BRITISH LIBRARY

Advances in Paper Conservation Research

23 – 24 March 2009

Supported by
The Andrew W. Mellon Foundation

Collection Care
British Library
96 Euston Road
London
NW1 2DB
United Kingdom

Advances in Paper Conservation Research
Editor C V Horie

ISBN 978-0-7123-5086-0

Design British Library Design Office
Typeface Syntax
Printed by Spellman Walker
Printed on Revive 100 uncoated

Also available at
www.bl.uk/aboutus/stratpolprog/ccare/events/index.html

Foreword

The Identical Books Project sprang from a meeting convened by the Andrew W. Mellon Foundation in September 2003, at which a group of conservators and scientists active in conservation research was invited to outline the current trajectory of scientific enquiry related to the conservation of paper materials. A follow-up meeting was held at the British Library (BL) in September 2004, again supported by the Andrew W. Mellon Foundation, and attended by representatives of the six UK legal deposit libraries and two national archives, together with representatives from national libraries, research establishments and teaching institutions in North America and Europe. The meeting aimed to develop a strategy for applied conservation research into paper-based library and archive materials in the UK and Ireland. The discussions and conclusions of this meeting were published in 'Future Life of Collections.'

Three overarching themes emerged from the meeting, which form the agreed priorities for applied conservation research in the library and archive field:

1. Life-cycle prediction, natural ageing of materials, evaluation of preservation strategies for different materials.
2. Effects of the storage environment and selection of the optimum environment for different materials.
3. Non-destructive methods for assessing damage to materials.

The BL then submitted a research proposal to the Andrew W. Mellon Foundation to fund an ambitious project to compare the condition of a large collection of Identical Books in each of the legal deposit libraries, and to correlate any differences with known differences in their storage environment. The project also proposed to identify and quantify the volatile organic compounds emitted by books and paper as they age. This report is a record of that project, but it includes other material that sets the project in context and reports on related research.

This report of the conference 'Advances in Paper Conservation Research' which was held at the BL on 23–24 March 2009, marks the conclusion of the Identical Books Project. The success of the conference and the subsequent publication in this booklet and on the web was aided considerably by staff from the Collection Care department, led by Kissley Leonor.

The BL is grateful to the Andrew W. Mellon Foundation for its continued support for conservation research in the library and archive field in the UK. Thanks to the Foundation, conservation research at the BL has developed to the point where it is producing useful results that can be applied in this and other libraries and archives, and there is a clear path for future work.

Barry Knight
Head of Conservation Research, British Library

1. www.bl.uk/aboutus/statpolprog/ccare/introduction/research/futurelife.pdf

Contents

Conservation research in context

Helen Shenton, Head of Collection Care, British Library

How we arrived here

In 2002, the British Library (BL) created Collection Care to encompass conservation, conservation research, preservation, digital preservation, storage, training and development. In 2003, the BL established the first head of conservation research post in the UK library and archive sector, filled by Dr Barry Knight. This appointment enabled the development of the BL Conservation Research strategy, whose main themes were presented at the House of Lords Science and Technology Inquiry, published in 2006. The inquiry also brought forth the Science and Heritage programme, funded by the Arts and Humanities Research Council and Engineering and Physical Sciences Research Council (AHRC/EPSRC), which is making possible interdisciplinary research clusters and substantial research projects. The BL rewrote its Stewardship Research Strategy 2008–11 to reflect the widening responsibilities of Collection Care.

The creation of an overall strategy for the BL and wider library and archive sector in the UK has been supported by the Andrew W. Mellon Foundation. The Mellon Foundation went on to fund implementation of the strategy as the Identical Books Project (IBP) from 2006 to 2009.

Scale and type of collections in libraries and archives

There are some 12,000 libraries and 2362 archives in the UK. Historically, the collections of libraries and archives are largely organic, comprising paper, parchment, papyrus and leather, which gradually degrade, requiring changing strategies of care. Increasingly, the library sector has been acquiring large quantities of digital items. These have the risk of total loss as the carrier materials degrade, preventing copying onto new media. A recent physical manifestation of the BL's response to these different responsibilities is the Centre for Conservation (BLCC) building, which houses both book and sound archive conservation. The BLCC incorporates public programmes, training and conservation research, all applied to the care of collections.

BL conservation research model

The methods for conservation research in the BL are explicitly distributed and collaborative. For its research, the BL will draw upon, and help to develop, expertise in other institutions such as universities and other libraries in the UK and abroad. It will continue to take part in collaborative projects such as the recent highly productive INFOSAVE, SurveNIR and PaperTreat projects that address its core concerns. The key purpose of the research is to apply the new knowledge directly to the care of large swathes of library and archive material. In addition, item-specific research will be carried out to benefit the BL's collection.

