtained from hides subjected to a range of experimental 'leathering' treatments. Their results indicated that the skins had been processed using a combination of fat and smoke [133]. Subsequent investigations were undertaken by a group of leather chemists, using modern chemical and analytical techniques [134, 135]. Again, vegetable tanning agents were not detected but the fatty materials extracted were found to be very different from those obtained from modern chamois or ethnographically processed leathers. By examining lipids extracted from products of a series of experimental 'tannages' it was proposed that the Iceman's skins had been preserved by the application of an emulsion of animal fats that had been saponified with wood ash.

Between 2003 and 2009, more than three hundred archaeological finds were recovered from the Schnidejoch ice field in the western Swiss Alps [136]. These were dated from late Neolithic (about 2700 BC) to Medieval (900 AD) periods and included a 'leather' legging dating from 2215±55 BC [137]. Examination of the grain pattern and DNA analysis showed that it had been made from a goatskin. Analysis of the lipids extracted indicated the presence of significant quantities of materials of vegetable, including coniferous, origin. This was taken as "evidence for vegetable tanning based on aqueous extract of diverse plant material [138]." Volken reports that the lipids indicated the presence of alder, pine or oak but that the ferrous chloride test for the presence of tannins was only faintly positive [139]. Such false negative results are not unknown when examining archaeological specimens [140, 141]. She went on to process a calfskin using a method described in ethnographic sources as being employed in Siberia, combining a natural buffering agent (urine) with an extract of alder bark. This produced a material with "the exact same qualities" as the legging leather. She emphasises that these characteristics are very different from those found in leathers from later periods which had been fully vegetable tanned but concludes that a form of "primitive vegetable tanning is clearly present in Neolithic and later periods".

The first written evidence for the use of vegetable materials for tanning appear in Greek sources from the fourth century BC and it would appear that vegetable tanning might have spread throughout the Classical world from Greece. There are few other documentary sources for vegetable tanning dated from before the first century BC [142] but vegetable tanning technology appears to have been fully developed by the second century BC in southern Europe.

In contrast to the rarity of skin base artefacts unearthed from Bronze and Iron Age sites, large quantities of objects made from vegetable tanned leather have been recovered from excavations throughout the Roman Empire. In north-western Europe, and southern Egypt, these have been associated primarily with military conquest and then colonisation [143]. In Egypt, vegetable tanned object are associated with the Graeco-Roman period. This is particularly evident at Qasr Ibrim in Lower Nubia which was occupied by the Romans in the first century BC. Driel-Murray has shown that no skin based object dating from before the occupation had been vegetable tanned. Those from the military site were primarily vegetable tanned and when the army withdrew, the local population reverted to their traditional processing methods. The situation in north-western Europe is even more striking, where large quantities of vegetable tanned leather artefacts have been recovered from anaerobic waterlogged sites. These all date from the period of the Roman Conquest or while the area was part of the Roman Empire. The use of this technology spread from military bases to administrative centres and then to the wider population. It should be noted that this technology does not seem to have been accepted in areas outside the boundaries of the Empire.

Surprisingly, it has been found that, despite the undoubtedly superior properties of vegetable tanned leathers, as the Empire declined and Rome withdrew its control over its outer provinces, vegetable tanning ceased to be the major skin working process. The products of a technology which had been established for four hundred years disappear from the archaeological record [144, 145]. In England, the reintroduction of vegetable tanning appears to have taken place only after a gap of three hundred years [146] with evidence for an increasing expansion during the ninth and tenth centuries, possibly associated with the spread of monastic Christianity. The earliest evidence for an Anglo-Saxon tannery dates from the eleventh century [147].

Publication 2 also repeated the, then, equally accepted theory that a combination alum-oil-vegetable tannage was employed during the Babylonian period over five thousand years ago, another hypothesis which has since been shown to be inaccurate (see Section 3.2 Alum Tawing).

This paper introduced for the first time the concept that skin can be likened to a scaffold structure with the uprights as collagen molecules and the cross braces the naturally occurring cross-links. The audience was asked to consider what might happen to the scaffolding if the cross braces were removed (putrefaction). Tanning was likened to inserting extra, permanent, cross braces in order to stabilise the structure. This analogy was developed with an audience of engineers in mind but it has also been used with success when speaking to groups of conservators.

In the mid-1970s, a tannery site dating from the fifteenth through to the seventeenth centuries was excavated in Northampton [148]. Ten years later, the excavation was extended and further tanneries uncovered [149]. Together, these formed the largest excavation of a complex of tanneries in England [150]. In 1980, the Society for Post-Medieval Archaeology held its Annual Conference in Northampton with a major part of the programme being devoted to a discussion of these unusual finds. The author was asked to put these discoveries in context by contributing a paper describing the processes which would have been taking place on the site. The presentation (Publication 3) expanded the information on vegetable tanning given in Publication 2, incorporating the historical evidence taken from local records. A novel aspect of this paper was to show that during the post-medieval period 23% of Northampton's tax payers were employed in manufacturing or working leather. This figure had formerly been used to indicate that Northampton was a particularly important leather centre but Publication 3 pointed out that this proportion was by no means unusual. Raistrick [151] has shown that three hundred years later, in 1851, Northampton was "utterly unimportant as a tanning centre." He does note, however, that Northampton had the country's highest proportion of curriers per head of the population, reflecting the overwhelming presence of the town's boot and shoe industry. As described in Publications 2, 3 and 4, the trades of currying and tanning were strictly separated until the beginning of the nineteenth century. Until the middle of the twentieth century, Northampton's boot and shoe makers continued to purchase rough-tanned leathers and had them dressed locally by curriers or their successors, leather dressers.

The aim of Publication 4 was to outline some of the major events affecting the leather trades over a period of two centuries and to describe how one company reacted to these. It starts by briefly describing the period of political, artistic, scientific and technological upheaval of the late eighteenth century, the period of the Age of Enlightenment and the Industrial Revolution. It asks what was happening in the leather industry during this period and answers "Not very much"! It goes on to explain why and how this situation changed as the nineteenth century progressed. It gives reasons why Bevington's, typical of the English tanning industry as a whole, peaked during the 1890s and declined throughout the twentieth century.

This thesis argues that without a knowledge of leather manufacturing processes in general, and those of vegetable tanning in particular, as presented in the above publications, the nature and properties of leather cannot be properly understood. Preservation treatments carried out without such understanding could well have damaging results. It is further suggested that without such contextual knowledge, the information presented in the 2000 Wolstenholme Memorial Lecture (Publication 5) which examines the changes in manufacturing techniques that took place in the nineteenth century and the resultant long term effects cannot be fully understood. This Publication concentrates on bookbinding leather because, while the majority of products made of leather are expected to have a limited working life, book bindings are expected to survive almost indefinitely. It should be noted, however, that other types of leather underwent similar changes in production methods with the same deleterious results. While the type of deterioration known as red rot described in this paper is considered by many conservators to be associated only with book bindings, this is not the case. In the author's experience, it is also found extensively in such categories of objects as footwear, saddlery and harness and luggage of the late nineteenth and early twentieth centuries.