The 2004 Conservation Research Strategy collated previous work; for example, on deacidification methods. Building on that, the BL hosted an international round table, funded by the Andrew W. Mellon Foundation, to implement the distributed and collaborative model. Those invited included European and North American scientists, educationalists, collections managers, all the legal deposit libraries in the UK, the UK national archives, and so on. The group collectively identified gaps in conservation research by theme:

- life-cycle prediction, natural ageing
- effects of storage environment
- non-destructive damage assessment.

The report of the round table was published as *Future Life of Collections*, becoming known as the 'Green Book'. Building on this collaborative framework, the BL is grateful to the Andrew W. Mellon Foundation for the projects being presented in this volume in partnership with the UK legal deposit libraries and national archives.

- condition of Identical Books in different nationally significant libraries
- emission of Volatile Organic Compounds (VOCs) by books and paper.

The core of the project was the partners' collections, while the bulk of the scientific investigations were carried out by the Centre for Sustainable Heritage (University College London), the Department of Chemistry (University of Strathclyde, Glasgow), and Morana (Ljubljana, Slovenia).

Conservation research in context

The 2006–7 House of Lords Science and Technology Sub-Committee Inquiry into Science and Heritage is a key turning point in UK Conservation Research. This revealed some widely agreed ways of working; for example, not setting up a centre of research for the movable and immovable heritage in the UK. The report prompted the Science and Heritage programme by AHRC/EPSRC, which is funding research projects and interdisciplinary research clusters. Examples of such clusters include Catch-22, which looks at the access to collections and social benefit; and Booknet, which explores the manuscript as a physical artefact. In parallel, the major heritage science players in the UK (quasi-government bodies – the BL, English Heritage, Historic Scotland, National Trust, museums and academics) are coming together to develop an overview of needs and draw up strategies in the form of the National Heritage Science Strategy Steering Group.

Examples of BL conservation research

The principles of conservation research as a benefit to all library and archive collections or item-specific research are exemplified by two projects.

The BL has created a new storage building in Boston Spa for 262 km of stock incorporating a number of innovations: reduced oxygen environment for fire protection, high density, robotic retrieval. Real-time monitoring of books and the environment from the beginning of ingest is planned and these data will be made available in the future for study by libraries and archives.

By July 2009, the virtual reunification of the Codex Sinaiticus will be completed, bringing together the earliest New Testament from four different locations: London, St Petersburg, St Catherine's Monastery in Mount Sinai and Leipzig University. The Codex Sinaiticus Project has examined overwritings, erasures, text substitutions, different inks, scribal hand and animal sources for the parchment. The iconic prominence of this book is enabling item-specific research that will not only have relevance in its own field, but direct application to other items and collections in the BL and beyond.

Conservation research in context in 2009

In 2009, the Science and Heritage Programme issued another call for interdisciplinary research. By the end of 2009, the National Heritage Science Strategy Steering Group will produce a UK strategy for the entire movable and immovable heritage. The library and archive sector has collectively contributed to a research project that adds significantly to the quantity and quality of conservation science in the UK and abroad. This is demonstrated in the Advances in Paper Conservation Research Conference and the scientific papers flowing from the Identical Book Project.

Key documents

CONSERVATION RESEARCH STRATEGY
www.bl.uk/aboutus/stratpolprog/ccare/introduction/research/consresstratfinal.pdf

THE GREEN BOOK
www.bl.uk/aboutus/stratpolprog/ccare/introduction/research/futurelife.pdf

HOUSE OF LORDS SCIENCE AND TECHNOLOGY COMMITTEE INQUIRY INTO SCIENCE AND HERITAGE (2006–7)
www.publications.parliament.uk/pa/ld200506/ldselect/ldsctech/256/256.pdf

A STEWARDSHIP RESEARCH STRATEGY FOR THE BRITISH LIBRARY 2008–2011
www.bl.uk/aboutus/stratpolprog/ccare/projects/stewardshipresearchstrategyfinal.pdf

Websites

THE CODEX SINAITICUS PROJECT
www.codexsinaiticus.org/en/

NATIONAL HERITAGE SCIENCE STRATEGY
www.english-heritage.org.uk/nhss/server/show/nav.19891

THE SCIENCE AND HERITAGE PROGRAMME
www.heritagescience.ac.uk/index.php?section=1

The Identical Books Project: the new knowledge

Barry Knight, Head of Conservation Research, British Library

The Identical Books Project (IBP) has brought a number of tangible and intangible benefits both to the British Library (BL) and to the wider library and archive world. The BL has been established as a serious player in conservation research, and is a sought-after partner in national and international collaborative projects. The spirit of collaboration between the legal deposit libraries has been developed, and awareness of the role of conservation research in libraries and archives has been raised. Good relationships have been established with universities and small-to-medium-sized enterprises (SMEs).

We should contrast this with the situation five years ago, before this project started. At that time, the BL had just appointed its first head of conservation research, and although the library had been involved in various research activities – for example, the long-running graft copolymerisation project and the use of Raman spectroscopy for the identification of pigments on manuscripts – it did not have its own research strategy and it did not have an established research reputation.