Many book binders and book conservators working today generally attribute the rapid deterioration of late nineteenth century leathers to the introduction of cheaper imported tanning materials and the speeding up of the tanning process, a hypothesis first proposed by Calvert [152] as early as 1851. They consider that these changes led to skins having over-tanned outer layers which were prone to crack and an under-tanned central stratum which lacked durability. The novel aspect of this Memorial Lecture was to challenge this orthodoxy and explain how the changes that were introduced in the manufacturing of bookbinding leathers were a result of tanners' attempts to respond to changing requirements and not to cheapen the process and maximise profit. This publication hypothesises that the causes are multi-factorial, resulting from tanners attempting to satisfy their customers' demands for ever increasing quantities of uniform, bright coloured, thin leathers. Changes in processing techniques cited as contributing to the increasing incidence of acid deterioration include the application of synthetic dyestuffs, the use of imported crust leathers and the introduction of shaving machines.

The publication also highlights the way in which leather science and technology was applied throughout the twentieth century in an attempt to prevent these problems continuing and to develop techniques whereby conservators can treat deteriorated leathers.

Redacted content:

Thomson, R., 2009. ALUM AND THE LEATHER INDUSTRY. Journal of the Society of Leather Technologists and Chemists, 93(4), pp.125-129.
http://www.sltc.org/sltc-electronic-journal/

3.2.2 Alum Tawing commentary

The aim of the research on which Publication 6 was based was systematically to acquire a body of knowledge about alum tawed leather. This material was produced on a large scale throughout Europe and the Middle East from Classical antiquity until it was almost entirely superseded by chrome tanned leathers in the first quarter of the twentieth century. Following the development of chrome tanning (see Section 3.3), however, the manufacture of alum tawed skins has practically ceased. According to the Oxford English Dictionary, the differentiation between the term 'tawing', used to describe the processing of skins with a mixture of alum, salt and oils, from that of 'tanning', that is the treatment of skins with vegetable extracts, dates from the medieval period. This distinction was made because alum tawed skins lack resistance to the effects of water and therefore cannot be considered true leathers. On the other hand, provided they remain dry, artefacts made from alum tawed skins, are remarkably stable. As a result, they are frequently found in Heritage Collections. It was, therefore, considered that information regarding this material which, until the publication of this paper, was only available in the disparate collection of esoteric sources referred to in this Publication, should be synthesised, analysed and the results made more widely available for both conservators and leather specialists.

The paper was presented in 2006 at the Alum Meeting, organised by the Conservation Unit of the University of Northumbria. The Unit specialises in, among other topics, the treatment of works of art on paper. The primary foci of the Meeting were, therefore, the uses of alum in papermaking and in the preparation of alum/gelatine sizes employed in the past by paper restorers. Other topics were also covered. These included the methods used for the manufacture of alum from a variety of ores throughout Europe, from Roman Times to the mid-nineteenth century and the use of alum in the past for dyeing, tawing and the manufacture of pigment lakes. No proceedings of the Meeting were produced which would have been readily accessed by conservators. Publication 6 therefore appeared in the *Journal of the Society of Leather Technologists and Chemists* which is not generally available in specialist conservation collections.

The surprising new fact emerging from this research was that the widely held belief that some form of alum tawing had been developed in the Middle East in the second millennium BC or even earlier, is incorrect. This suggestion had been made by Levey [153] and disseminated by Reed [154] in his seminal work *Ancient Skins, Parchments and Leathers*.

Ronald Reed was a lecturer in the Leather Industries Department of the University of Leeds. He was a pioneer in the use of electron microscopy for studying skins and leather and had become expert in identifying minute samples of leather from archaeological sites. As such, he was asked to examine examples of the Dead Sea Scrolls when they were first found [155]. This led to a fascination with both historical parchments and the conservation of skin based materials [156, 157]. In this role, he was asked to advise on the treatment of the tens of thousands of books and documents inundated in the Florence floods of 1966 [158]. An indication of his eminence in the field is shown by the fact that the major multi-authored work on parchment, its historical manufacture and conservation, published in 1991, was dedicated to his memory [159]. This volume included his last published paper. In view of this, it is not surprising that anything published under his imprimatur is rarely questioned.

The orthodox view of alum tawing was originally developed by Levey in his discussions of ancient Mesopotamian chemical technology. His interpretation had been accepted not only by Reed but by widely recognised authorities such as Waterer [160], Singer [161], Bravo [162] and Forbes [163]. This author had also used this interpretation in one of the publications discussed in this thesis (Publication 2) and elsewhere [164].

During the research it was found that this view has been recently challenged by Driel-Murray [165, 166] initially as part of a chapter in a larger volume on Ancient Egyptian technology and then as part of a paper on Roman tanning techniques delivered to a specialist archaeological conference on historical skin processing. Her argument revolves around the translation of a single word found in texts inscribed in cuneiform on tablets dating from 1,000 – 600BC. These Sumerian texts include the word *huratu* which had been translated as oak galls [167]. This led to the interpretation that leather was produced by employing a combination tannage using alum, oak galls and sesame oil. Driel-Murray pointed out that specialist Assyriologists had recognised this mistranslation since the 1950s and that the true meaning of the word *huratu* was madder but that this correction has not been recognised in the secondary literature. She concluded that alum was used in a straightforward process as a mordant with madder to dye leathers red and not with oak galls in a somewhat complex combination tannage. Despite the radical nature of this challenge to the accepted view, her conclusion has not become part of the conservation, or indeed, leather science literature.

In addition to raising awareness of Driel-Murray's argument based on the incorrect translation of the word *huratu*, the writer took issue with the other evidence commonly cited for the early development of alum tawing. This is based on the assertion that the term *alutae* used by Caesar to describe the material used by the Gauls to make the sails for their ships referred to alum tawed pelts [168, 169]. As pointed out in Publication 6, "alum tawed pelts are notoriously unstable to the action of water". The question therefore arises as to when alum tawing was in fact introduced. It is only with the tangible archaeological evidence associated with a second century AD whittawyer's workshop that alum tawing can be firmly established .

As well as analysing texts, dating from the early medieval period to the nineteenth century, detailing how alum tawed leather was produced, Publication 6 describes and defines the differences between alum tawed and alum tanned skins, a concept conservators often find difficult to grasp. It also outlines the use of combinations of alum with vegetable tannins and other organic compounds to produce leathers with high hydrothermal stability and resistance to the effects of acidic atmospheres (see Sections 4 Deterioration Mechanisms and 5 Conservation Methods.)

The publication of this paper raised considerable interest. In particular, both Redwood [170] and Laight [171] contacted the author asking for more information about the Dongola process (the tanning method using a combination of gambier and alum described in the paper) as such processes are currently being developed to produce 'environmentally friendly, heavy metal free' leathers. Sykes [172] also contacted the author commenting that in the nineteenth century, vegetable tanned leathers were occasionally treated with an alkaline solution of alum to render them heat resistant so that linseed oil based japan or patent finishes could be stoved at higher temperatures than normal, leading to improved properties.

It is significant that these responses to Publication 6 have come from leather scientists and not from conservators. The fact that this major revision of ideas on the historical development of alum tawing has not been widely disseminated among conservators exemplifies the wider problem which this thesis seeks to address. Aspects which relate closely to leather science and technology have little prominence in conservation literature aimed at non-specialist conservators. This matters because leather is not a rare material in Heritage Collections. Different types of leather are, in fact, commonly found and all require treatment.

Redacted content:

Thomson, R.S., 1985. Chrome tanning in the nineteenth century. Journal of the Society of Leather Technologists and Chemists, 69, pp.93-98.
http://www.sltc.org/sltc-electronic-journal/

3.3.2 Chrome Tanning commentary

Unlike the processes of vegetable tanning and alum tawing which have been carried out for millennia and whose origins are obscure, chrome tanning is a relatively recent technique and its development can be traced using historical sources. The properties of chrome tanned leathers differ markedly from those prepared by other methods (see Section 2 Materials Science). Since the beginning of the twentieth century, for example, it has been known that chrome tanned leathers are significantly more resistant to deterioration than those prepared by other processes (see Section 4 Deterioration Mechanisms). Nevertheless, now that the development of chrome tanning dates back more than one hundred years, artefacts made from this material are increasingly likely to require preservation treatment and conservators need to be increasingly aware of whether the object they are dealing with is made from leathers which were chrome tanned. One important signifier to this is the date of manufacture. An appreciation of the early development of the use of chromium chemicals in the leather industry is therefore necessary. This information was the substance of Publication 7 which radically revised the view accepted by leather scientists and technologists and consequently by conservators. Without this understanding, appropriate decisions cannot be made regarding the examination and subsequent treatment of leather based objects dating from the period when chrome tanning was being introduced.

This Publication was presented at the Annual Conference of the Society of Leather Technologists and Chemists in 1984. The Society's Council had originally proposed that the author should deliver the triennial Atkin Memorial Lecture that year and that it should be entitled *1884-1984: One Hundred Years of Chrome Tanning*. It should discuss the century of progress in the science and technology of chrome tanning since the revolutionary invention of the process by Augustus Schultz [173, 174] and celebrate the fact that chrome tanning had become the dominant technique, employed to produce nearly ninety percent of leather worldwide [175]. It was also suggested that the paper should start by outlining the somewhat esoteric trigger for Schultz's introduction to the tanning trade which was to have such a far-reaching scientific and technological consequences.

The view, then generally accepted, of the genesis of chrome tanning had the bizarre starting point of women's corsets. These were considered essential garments for women of all classes in the late eighteenth and nineteenth centuries [176]. The supportive stays had normally been made from baleen whalebones and were usually covered with soft, alum tawed sheepskin. By the second half of the nineteenth century, the demand for whalebone had outstripped the supply and baleen bones were being replaced by steel strips. Unfortunately, the acids present in alum tawed leather corroded the steel, resulting in staining to undergarments and their wearers. Vegetable tanned leathers could not be used as, under moist conditions, iron reacts readily with vegetable tannins to produce blue-black inks which also stain. Chamois-type leathers produced by the oil tanning process, whilst otherwise suitable, retain a characteristic fishy odour. In 1853, Julius Kuttner, manager of a Stuttgart corset factory, emigrated to the USA. In 1876, the corset factory he had founded there failed and he joined Alfred Booth and Co., steam ship owners and skin and leather merchants, as a book keeper. He lunched regularly at a small restaurant, Racky's [177]. Another regular, who frequently shared a table with him, was Augustus Schultz, a chemist and dyestuffs salesman. In conversation, Kuttner mentioned the corset steel problem and Schultz, who had experience in using chromium chemicals in textile dyeing, offered to help. It was from this chance conversation that the two bath method of chrome tanning arose, in which skins were impregnated with an acidic solution of potassium bichromate, which was then reduced *in situ* to form reactive trivalent chromium salts.

While carrying out research in preparation for lecture, it was soon revealed that, although these facts were true, this 'big bang' view of the invention of chrome tanned leather, as set out in the standard text books on leather manufacture, was simplistic. This research showed that the technology had a complex, multi-national, 'steady development' prehistory. The emphasis of the Memorial Lecture therefore underwent an unforeseen change and was refocused. The aim was now to correct the record by providing an analysis of the detailed chronology of the investigations into the application of chromium chemicals to the production of leather over the forty-three years prior to the publication of the Schultz patents. It particularly referred to the work of Heinzerling who, over the previous decade, had shown that chrome tanning was a practical commercial proposition.

The publication was well received. In a review in the *Journal of the American Leather Chemists' Association*, Ludwig Seligsberger wrote, "By patiently sifting the great mass of materials available to him, the author has presented the most reliable brief history of chrome tanning available to date [178]." In addition, Professor Heidemann of the Technische Hochschule at Darmstadt considered that the information merited wider dissemination and translated the paper into German [179]. The concepts developed in

Publication 7 appear to have become the new orthodoxy and were discussed over the following years by Elsinger [180], Stellmach [181], Seligsberger [182] and Allan [183], each of these authors approaching the history of chrome tanning from their own perspective.

Elsinger, Director of the Vienna Experimental Station and Tanning School, cited Publication 7 as a valuable summary of the early history of the development of the use of chromium chemicals in the manufacture of leather. He went on to discuss the Heinzerling controversy, defending his predecessor, William Eitner, the Founding Director. Eitner had patented his own chrome tanning system which appears to have been taken up by an Austrian tannery and was used into the first decade of the twentieth century to produce what was known as *Patentleder Elefant* [184]. He noted that the tannery took care to disguise the fact that chrome had been used in the production of this material. This has implications for today's conservators, as discussed below.

Stellmach termed "the state of the chrome tanning art" prior to Schulz's patents, "the Chrome Tanning Awareness Period". He went on to give a detailed description of early developments in chrome tanning, based on the information given in Publication 7.

Seligsburger also briefly discusses the prehistory of chrome tanning, again basing his arguments on Publication 7, concentrating on the work of Heinzerling whom he calls "the most controversial figure among those to be included in any such historical review." He concludes, perhaps somewhat harshly, that, "In retrospect, I side with Eitner in judging Heinzerling to be not much better than the many charlatans who used to sponge on the gullible tanner, charging enormous sums of money for worthless formulas."

Allen also cites Publication 7 in his bibliography when he refers briefly to Heinzerling but concentrates his paper on a discussion of practical technological aspects of the two bath tanning process as it was carried out in a number of UK tanneries. He points out that two bath chrome tanned kid skins were processed with virtually no changes in manufacturing methods at the Surpass Leather Company factories, in Gloversville and Philadelphia, from their company's foundation in 1892 to its closure in 1954.

With the above in mind, one would have thought that the 'big bang' theory of the invention of chrome tanning would have been undermined. This has, however, not been the case. Luck, for instance, in his paper, *The History of Chrome Tanning Materials* [185], states that "The history of industrial chrome tannage goes back a hundred years to 1884 when Augustus Schultz carried out the first two bath tannage in the USA." Similarly, Kochta, *et al* [186], write, "Starting up in the USA in the late nineteenth century chrome tanning became established as the standard method throughout the world" and Baozhen, *et* *al* [187] state that "In 1884, an American, A. Schultz applied for the first patent for chrome tanning."