The BL therefore developed a research strategy, and, with the assistance of the Andrew W. Mellon Foundation, it convened a meeting to identify the major research priorities for libraries and archives in the UK. This was the first attempt to engage with all the legal deposit libraries (National Library of Wales, National Library of Scotland, Cambridge University Library, Oxford University Library Services, Trinity College Dublin Library) and national archives (The National Archives, Kew, and the National Archives of Scotland). The relevance of the conclusions was validated by the participation of a number of international experts, from Europe and North America.

We were then fortunate in obtaining funding from the Mellon Foundation for the IBP, which started in earnest in October 2006. At the same time, we had become end-user partners in the EU-funded PaperTreat and SurveNIR projects, and we immediately recognised the synergies between these projects and the IBP. Bringing background knowledge and access to the BL's collections, we were able to contribute to the analysis methodology and the development of the surveying tool. This helped to increase our standing and led to increased international recognition of the BL as a serious research player and of the IBP as a worthwhile project. As a result, we were able to contract with the University of Ljubljana and Morana RTD to carry out analyses that we had not envisaged at the start of the project, again increasing the value of the results.

It would also be fair to say that at the beginning of the IBP, the legal deposit libraries had not considered that conservation research had a significant role in their activities. They were at best passive consumers of research, and were not equipped or staffed to carry out research on any scale. In the same way, conservators did not consider that research was part of their function. As a result of this project, some at least of the conservators have been able to take part, and have learned new techniques that they can apply in their daily work. By holding meetings and training sessions, we have fostered contacts between conservators in different libraries, so that collaboration becomes a more natural part of their approach.

Finally, we have established productive relationships with our academic partners in the UK (the University of Strathclyde and University College London) and abroad (University of Ljubljana), and with three SMEs: Morana, Owlstone and Syft. The last two companies make specialised equipment for volatile organic compound (VOC) analysis, which is much in demand for security applications as well as in the petrochemical and food sectors, but they are choosing to work with us – even though we have little money – because they find the idea of analysing the smell of old books fascinating.

Amongst the tangible benefits, we may count the gathering of a very well-characterised collection of 370 Identical Books in the six legal deposit libraries. These are not only a rich source of data for this project; they are an invaluable resource for future materials science studies and for long-term real-time ageing studies. Books are not only important for the text they contain; they are a sample of a number of different materials of known age: paper, card, adhesives, textiles, leather … . Their present state reflects the environments that they have experienced and the pollutants that they have absorbed. By characterising their present state, we have a baseline for future studies of the evolution of their condition, or the degradation of the different materials they contain. Another study in fifty or a hundred years' time will reveal how the materials have changed and, if environmental and usage data are collected and retained, our successors will be able to relate these changes to the conditions they have experienced. Finally, the data relating to these six collections are part of a growing international corpus of research data. By making the data available for study we enable other researchers to make correlations and to draw conclusions that we had not considered, or to use the data for other purposes entirely.

We have characterised the storage environments at the BL at St Pancras, the National Newspaper Library at Colindale and the National Library of Wales (NLW) in terms of the average conditions and their variation, and of the level of air pollution. As far as pollutants are concerned, historic data show that until the 1960s SO_2 levels in London were five to fifteen times higher than in Aberystwyth, but that now the levels of pollutants (SO_2, NO_x, ozone) are similar. However, the books in the BL will have absorbed more SO_2 in the past, and this will be still actively degrading the paper in spite of the lower current levels.

We can see that the environment at St Pancras is very tightly controlled, so that all storage locations are essentially equivalent, while at Colindale the environment is not controlled and there is a very marked difference between different locations, which implies similarly large differences in the rate of deterioration in these locations. In general, though, the variations within sites are greater than the variations between sites, which makes it impossible to draw conclusions about the effects of the environment on individual books. In addition, the unrecorded movement of books within stores compounds the difficulties.

However, we can measure systematic differences in the average condition of books stored at the BL and NLW, and we can also measure systematic differences between books in the same collection. We have confirmed the value of non-destructive testing, using the SurveNIR instrument, to estimate physical and chemical properties of the book papers. This has complemented the micro-destructive measurements that we have been able to make – pH, degree of polymerisation of cellulose, and fibre furnish – and has provided an additional independent verification of the calibration of the SurveNIR instrument. This increases our confidence in the validity of the results obtained using SurveNIR, and enables the estimates of the parameters to be refined.

Together with our colleagues at the University of Strathclyde, we have been working on characterising the volatile organic compounds (VOCs) emitted by books. We have used a variety of techniques:

- SPME (solid phase micro extraction)
- SATVA (sub-ambient thermal volatilisation analysis)

- FAIMS (field asymmetric ion mobility spectrometry)
- SIFT-MS (selected ion flow tube mass spectrometry)

which have allowed us to estimate the total quantity of VOCs being emitted and to compare the range of VOCs captured by each technique, since each of the sorbents is selective to a greater or lesser extent.