These findings draw attention to the general implications for research raised by this persistence of outdated theories. More particularly, in the context of this study, the question arises as to how a knowledge of the introduction of the technology of chrome tanning informs the Heritage Conservation practitioner. As discussed above (Section 3 Historical Leather Technology), when an artefact is assessed for treatment, there is the necessity in conservation for an understanding of how the material from which it was made was produced. Fundamental changes in manufacturing methods, such as the substitution of the traditional organic polyphenolic vegetable tannins with inorganic chromium complexes, must call for an informed reappraisal of the conservation techniques which are appropriate for use with the object.

The 'big bang' view of the introduction of chrome tanning would suggest to the conservator that all skin based objects made before 1884 must have been produced using vegetable tannins, oxidisable oils or alum. This view also suggests that there was a rapid and almost universal acceptance of the new processes, implying that all leathers produced in the twentieth century are likely to be chrome tanned. The Publication under discussion indicates that this was not so and the situation is more complex [188]. If a conservator is unaware of this, incorrect decisions could well be made, resulting in damage to objects being treated.

As an example, if an object known to date from 1880 and assumed to be vegetable tanned is being examined prior to conservation, it is likely to have its pH measured [189]. If it had, in fact, been processed using one of the early chrome methods, it would probably have a pH of 2.8-3.2. A vegetable tanned leather with this value could well be diagnosed as suffering from the form of acid damage known as red rot. This would be supported by the fact that vegetable tanned leathers manufactured in the late nineteenth century are particularly prone to this form of deterioration. (see Section 4 Deterioration Mechanisms). Treatments for red rot have included neutralising the strong acid present in the leather, using either buffer salts, particularly potassium lactate, or chemical stabilisers such as aluminium alkoxide. Both these treatments damage chrome tanned leathers. Salts of organic acids, such as lactates, react readily with chrome leather, breaking the tanning bonds between the chromium complexes and the collagen. It is the presence of lactates in perspiration that has been shown to lead to the deterioration of military footwear and flying gloves [190]. The use of aluminium alkoxide was developed specifically for the treatment of acid deteriorated vegetable tanned leathers [191]. In practice, applying this material to chrome tanned leathers (or to untanned or alum tawed skins) results in excessive stiffening and a tendency towards cracking.

Conversely, conservators should be aware that while it is most likely than any object made from leather found on examination to contain chromium is likely to post date 1884, this is not necessarily so. An important, rare artefact produced from leather tanned by the Heinzerling or other pre-Schultz process may go unrecognised.

It is precisely such knowledge of leather science and technology which has such a vital role in Heritage Conservation.

Redacted content:

Thomson, Roy (1996). Pest Attack on Leather. In: Neher, A & Rogers, D. (eds.) *Pest attack & pest control in organic materials: postprints of the conference held by UKIC Furniture Section at the Museum of London, 18 November 1996.* London: United Kingdom Institute for Conservation of Historic and Artistic Works.
http://www.worldcat.org/oclc/501448686

Thomson, R., 2006. The deterioration of leather. Journal of the Society of Leather Technologists and Chemists, 90(4), pp.137-145.
http://www.sltc.org/sltc-electronic-journal/

4.3 Deterioration Mechanisms commentary

Before any preservation treatment is undertaken to any object forming part of the Cultural Heritage, be it preventive or remedial, an understanding is required of the causes and mechanisms of the deterioration that has led to the need for this treatment. Without such information it is not possible to forestall, halt or even reverse such deterioration safely. Inappropriate treatments can too frequently result in damage greater than that which they are intended to remedy. The research undertaken during the preparation of Publications 8 and 9 brought together information on the deterioration of skin based products from a variety of sources for the first time. Many of these sources would have been familiar to leather scientists and technologists but were not readily accessible by conservators. An analysis of this information supported the author in his rejection of a number of then accepted assumptions among conservators and gives an explanation for phenomena not at the time understood by them.

As with other materials, the causes of the deterioration of leather and other skin products can be categorised as biological, physical or chemical. As the title of the publication, *Pest Attack on Leather* (Publication 8) suggests, this paper concentrated on biological factors, discussing the parts played by bacteria, moulds and fungi, insects and mammals (including humans). The lecture on which this paper was based was given by invitation to a Conference of the United Kingdom Institute of Conservation whose theme was *Pest Attack and Pest Control in Organic Materials*, a fundamental aspect of preventive conservation. In addition to presenting a synthesis of the extant information, it challenged the accepted orthodoxies regarding the mechanisms of fungal and insect attack.

Firstly, it had generally been considered that the signs of physical deterioration associated with mould growth were due to the proteolytic effects of enzymes secreted by the fungi on the collagen-tannin complex. This conclusion had been based largely on the work carried out by Seligsberger and Mann [192] of the Quartermaster Research and Engineering Research Center in the USA. This work was undertaken following the experiences of the US Army in South East Asia during the 1939-45 War when "thousands of pairs of military boots, shipped and stored until needed, became entirely unfit for issue before being removed from the original packing cases … The leather in many pairs was so weak it could be cracked and torn easily." Publication 8 suggests that the loss of strength and tendency of leather to crack is a result of the acids liberated when the fungi digest fats, sugars and other carbohydrates present in the leather and not of direct proteolytic action. This conclusion is supported by Cordon [193] who suggests that the "rotting and falling apart" of the footwear was mainly due to failure of the cellulosic stitching threads. It should also be pointed out that the warm, moist conditions that encourage mould growth are also conducive to hydrolytic breakdown of the leather.

Secondly, just as Publication 8 showed that moulds and fungi do not attack the collagen-tannin complex directly, it also maintained that, despite common names such as hide beetle, bookworm and leather beetle, insects cannot digest leathers. Insect damage to leather artefacts therefore occurs as they pass along or through them to reach more suitable sources of nutrition.

Publication 8 also presented information on how such biological attack can be prevented and how such infestations can be eradicated. Evidence for technological transfer between leather technology and conservation practice was demonstrated by reference to specific fungicides originally developed by leather technologists for use in tanneries. This Publication also refers to the author's research into the application of the, then, novel Thermo Lignum process for pest eradication to leather and other skin products, detailed in Section 5 Conservation Methods. In addition, by presenting a number of case studies, detailing treatment methods, Publication 8 showed how the effects of biological deterioration can be mitigated in practice.

Whereas Publication 8 had concerned itself with the application of leather science and technology to conservation, the prestigious Procter Memorial Lecture which the author was invited to deliver in 2005 (Publication 9), concentrated on leather chemistry with an analysis of the mechanisms of the deterioration of leather. In addition to expanding the discussion of the causes of biological damage given in Publication 8, it examined the scientific and technological understanding of physical and chemical deterioration.

The section on physical deterioration emphasised the fact that leather undergoes considerable expansion and contraction as the humidity of the surrounding atmosphere changes. This phenomenon is widely appreciated by leather scientists and technologists, the audience for this Memorial Lecture. On the other hand, in the author's experience, conservators and others in the field of the preservation of the Cultural Heritage often find it hard to believe that leather can decrease in area by more than 10% if the relative humidity is reduced from 80% to 20%. This could occur if an object is transferred from an open, unheated store on a rainy winter's day into a centrally heated display area, with disastrous results if this property is not taken into consideration. It is just such basic information, readily available in the scientific and technological literature associated with the manufacture and properties of leather that needs to be disseminated to such practitioners.