Although this work is still in its early stages, we have demonstrated that there are differences in the VOCs emitted by identical copies of the same book in the different libraries, and that there are differences between different issues of annual publications such as *Whitaker's Almanack*. There is much more to be done to understand the significance of these differences.

We are very grateful to our commercial partners, Owlstone and Syft, who have chosen to work with us because they find the smell of old books interesting, even though they have much more lucrative contacts with the defence and petrochemical industries. We believe that their instruments have the potential to be the basis of a practical nose for sniffing books, although there is much more development work to be done.

So, finally, what are the main benefits that this project has brought? Apart from the collection of analytical data and the creation of a research archive, there is no doubt that the collaboration between the library partners has been vital and rewarding. People have perceived the value of the work and have supported it wholeheartedly. Collaboration with the university partners has brought invaluable expertise, again vital to the success of the project, and, finally, the project has generated real interest in the wider research community. All this has been achieved in a comparatively short space of time, thanks to the generosity of the Andrew W. Mellon Foundation.

Paper conservation research 1974–2004

Vincent Daniels, Emeritus Researcher, British Museum

I have been asked to provide a reflection on the way paper conservation research has changed over the time I have been involved as a researcher. This is a purely personal view and as such is certain not to be representative of the field. The time span corresponds to the thirty years following my first employment in conservation research at the British Museum until a year after I started working for the Royal College of Art.

Figure 1. A D Baynes-Cope, died 2002

I started as a conservation scientist at the British Museum (BM) in April 1974, working with A D Baynes-Cope (BC to his friends) and co-workers (Figure 1). I soon made the acquaintance of many conservators who worked on the BM site. These were not only the BM's own staff but those in the then recently split-off British Library (BL), including binders and conservators of manuscripts, both European and Oriental. I was welcomed in all the conservation areas, making the BM site an excellent place to learn about paper and book conservation. The state of conservation training had not reached the sophisticated heights that we are used to nowadays and some conservators, particularly those from craft backgrounds, were not at home with technical concepts. The only paper conservation scientists in the UK were those at the BM, which made us a magnet for telephone calls from paper conservators and members of the public wanting information.

It is important to be aware of the dearth of printed information about conservation at that time. The only conservation textbook was *The Conservation of Antiquities and Works of Art* by Harold Plenderleith, updated by Tony Werner (Plenderleith & Werner 1971), both of whom were heads of the Research Laboratory at the BM. The Institute of Paper Conservation (IPC) was not yet formed, so there was no *Paper Conservator. Restaurator*, nowadays a prominent journal for paper conservation research articles, did not come out until 1969 and at that time was a slim volume. The fourth triennial meeting of the International Council of Museums Conservation Committee (ICOM–CC) was in 1975 and these are the first proceedings that I am aware of. At that time the graphic documents group was headed by Françoise Flieder. Over the last thirty years, paper conservation scientists have been reluctant to publish books. While we have seen books on the conservation science of a wide variety of materials, it is only recently that the first books on paper conservation science have started to come out.

Nowadays a good quantity of sophisticated research on paper properties is generated by the conservation research community. I particularly remember the high quality of work coming from the Library of Congress Laboratory and its head William K. Wilson. However, in 1974 much of the experimental work on which we based our assumptions about paper came from research in the paper industry in Scandinavia and North America.

At that time, the research done by the W.J. Barrow Research Laboratory in the 1950s and 1960s (it closed in 1977) was the bedrock of the theory of paper deterioration and the majority of paper deterioration was explained by 'acid'. Paradoxically, they also pioneered a laminating process which used cellulose acetate. The subsequent deterioration and release of acetic acid led to the deterioration of laminated paper that was not sufficiently buffered with alkaline material. Having recently completed a PhD on

PVC degradation with a heavy emphasis on free radical reactions, I was only too aware of the lack of emphasis on free radical oxidation reactions, a failure that was gradually remedied internationally by subsequent work. Robert Feller and co-workers at the Mellon Institute were interested in oxidation of museum materials, but they did not work on paper until 1978.

Figure 2. Helen Burgess, died 1999

In the BM's Department of Prints and Drawing's conservation studio, I gained practice in the conservation of the very large Italian print collection, items from which were then routinely bleached, usually with chlorine dioxide in solution, and then deacidified. Bleaching is out of fashion now as curators and the public seem to be able to accept a higher degree of discoloration than they did then and seem content with the results of water washing. However, we now know that there is no water-washing technique that will restore the paper to the colour it probably was when new and there is still a place for bleaching – which may become popular again. During my career, one of my favourite paper conservation scientists was Helen Burgess (Figure 2), who worked at the Canadian Conservation Institute. She published a large amount of work on hydrogen peroxide bleaching just as bleaches were falling out of favour (Burgess 1988). Chlorine dioxide also fell out of favour and I don't think anyone uses it now. A lot of conservators used chloramineT, a powder which when dissolved in water releases hypochlorite ions. In my first years at the BM, I published a paper (Daniels 1976) saying that some papers, particularly those which contained aluminium ions, would retain chloramineT when being washed. Conservators seem to take any criticism of a conservation material very seriously and it was not long before chloramineT entered the word-of-mouth list of substances of which it was whispered 'it's been banned' and joined the ranks of barium hydroxide in methanol (deacidification) and chloroform (for sticking Perspex). 'Banning' of conservation materials has been due sometimes to toxic hazards or a realisation that there were better products – for example, methanol solutions of soluble nylon sometimes used by paper conservators to protect water fugitive inks were banned when it was realised that it became insoluble on ageing. ChloramineT is still used in the private conservation sector.