The paragraphs of the Memorial Lecture devoted to chemical deterioration went on to summarise the work on the causes and prevention of the type of deterioration of vegetable tanned leathers known as red rot that had taken place over the previous century. It also considered the controversy about whether red rot is a result of oxidative or hydrolytic activity. Conservators who are treating leather based objects might not need to have a detailed knowledge of the various chemical pathways given in the paper which have been postulated as the mechanisms for this chemical deterioration. They should, however, have a broad awareness of the current research on the subject. At the time when the Memorial Lecture was given, the results of the European funded STEP[194] and Environment [195] Leather Projects were being highlighted throughout the specialist field of leather conservation. These suggested an oxidative route for chemical deterioration and, based on these findings, put forward methods for testing leathers for durability and a set of specifications for new leathers to be used in conservation. Publication 5 countered this argument citing the results of the EU funded CRAFT Leather Project (see Publications 11 and 12 in Section 5 Conservation Methods), contending that, depending on the conditions that the object has been subjected to in its lifetime, both oxidative and hydrolytic decay will have taken place to a greater or lesser extent. This is now the accepted argument [196].

Redacted content:

Thomson, R.S., 1995. The Effect of the Thermo-Lignum Pest Eradication Treatment on Leather and Other Skin Products. In ICOM Committee for Conservation Working Group no. 10 Conservation of Leathercraft and Related Objects Interim Meeting on the Treatment of and Research into Leather, in Particular of Ethnographic Objects (pp. 67-76). http://www.icom-cc.org/ul/cms/fck-uploaded/documents/LWG/Amsterdam%201995_%20The%20Effect%20of%20the%20Thermo-Lignum%20Pest%20Eradication%20on%20Leather_%20THOMSON.pdf

Thomson, R., 2003. Towards a longer lasting leather: a summary of the CRAFT Leather Project. Bookbinder 17(1), pp.65-70. http://www.hewitonline.com/Bookbinder_Volume_17_2003_p/pb-050-17.htm

Thomson. R. The CRAFT Leather Project: artificial ageing studies. In: *Recent Preoccupations Concerning Textiles, Leather, Legislation. Postprints of ICOM- CC Leathercraft Group Meeting*. Athens, 2004, pp.46-49. http://www.lulu.com/shop/icom-cc-leather-group-groupe-cuir/recent-preoccupations-concerning-textiles-leather-legislation-post-prints-relating-to-leather/paperback/product-2375682.html

5.4 Conservation Methods commentary

Techniques employed in the preservation of objects in the custody of professionals whose role is to safeguard the Cultural Heritage are continually evolving. Any developing conservation techniques, however, must be closely monitored to ensure that unforeseen side effects of such novel procedures do not result in damage to the artefact being treated. For this reason, many conservators are rightly tentative when considering the application of newly developed methods and prefer to continue to employ those with which they are familiar. This reluctance will inevitably be particularly acute if the conservator lacks sufficient understanding of the materials they are handling.

Conservation treatments can be categorised as active and interventive or passive and preventive. This Section considers two representative investigations, one from each category, both of which required a knowledge of leather science or technology for their successful completion.

Publication 10 describes a, then, new interventive treatment. In the early 1990s, a method was developed by Thermo Lignum GmbH for the eradication of insect pests in wooden artefacts, using elevated temperatures [197]. It was then suggested that this procedure could be applied to a wider range of Cultural Heritage objects, including those made from leather. The response of most conservators dealing with leather was negative. They feared that the increases in temperature experienced during this process were likely to cause damage to skin based products, particularly if they were in a deteriorated condition. Despite these misgivings, in view of the potential advantages that this novel technique demonstrated over many existing pest eradication methods, a project was undertaken by the author to investigate the potential hazards. The results of this investigation were reported in Publication 10. Contrary to expectations, the results showed that, even with samples whose appearance and shrinkage temperatures indicated significant deterioration, the process had no deleterious effects. Although these findings were unambiguous, many conservators remained unconvinced, arguing that it was unsafe to subject leathers whose shrinkage temperatures had been reduced to 50-60°C by chemical deterioration to a procedure which involves holding them at 55°C for a period of hours. They did not appreciate that shrinkage temperatures are not just a measurement of resistance to heat but a measure of hydrothermal activity, requiring the presence of high levels of water to obtain meaningful, reproducible results. Leather scientists are aware that the temperatures at which skin based products shrink and the rate at which this shrinkage occurs are critically dependent on their moisture content, the shrinkage temperature reducing and the rate increasing as the water content rises. Publication 10 asserted that under the conditions prevailing during the Thermo Lignum process, even deteriorated leathers should be unaffected.

Following the presentation of the paper (Publication 10) to the ICOM-CC Leathercraft Group meeting and its publication, the Thermo Lignum process gained acceptance as a suitable process for treating leather artefacts [198]. The author has employed the procedure to eradicate insect pests in objects where other treatment methods would have been problematic. These include a bulky post-medieval saddle with a complex structure made up of different types of leather, textiles, metals, wood and miscellaneous organic stuffing materials. Large insect-infested panels of gilt leather, lined with linen and stretched on a wooden frame were also successfully treated.

Publication 10 remains the only published research on this method referring to leather. Thermo Lignum has highlighted these results as well as listing the leading museums, heritage organisations and conservation practices that have subsequently employed the system on a wide range of artefacts [199].

Publications 11 and 12 discuss the European Commission CRAFT Leather Project, an example of research undertaken into the development of a preventive conservation method. They differ in that Publication 11 summarises the whole Project, whereas Publication 12 concentrates on examining the detailed data obtained to validate the testing protocol employed.

Persistent complaints among conservators, particularly book conservators, are that modern commercial leathers lack many of the handling qualities essential to their work and that those tanned solely with vegetable tanning materials lack durability. The increase in the incidence of red rot in vegetable tanned leathers at the end of the nineteenth century has been signalled in Publications 5 and 9 which also demonstrate that during the first half of the twentieth century, methods were sought both to treat red rotted leathers (interventive conservation) and to prevent its occurrence (preventive conservation). In the 1940s, tanning procedures were developed using aluminium salts to re-tan vegetable tanned leathers which produced leathers resistant to the deleterious effects of acidic atmospheres. The use of such leathers could be considered as preventive conservation. Unfortunately, the leathers produced using these techniques lacked the desirable working properties of those tanned solely with vegetable tanning materials which practitioners demand. As a result, they were not accepted commercially.

The dual aims of the European Commission CRAFT Leather Project, of which the author was joint co-ordinator, were to develop a leather whose properties combined chemical resistance to acidic atmospheres with the physical characteristics demanded by the end user and to develop a set of standards whereby these properties could be tested. The Project resulted in major scientific and technological findings which led, crucially, to a significant commercial break-through.

Scientifically, it was proved that the artificial ageing regime developed during the CRAFT Project gave physical results more closely related to natural ageing than that proposed in the STEP and Environment Final Reports (see Section 4.3 Deterioration Mechanisms commentary.) Using this regime, it was possible to determine accurately the ageing properties both of modern commercial leathers and experimental samples developed during the Project. Technologically, it was demonstrated that of the seventy-one different leathers purchased from across Europe as suitable for binding books, only those produced by specialist tanners of bookbinding leathers were considered acceptable by experienced craftsmen binders. This has immediate implications, not only for book binders but also for conservators who are sourcing leathers suitable for use in preservation treatments. The signal commercial success of the Project was evidenced by the fact that one industrial partner, basing his own work on concepts demonstrated, and testing protocols defined during the Project, developed a range of leathers whose properties combined the desired chemical and physical characteristics. These leathers were being produced and sold on a commercial scale before the end of the Project and remain a significant proportion of the tannery's output.

As part of the dissemination of the results of the CRAFT Leather Project, a paper summarising the work undertaken was given at the request of the Society of Bookbinders to their 2003 Annual Meeting (Publication 11). This outlined the tasks undertaken by analytical chemists, craftsmen binders, materials scientists and leather technologists. It proposed a test protocol and the standards required for an archival leather and showed how leathers developed by one industrial partner had met these standards.

The artificial ageing results presented in Publication 11 were expanded further when more detailed scientific data were presented to a specialist group of leather conservators and conservation scientists in a paper given at the ICOM-CC Leatherworking Group meeting in 2004 (Publication 12). This paper demonstrated the effects of the STEP and CRAFT artificial ageing regimes on the shrinkage temperatures of 69 commercial book binding materials categorised as chrome tanned (high chrome), chrome tanned (low chrome), alum (tawed or tanned), semi-alum, vellum or vegetable tanned. These data indicated the superior nature of the CRAFT artificial ageing regime and it was argued that the view that chemical deterioration was primarily oxidative as laid out by the STEP Final Report was simplistic. During discussion of the paper, it was accepted that the mechanisms of chemical ageing are multifactorial, depending on the conditions to which the object has been subject throughout its lifetime [200]. Further evidence of the acceptance of the superior nature of the CRAFT artificial ageing regime is indicated by the fact that this method has been employed in a project examining the effects of novel chemical stabilisation treatments for red rotted leathers [201].

Publications 11 and 12 describe different aspects of an example of the application of both leather science and technology to a practical problem. They demonstrate that the systematic use of analytical techniques familiar to leather scientists and the exploitation by leather technologists of the results obtained can lead to a successful outcome. It is not to be expected that conservators, even those who specialise in leather should have the depth of knowledge to initiate research products such as these. With sufficient scientific and technological understanding of the materials involved, however, they will be able to appreciate the results enough to be confident in exploiting the final outcomes.

6. Discussion

In the preceding pages, twelve of the author's peer reviewed Publications relating to four aspects of Leather Science and Technology have been critically analysed with respect to their role in the field of Heritage Conservation. This analysis has been undertaken from the possibly unique viewpoint of a widely experienced leather chemist and tanner who had retrained as a professional conservator restorer. It was intended that in this way a contribution would be made to current thinking in the field. The overriding purpose for each of these presentations has been the dissemination of information about leather and the other materials made from hides and skins which, despite their ubiquity, are little understood by those not immediately involved in their manufacture. These Publications have given an insight into a group of materials whose technological development have been vital to human societies across time and throughout the world.

This Discussion must now address the essential integration of the information presented in the individual Publications. It is only through an understanding gained from such a synthesis that conservators and other professionals whose role it is to preserve the Cultural Heritage can achieve the necessary comprehension of the concepts within leather science and technology, an appreciation of which would enable the construction of an holistic understanding of leather and other skin products. Without this, correct treatment decisions cannot be made.

The initial analysis of the ideas of, among others, Knapp [202], Lollar [203] and Covington [204] has lead to a synthesis which has the needs of the Heritage Conservation professional in mind. The core of this synthesis is the way in which the main proteinaceous component of hides and skins, collagen, reacts chemically with different tanning materials, stabilising the structure by forming crosslinks to produce leather. It is to this fundamental concept, the basis of leather science [205], that the other aspects are linked. It should be noted that the term 'leather' covers many different but related materials each varying in its properties and reactions to conservation treatments, a fact rarely appreciated by non-specialists. Other collagen based materials which have not been subjected to these stabilising, crosslinking reactions, are not true leathers. A lack of such understanding may well result in misidentification of the material under investigation, leading to inappropriate, damaging treatment.

Just as it is important for conservation professionals to have an appreciation of these basic tenets of leather science, it is necessary for them to have a knowledge of leather technology and how the interaction between these two related but separate aspects affect each other. Historical technology is of interest in itself from an industrial historical point of view. The Publication *Leather Manufacture in the Post Medieval Period*, for example, has been widely cited in the archaeological and historical literature [206-216]. In the context of this study, however, if historical leather technology is not considered in conjunction with leather science, it is of little use in analysing the causes of the decay in, or determining appropriate treatments for, leather artefacts. When applied to conservation, where an understanding of why a particular leathermaking process was carried out and what effects it had are as important as how it was done, both sets of knowledge are interdependent. This is particularly apparent when the effects of 'improvements' in technology during the latter half of the nineteenth century are considered [217-219]. Without a scientific appreciation of the chemical reactions involved and the resultant changes in the physical nature of the leather, the consequences of what, at the time, seemed to be desirable technological changes can only be understood superficially. The significance of these 'improvements' cannot, moreover, be fully recognised without an understanding of the background information on the processing of hides and skins during earlier periods. It should also be appreciated that there appear to have been few fundamental advances in the technology of leather manufacture between the classical Greco-Roman period and the mid-nineteenth century [220]. It was only then that changes to processing techniques, such as the introduction of imported, condensed vegetable tanning materials, the application of synthetic dyestuffs, the use of vegetable tanned crust leathers brought in from the expanding Empire and the introduction of shaving machines, took place, resulting in dramatic changes in deterioration patterns [221].

The interaction between leather science and leather technology is also evident where the differences between materials which are and are not true leathers are considered in the context of the modifications to the traditional alum tawing procedure. This changed the traditional craft technique into a scientifically based tanning process which yielded a true leather with significantly improved resistance to deterioration [222, 223]. As with leather science, a basic knowledge of the technologies involved in the production of various materials which require preservation, and of the interaction between these two disciplines, need to be at the centre of any judgements about the conservation of leather.

Any examination of the causes of decay in skin based materials also reveals how the core scientific concepts which define skin, leather and the tanning process underpin how, and in what circumstances, these products deteriorate [224-226]. It is the mitigation of such deterioration that is the conservation profession's *raison d'être*. It follows that, without an awareness of these core concepts, the causes and processes of decay cannot be properly understood and, as a result, appropriate remedies will not be applied [227]. These publications both indicate how different leathers and skin based products react differently to agents of decay, be they biological, physical or chemical. The reasons how and why changes in leather technology led to an increase in the incidence of red rot in vegetable tanned leathers are of particular significance. Again, it is the knowledge of the interactions between materials science, leather technology and the mechanisms leading to deterioration which proves crucial to informed conservation decisions.

The Publications selected to illustrate two of the author's investigations into new conservation methods emphasise that scientific or technological knowledge was inherent in their successful completion. As an example, without having an insight into the relationship between shrinkage phenomena and moisture content [228-230], the use of heat for the eradication of insect pests in leather objects would not have been considered. It was also a result of having an awareness of the interaction between oxidative and hydrolytic deterioration of leathers produced using different technologies and the subsequent physical, as well as chemical effects [231, 232], that the artificial ageing regime employed in the CRAFT Leather Project was successfully developed.