If bleaching is done at all today, it is often done using light. Sunlight has been used for centuries for bleaching cotton and linen and the principle was adapted by Keiko Keyes (1980) for use by paper conservators. This is seen as a very 'green' process and indeed has a great deal going for it in that the laws of photochemistry predict that only discoloured areas are bleached as these are the only areas that should absorb visible light. The bleaching is performed in alkaline conditions, often magnesium bicarbonate or calcium hydroxide solution.

The development of suction tables and ultrasonic mist methods are extra tools that conservators use when washing paper, and these allegedly obviated the need for some bleaching methods. I have been interested in the basics of paper washing for many years (Daniels & Kosek 2002), and we are gradually learning more about the interaction of water with paper. Indeed, a summary of the most useful information on this will soon be published (Banik & Brückle forthcoming). Hot-water washing is a traditional Chinese practice and Western conservators have occasionally used water up to 100 ˚C to wash iron gall ink documents. Despite comprehensive research (Tse *et al.* 2005) which showed very positive results, the method is shunned by most practising conservators.

The discoloration of paper on ageing is a large area and presents several mechanisms that may take place. Although development of colour is an undesirable consequence of ageing, it has probably rightly been neglected in favour of the study of strength change or chemical change. However, colour is easily and cheaply measured non-destructively. It is a pity that the types of chromophore present in discoloured paper are so poorly characterised. When washing discoloured paper, conservators talk about washing out discoloured size and Maillard products, but the presence of this has never been demonstrated. The mysteries of what happens at the wet–dry boundary to promote the formation of fluorescent and eventually brown compounds are still promising research areas (Pedersoli Junior & Ligterink 2001).

Deacidification is a field that is full of interest for the paper conservation scientist with imagination. In my early days there were three aqueous treatments: calcium hydroxide and bicarbonate and magnesium bicarbonate. On the non-aqueous side, there was barium hydroxide in methanol (invented by BC and thus well known at the British Museum). A later entrant non-aqueous was magnesium ethoxide, which reacts with water on storage but can be stabilised by reacting it with carbon dioxide. Barium hydroxide fell out of use as toxicity issues came into focus owing to a greater emphasis on health and safety. Plenderleith and Werner mention a vapour-phase treatment invented by Langwell and based on cyclohexylamine carbonate, which was sold as an interleaving tissue for insertion in books. This was not very effective and made the paper go yellow. In the last few decades, a wide range of interesting and chemically sophisticated methods have been invented. A paper by Cedzová *et al.* (2006) lists seventy patents for deacidification processes.

Good mass deacidification processes are much in demand as libraries and archives are full of acid paper in need of deacidification and in some cases subsequent strengthening. One of the most exciting was diethyl zinc, a vapour-phase process developed by the Library of Congress using vessels left over from the space programme for the reaction chambers. However, several novel treatments have achieved commercial success, including one with particles of magnesium oxide. I remember that we used to pour scorn on the idea that particles of solid could cause deacidification because there was no mechanism for chemical reaction to take place. Maybe we were reckoning without the mechanism of acid migration.

Whatever the process to be tested, the efficacy could only be tested with accelerated ageing tests. In 1974, 100 ˚C for three days in a dry oven was a popular ageing regime. Nowadays temperatures tend to be lower and may include an elevated relative humidity if the laboratory has access to a climate chamber. There cannot be any doubt that the lower the test temperature, the more the degradation mechanisms during the test reflect those in natural ageing. I recall testing a sample of PVC laminating film which I tested at 100 ˚C. At the end of the test, the PVC had turned purple due to dehydrochlorination and the formation of polyenes. I knew all about that, having just studied PVC degradation for my PhD. This deserved greater study and I performed ageing at several temperatures from 80 to 120 ˚C and plotted an Arrhenius graph to calculate the activation energy. This is a similar methodology to that used by paper conservation scientists studying paper degradation. Extrapolation of the graph revealed that the new tape would turn purple in twenty-two years. I kept the samples, and twenty-nine years later the samples had not changed at all, including some that were exposed to accelerated ageing and already starting to go purple.