As the research carried out during the preparation of this thesis progressed, a number of points germane to the central argument arose. These are worthy of further discussion.

That such a study is timely was indicated by the fact that, while this thesis was being prepared, a paper was published addressing the same subject [233], albeit from a somewhat different point of view. This had been presented by a group of Italian leather scientists at an international conference of museum professionals, *Diagnosis for the Conservation and Valorisation of Cultural Heritage*. More than a third of the references cited in the paper were to publications written by the present author. The appearance of this paper supports the proposal that the need for the application of information regarding leather science and technology to Heritage Conservation is at last beginning to be recognised elsewhere.

It became increasingly apparent that a significant minority of conservators suffer from what the author has termed 'chemophobia'. This is despite the fact that it is considered necessary for professional conservators to have a basic scientific training [234]. This impression is exemplified in a review by two leading book conservators of the recently published, *The Conservation of Leather and Related Materials* [235]. Referring to chapter 4, they write, "Chapters such as that on *The Chemistry of Tanning Materials* could have benefited from a diagrammatic representation of the information presented, rather than a purely chemical approach. Considering the audience at which this book is aimed, it is likely that many readers will lack, or possibly have forgotten, the background chemistry required to fully appreciate this chapter [236]." The chapter had been written for non-specialists and edited particularly with conservators in mind. The comments demonstrate that there is an ethos within sections of the conservation profession where such an admission, made in writing, in a leading conservation journal, is acceptable. Leather making is fundamentally a chemical process, as is its deterioration. As with other conservation specialities, a knowledge of chemistry must be a prerequisite for an understanding of the material. Leather science and technology are, however, very specialised fields and it is not surprising that practising conservators and conservation educators rarely come into contact with either. It is within this context that the role of leather science in Heritage Conservation has had to be considered. This thesis seeks to begin to redress this situation.

There is a lack of literature relating the science and technology of leather to its conservation. The publications which exist are concerned mainly with descriptions of practical conservation projects, without addressing this aspect. This thesis therefore represents a substantial contribution to a hitherto neglected body of literature. A related point is the unhelpful diversity of sources of information about leather and its conservation. This is demonstrated by the Publications selected for this study. They range over articles in journals aimed at industrial historians, specialist archaeologists, leather chemists and book binders, papers delivered to national and international conservation conferences and a chapter in a specialist book on leather conservation. Nearly half were published in the *Journal of the Society of Leather Technologists and Chemists.* There is no great awareness of such specialist technological literature among Heritage Conservation professionals. It is not insignificant that the paper by the Italian leather scientists mentioned above was also published in a journal aimed primarily at leather chemists, as was another on a related subject written by the same group [237]. The only arena within the conservation world which might have welcomed material of this kind would have been *Leather Conservation News* which unfortunately ceased publication in 2003 after seventeen years. Although this journal did not carry long articles, it included summaries of latest research. To date, nothing has taken its place.

It also became evident that little literature has been published by Heritage Conservation professionals on the manufacture of different products from hides and skins. What has been written is often characterised by a lack of precision in the nomenclature employed [238]. Such inaccuracies would not be tolerated when dealing with other specialities, such as textile or ceramic production. This can be attributed to the authors of these publications having only a superficial knowledge of the subject. They sometimes give an impression of having read what the different processing stages consist of without understanding why they are carried out or how they are affecting the properties of the final product. In some cases, however, the misuse of widely accepted technical terms can only be described as dismissive. In a section of a paper headed 'Terminology', for example, Driel-Murray, one of the most widely acknowledged authorities on archaeological leathers, reserves the term 'tanning' solely for the vegetable tanning process. The production of all other skin based products she calls 'curing'. She states that, "Although modern literature distinguishes between 'curing', 'oil tannage', 'alum tawing', etc. none of the leathers produced by these methods survive in damp conditions, and since there is no method of analysis to distinguish satisfactorily between these processes even in desiccated material, the simple twofold distinction between them [the terms 'tanning' and 'curing'] adequately serves the needs of archaeological description [239]." Apart from referring to cured and alum tawed skins as 'leathers', her incorrect usage of technical terms can only confuse those with a less detailed knowledge of skin processing than her own. Under these circumstances, it is not surprising that the term 'cured' is widely misused in archaeological and conservation literature. In an attempt to correct the record, the present author has included definitions of some common leather related terms in his chapter in a recently published book [240] (not one of the publications proposed for this thesis.) In particular, this chapter includes the author's definition of tanning.

The last point relates to the fact that a number of the Publications which form part of this thesis challenged the current orthodoxy. In particular, the accepted belief that alum tawing was first developed in the Middle East in the second millennium BC was challenged and the assertion that commercial chrome tanning only dated back to Schultz's patents of 1884 was shown to be erroneous. This raises the problem that, despite the evidence presented in papers such as these, if the orthodox views have been put forward in standard text books by recognised authorities (Reed in the case of alum tawing [241]; Wilson [242], Woodroffe [243] and Thorstensen [244], among others, in that of chrome tanning) they become entrenched. It is a problem common to all disciplines that statements which were considered true at the time they were published, continue to be cited frequently despite the fact that later work indicate that they are inaccurate. In the case of leather chemistry, there is no strong academic corpus with an interest in historical aspects of the subject. Conservators of leather are therefore particularly vulnerable to such perpetuated errors, due to the narrow range of relevant, up to date literature available to them.

All of these points reinforce a conviction that there is a general lack of knowledge about the subjects considered in this thesis and, in particular, the fundamental nature of skin based materials. There is a danger that this could lead to a lack of confidence or, worse, uninformed overconfidence among conservators and others, with resulting damage to artefacts. Further, as argued in the commentary on Section 5, this can also lead to an unwillingness to move beyond familiar traditional practices which in some cases are harmful. An improvement in this situation can only come about if there is closer collaboration between leather scientists and technologists with conservators, archaeologists and curators. In this way, information such as that analysed in this thesis could be disseminated. The author's experience suggests that this can be mutually beneficial.

Some of these comments may have given the impression that all Heritage professionals lack any knowledge about leather. This is not the case. There exist specialist groups and individuals whose aim is to raise the profile of all aspects of leather within the Heritage community. These include the Archaeological Leather Group whose remit is much wider than its name suggests, covering historical as well as archaeological aspects and the Leatherworking Group of ICOM-CC who are mostly concerned with conservation issues.

The above discussion has argued that Leather Science and Leather Technology, as exemplified by the peer reviewed Publications selected for inclusion in this thesis, provide the essential information required if skin based objects are to be preserved safely. Each of the subjects considered in the individual Publications has been shown to be important in its own right with respect to Heritage Conservation. It is, however, only through a synthesis of the information from each of these fields, such as this study has provided, that the essential holistic understanding of the materials can be achieved.

7. Conclusions

By critically appraising twelve of the author's peer reviewed published works, selected from a wider range of publications, this thesis has argued the necessity for a basic understanding of leather science and technology if artefacts made from leather or other skin based products which form part of the Cultural Heritage are to be treated safely. It has demonstrated that this understanding cannot be achieved without a knowledge of the nature and properties of these materials, the technology of their manufacture, the causes and mechanisms of their decay and how this deterioration can be mitigated. In particular, the study has shown that it is not only from the results of the research presented on each of these individual subjects that a sufficient insight can be gained but, more importantly, by the comprehension of the synthesis of the evidence from these separate but interlinked areas.

The research has indicated that for decisions to be made regarding appropriate preservation treatments, be they interventive or preventive, a recognition of the basic tenet of leather science is essential. This is that tanning is fundamentally a chemical process involving reactions taking place between tanning materials and the main proteinaceous component of the skin, collagen. The nature of these reactions differ depending on the tanning material employed but they all result in the formation of stabilising crosslinks within and between collagen macromolecules. It is necessary to recognise that by using different tanning materials, a range of different leathers can be produced, each with their own characteristics and deterioration mechanisms. These therefore each require specific conservation treatments. It also needs to be understood that a wide variety of other materials can be made from hides and skins using processes which do not involve the formation of these stable chemical crosslinks. These are not true leathers. They also have their own individual properties, each demanding their own treatment methods. The thesis has shown that applying preservation treatments which have been developed for leather to these materials can have disastrous effects.

The study has also argued for a knowledge of the technologies employed over different historical periods for the manufacture of skin based products. Specifically, there should be an understanding of how these processes changed over time and how these developments affected the properties, especially the ageing properties, of the final products. It has been demonstrated that this is particularly relevant in the case of vegetable tanned leathers produced in the late nineteenth century. It is these materials which currently make up the majority of those requiring interventive preservation treatments.

It has also been shown that before any preservation treatment is considered, the conservation practitioner needs to understand the underlying causes and mechanisms of the specific type of deterioration leading to the need for such treatment. These can be biological, physical, chemical or a combination of these. This study draws attention to the fact that much relevant information about the deterioration of leather and related materials is extant among leather chemists but less so among many Heritage Conservation professionals. Without such understanding, inappropriate procedures could be applied, leading to further damage.

With the introduction of scientific conservation, a number of novel treatment procedures have been introduced specifically for application to artefacts made from skin based products. This investigation has highlighted the need for a comprehension of the scientific and technological foundation on which specific conservation methods are based. Without such informed knowledge, many practitioners are unwilling to introduce these new techniques. Alternatively, there is a risk of their being used incorrectly to the detriment of the object.

All these factors underline that, if skin based products are to be treated safely, there is a necessity for Heritage Conservation professionals to have an appropriate knowledge and understanding of the sciences, in particular, chemistry. Science and technology are of equal importance to art history, craft skills and aesthetics when determining preservation strategies. This study has indicated that for a significant minority of conservators this is not the case. The problem is exacerbated by the lack of literature relating the science and technology of leather to its conservation and the fact that what has been written often lacks precision in the nomenclature employed.

This thesis demonstrates that the role of leather science and technology in Heritage Conservation has hitherto not been sufficiently considered. Given the importance of skin based products in the Cultural Heritage, this deserves to be corrected. The evidence provided by this research suggests that this may best be achieved by closer collaboration between Leather Chemists and Heritage Conservation professionals. The Publications presented here, together with the critical appraisals, have made a contribution towards this end.

Appendix: Other relevant published works

Materials Science

Thomson, R. Surface coatings and finishes. *In*: C. Calnan and B. Haines, (eds.) *Leather: its composition and changes with time.* Northampton: The Leather Conservation Centre, 1991. 34-38.

Thomson, R. Leather for clothing. *In: Proceedings of Leathercraft Group Symposium*, ICOM, London, 1992. 29-31.

Thomson, R. Leather working processes. *In*: E. Cameron, (ed.) *Leather and Fur: aspects of early medieval trade and technology.* London: Archetype, 1998. 1-9.

Thomson, R. Testing leathers and related materials *In*: Marion Kite and Roy Thomson, (eds.) *The Conservation of Leather and Related Materials.* Oxford: Butterworth-Heinemann, 2006. 58-65.

Historical Technology

Thomson, R. The industrial archaeology of leather. *Leather*, 1978, **76**. 189-193.

Thomson, R. The nineteenth century revolution in the leather industries. *In*: R. Thomson and J. Beswick, (eds.) *Leather Manufacture Through the Ages.* Northampton: EMIAC, 1983. 24-35.

Thomson, R. Chromgerbung im 19 Jahrhundert. *Leder*, 1986, **36**. 190-196.

Thomson, R. A history of leather processing. *In*: C. Calnan and B. Haines, (eds.) *Leather: its composition and changes with time.* Northampton: The Leather Conservation Centre, 1991. 12-15.

Thomson, R. The history and technology of transport leather production. *In*: *Conservation of Leather in Transport Collections*, UKIC, 1991. 3-7.

Thomson, R. The manufacture of bookbinding leathers in the nineteenth century. The Beginning of the Rot? *In*: *Preprints of Conference on Conservation of Archive and Library Materials,* Erice. 1996. 499-503.

Thomson, R. Manufacture of leather. *In*: *Leather/Skin and its Conservation for Museums and Archaeologists.* Athens: PK Net Informatics, 2000. [CDROM]

Thomson, R. When did chrome tanning start? *Leather Conservation News*, 1997, **13**. 1-3.

Thomson, R. Post medieval tanning and problems caused by sixteenth and seventeenth century bureaucrats. *In*: F. Audoin-Rouzeau and S. Beyries, (eds.) *Le Travail du Cuir de la Préhistoire à Nos Jours*. Antibes: Editions APDCA, 2002. 465-472.

Thomson, R. The nineteenth century revolution in the leather industry and the rise in chrome tanning. *In*: R. Córdoba de la Llave, (ed.) *Mil Años de Trabajo del Cuero*. Cordoba: Litopress, 2003. 423-442.

Thomson, R. The manufacture of leather. *In*: Marion Kite and Roy Thomson, (eds.) *The Conservation of Leather and Related Materials*. Oxford: Butterworth-Heinemann, 2006. 66-81.

Thomson, R. Gilt leather. *ibid*. 90-93.

Deterioration Mechanisms

Thomson, R. Deterioration of historical leather. *In*: *Leather/Skin and its Conservation for Museums and Archaeologists*. Athens: PK Net Informatics, 2000. [CDROM]

Thomson, R. and Lochmuller, T. Ageing experiments LCC. *In*: R. Larsen, (ed.) *STEP Leather Project*. Copenhagen: Royal Danish Academy of Fine Arts, 1994. 35-38.

Thomson, R. and Lochmuller, T. Standard chemical and physical analysis. *ibid*. 131-150.

Thomson, R. *et al*. A survey of current bookbinding leathers. Part 1 Chemical and physical properties. *J. Soc. Leather Technol. Chem.*, 2002, **86.** 163-170.

Thomson, R. *et al*. A survey of current bookbinding leathers. Part 2 Organoleptic properties. *J. Soc. Leather Technol. Chem.*, 2002, **86.** 249-256.

Conservation Methods

Thomson, R. Another house, another method: variations in approach to the conservation of gilt leather. *In*: *Proceedings of Conference, The Impact of Location on Conservation Treatments*, SSCR, Dundee, 1998. 56-62.

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