Such apparent failures in extrapolation of the Arrhenius equation to predict the future performance of materials make me admire workers who have the foresight, time and patience to perform ageing at low temperatures and for long times. The alternative is to devise a method for studying degradation at ambient temperature. Long-term trials have been set up by scientists and some experiments are underway. One other approach is to look back at the experiments that have been unintentionally set up for us in libraries and museums. The BL's project on looking at Identical Books in different libraries is one example. However, those scientists who work in museums and libraries should realise that whole collections are different experiments of different degrees of interest. If we only could know what the objects were like before they started to age and what their storage history is! Another approach is to monitor ageing at ambient temperature. One example has been my own work on the Russell effect (Daniels 1984), which studied a process that produces a latent photographic image produced (probably) by hydrogen peroxide from objects due to their oxidation. Unfortunately, the process is difficult to quantify and the amount of hydrogen peroxide evolved probably differs from one material to another. The phenomenon of chemiluminescence may be used to monitor the oxidation of paper. Modern equipment has made it possible to detect the very low levels of light produced with reliable and inexpensive equipment. The PAPYLUM project (Strlič et al 2004) had this as its core subject. Again the mechanism that causes chemiluminescence is oxidation.

Methods for measuring acid-catalysed hydrolysis, the other principal mechanism for paper deterioration, are not sensitive enough to follow degradation at room temperature. However, it may be that methods for the detection of evolved volatile organic compounds may be developed to do this. Mass spectrometers are now highly sensitive, reliable and robust instruments and are capable of detecting the low levels of the organic acids which may accelerate the ageing of paper. Buchbauer *et al.* (1995) detected over seventy compounds in the head space above old books. The BM has pioneered the use of accelerated corrosion tests for the effect of materials on metals (Thickett 2004). Lead is extremely sensitive to the effects of organic acids, which are catalysts for the reaction of lead with carbon dioxide and water to form basic lead carbonate. However, I shall not comment further as I do not wish to second guess the conclusions of this meeting.

Several papers have been published on the differences between the ageing of single sheets of paper and stacks of paper (e.g. Carter *et al.* 2000). Invariably, there is more degradation when the paper occurs in bulk, which tempts the interpretation that volatile materials – either oxidants or acids – may be being released from one sheet of the paper and are influencing the adjacent sheet.

Hydrolysis produced non-volatile organic compounds too, and work has been done on simple sugars such as glucose produced during degradation, with very interesting results. One recent experiment has studied the effect of fluctuating relative humidity (RH) on paper with an amazingly high acceleration in degradation rate, as indicated by the release of sugars (Bogaard & Whitmore 2002).

As a scientist who has worked on organic materials in general, I often find that it is a shame that there is not more connection made between research done on cellulosic textiles and plant fibres and paper. The smells in stores of plant material may owe something to other associated materials, but amongst these must be volatile organic compounds from cellulose-based products. Black-dyed New Zealand flax is coloured with a similar dye to that in iron gall ink. An accelerated lead corrosion test on the black-dyed New Zealand flax showed a prodigious outpouring of acetic acid, possibly due to the hydrolysis of acetyl groups in the hemicellulose. Hemicelluloses are also found in paper, but I don't know of any recent work on the acetyl content of papers.

Much paper conservation research involves accelerated ageing, and the paper then has to be tested to see if there is loss of desirable mechanical properties or chemical change. There are a large number of tests to choose from, but many laboratories opt for tensile testing as the machines can also be used to test a wide variety of different materials – for example, stone crushing or the strength of adhesive joints. The folding endurance test or a tensile test after one fold as suggested by Bansa and Hofer (1980) more accurately reflects the usability of the paper. Methods for non-destructive testing of paper are much to be desired and mention must be made of the valuable work done by Derek Priest and colleagues at UMIST's Department of Paper Science in the 1980s to 1990s. Research topics included cockling, non-destructive testing of paper and the effects of alum on paper deterioration. The close liaison between this department and the paper conservation community led to Dr Priest serving a term as chairman of the IPC.

Chemical tests for paper were developed industrially and were available as British Standards or American TAPPI (Technical Association of the Pulp and Paper Industry) standards. Chemical tests can be used to test the relative amounts of α-, β- or γ-cellulose. Feller introduced the useful idea that alkali solubility was related to copper number, which in turn is linked to the extent of oxidation of the paper or pulp. This test was useful as the lignin content of papers often made other tests invalid. Viscosity of cellulose solutions could be used to follow the changes in molecular weight of cellulose. The industry standard tests were those in which cellulose (either paper or textile) was dissolved in cuprammonium hydroxide or a copper ethylenediamine complex. Both these solutions were alkaline enough to cause alkaline degradation of badly degraded cellulose and the solutions had to be kept free of oxygen – no mean task. Helen Burgess introduced to conservation Cadoxen (cadmium ethylenediamine) as a solvent

for of cellulose to conservation. The problem was that, as time went on and health and safety data were getting more reliable, it was realised that Cadoxen was hazardous because of cadmium toxicity. A major advance in determining the molecular weight of cellulose is that simpler and safer solutions can now be made; one popular method is to dissolve cellulose in lithium chloride and N,N-dimethyl acetamide (Strlič *et al.* 2005). Furthermore, the distribution of molecular weights in a single sample can be determined by passing the solution through a gel permeation chromatography apparatus (also known as size exclusion chromatography); the shape of the curve obtained reveals the molecular weight distribution. The calibration of the apparatus is done against a pollulan (maltotriose polymer) solutions of known molecular weight, so there may be some errors introduced because of the dissimilarity of the polymers. However, this is a great leap forward for assessing the degradation of paper.

This is probably a good point to reflect on the advances in computer technology that have taken place over the review period. In 1973–4 the price of the electronic pocket calculator had recently fallen below the $100 mark and the term 'personal computer' was not yet coined. The concept of Fourier transform infra-red spectroscopy had been around for a long time but was awaiting cheap computing technology to enable apparatus to enter the chemical laboratory. The first instruments were built in 1969, but started to appear in conservation laboratories only in about 1981. FTIR microscopes were invented in 1982 but were not in conservation laboratories until several years later. Tensile testing machines became much more useful when attached to a computer. The first one at the BM had an x–y pen plotter and was difficult to set up, having two sensitivity knobs that needed continuous adjustment. Computers enabled the stress–strain curve to be measured and a myriad different parameters calculated, including maximum stress, tensile energy absorption (TEA) and the Young's modulus. When sufficient results were obtained, the statistical treatment to obtain mean and standard deviation was calculated in a trice. However, the movement from analogue to digital displays has meant that scientists have probably lost a feel for errors in experimental measurement.

Finally, I shall mention collaboration between scientists. First, the bad news: the BM was once a fully integrated part of that great national institution called the Civil Service, the civilian counterpart to the armed forces. Different areas of the Civil Service used to cooperate and share knowledge and expertise free of charge. Why not – it was all paid for by the government? As the Civil Service fragmented into smaller partly or fully privatised sections, all this stopped. Similarly, in industry individuals in large multi-national companies became afraid to speak freely about the fields in which they were working in case they were giving information that could be charged for.

The good news is that cooperation between conservation scientists has grown owing to well-funded international interdisciplinary projects. A number of the more recent European projects have been summarised (Havermans 2002). Some of the recent projects are PAPYLUM chemiluminescence for studying deterioration of paper, PARELA laser technology for laser cleaning of paper, MIP research on the effect and occurrence of metals in paper, and deterioration of paper by iron gall ink. Very recently there has been the SurveNIR project that looked at the use of near infra-red spectroscopy for characterising paper. In Canada, the effect of lignin on the permanence of paper has been studied. The American Society for the Testing of Materials (ASTM), with a team of twenty-five researchers from all over the world, studied tests for the accelerated ageing of paper (Havermans 2002).

References

BANIK, G. AND BRÜCKLE (forthcoming), *Water in Paper*, Elsevier

BANSA, H., AND HANS-H. HOFER (1980), Increase of paper permanence by treatment with liquid ammonia or ammonia solutions; part 3, testing of the usability of papers. In G. Petherbridge (ed.), *The Conservation of Library and Archive Materials and the Graphic Arts*. Society of Archivists and Institute of Paper Conservation, 28–33.

BOGAARD, J., AND P.M. WHITMORE (2002), Explorations of the role of relative humidity fluctuations in the deterioration of paper. In V. Daniels, A. Donnithorne and P. Smith (eds.), *Works of Art on Paper, Books, Documents and Photographs*, International Institute of Conservation, London, 11–15.

BUCHBAUER, G., L. JIROVETZ, M. WASICKY AND A. NIKIFOROV (1995), On the odour of old books. *Journal of Pulp and Paper Science*, Vol. 21, No. 11 (November), J398–J400.

BURGESS, H.D. (1988), Practical considerations for conservation bleaching. *Journal of the International Institute of Conservation Canadian Group*, Vol. 3, 11–26.

CARTER, H., P. BEGIN AND D. GRATTAN (2000), Migration of volatile compounds through stacked sheets of paper during accelerated ageing. *Restaurator*, Vol. 21, 77–84.

CEDZOVÁ, M., I. GÁLLOVA AND S. KATUCŠK (2006), Patents for paper deacidification. *Restaurator*, Vol. 27, 35–45

DANIELS, V. (1976), The elimination of bleaching agents from paper. *The Paper Conservator*, Vol. 1, 1–9.

DANIELS, V. (1984), The Russell effect – a review of its possible uses in conservation and the scientific examination of materials. *Studies in Conservation*, Vol. 29, 57–62.

DANIELS, V., AND J. KOSEK (2002), The rate of washing of paper. In V. Daniels, A. Donnithorne and P. Smith (eds.), *Works of Art on Paper Books Documents and Photographs, Techniques and Conservation*. International Institute of Conservation, London, 47–51.

HAVERMANS, J.B.G.A. (2002), The impact of European research strategies relating to paper ageing on preventative conservation strategies. *Restaurator*, Vol. 23, 68–76.

KEYES, K.M. (1980), Alternatives to conventional methods of reducing discoloration in works of art on paper. In G. Petherbridge (ed.), *The Conservation of Library and Archive Materials and the Graphic Arts*. Society of Archivists and Institute of Paper Conservation, 166–170.

PEDERSOLI JUNIOR, J.L., AND F.J. LIGTERINK (2001), Spectroscopic characterization of the fluorescence of paper at the wet–dry boundary. *Restaurator*, Vol. 22, 133–145.

PLENDERLEITH, H.J., AND A.E.A. WERNER (1971), *The Conservation of Antiquities and Works of Art*, Oxford University Press.

STRLIČ, M., J. KOLAR AND B. PIHLAR (2005), Methodology and analytical techniques in paper stability studies. In M. Strlič and J. Kolar (eds.), *Ageing and Stabilisation of Paper, National and University Library, Ljubljana*, 27–48.

TSE, S., H. HENDREY, P. BÉGIN, J. SIROIS AND M. TROJAN-BEDYNSKI (2005), The effect of simmering on the chemical and mechanical properties of paper. *Restaurator*, Vol. 26, 14–35.

THICKETT, D. (2004), *Selection of Materials for the Storage or Display of Museum Objects*. British Museum Occasional Paper 111.

Best practice and standards in environmental preservation for cultural heritage institutions: goals, knowledge, gaps

Fenella G. France, Preservation Scientist, Preservation Research and Testing Division, Library of Congress[1]

With common issues and concerns, a growing convergence of institutions – libraries, archives, museums and historic houses – face the same challenges for cultural heritage preservation. These include storage, display, research and exhibition areas that meet the needs of preservation, while also allowing for the increasing demand for access to original historic materials. The needs, demands and requirements for collections and cultural heritage in general have long been recognised, and it is nothing new for the cultural heritage field to have to deal with funding challenges and the prioritisation of resources in a difficult economic environment. This puts an even greater emphasis and a broader and encompassing focus on the identification of best practices and 'appropriate' standards for environmental preservation. This is of critical importance since the range of environmental parameters has now greatly expanded to include economic, political and climatic challenges, while also encompassing the need to address the digital age and the global explosion of demand for access to knowledge.

In this new climate of change, it is imperative that cultural heritage professionals and practitioners collaborate to share and integrate the knowledge required to underpin environmental guidelines, recommendations and standards that are based upon real material science, rather than on accepted practice, since as organisations are called upon to justify costs and allocation of resources, we must ensure that energy, money, personnel and other resources are being utilised most effectively for the long-term preservation of collections.

Goals

The underlying goal of best practices in environmental preservation is to attain the optimum conditions for the protection of items of cultural heritage. This should be closely aligned with the specific material-based needs of the artefact. Environmental controls for preservation of cultural heritage items are long overdue for revision, since conservation recommendations often impose rigid controls that do not relate to local environmental conditions and are liable to misinterpretation as people fail to relate to a range rather than a specific number and set-point. Nor are they necessarily based upon a true understanding of the underlying needs of various materials in collections. Furthermore, standards should enable cultural heritage professionals to optimise the preservation of our collections, not deter them, while at the same time recognising the need to move from a reliance on accepted or historic practice towards standards that are based upon evidence-based material science needs of collections.

The current economic, political and ecological climate challenges us to address these issues and develop standards that are optimal for the specific artefact and location, and that can be met without greatly expanding the carbon footprint. Closely aligned with this are climate change issues and the sustainability of institutions – including libraries, archives, museums and historic houses. Current economic, political

1 frfr@loc.gov

and climate changes challenge cultural heritage professionals to address the revision of standards in the context of these issues.

There is global move towards reducing energy costs and the carbon footprint of human activities. The preservation of cultural heritage is not exempt from this. Institutions are forced to consider how they can justify costs (e.g. of humidification) as well as to reduce energy costs for controlling the environments that preserve our heritage. The impact of global warming suggests a greater range of variability of external climates – a higher incidence of storms, extreme events and seasonal fluctuations. These factors all point to the importance of control of fluctuations to try to reduce the impact of changes on our cultural heritage, and this has to be achieved within the context of reduced budgets, while also addressing actual material tolerances in terms of upper and lower limits and rates of change.

Cultural heritage institutions of all kinds need to address the common issues of storage, exhibition and access in conjunction with the implementation of standards requirements for environmental control Figure 1. Owing to human comfort factors, the environmental conditions in specific spaces may differ in order to meet the needs of those requiring access to the collection. This often results in variable conditions that can cause damage, as well as tolerance levels that may not be the best for the specific collection.

Figure 1. Converging issues for cultural heritage institutions.

The environment for cultural heritage that needs to be controlled may be defined in terms of a 'macro to micro' perspective, and standards for cultural heritage need to be considered in the context of a spectrum leading from the macro-environment down to the micro-environment Figure 2:

- building (historic architecture or modern)
- room (storage / exhibition / research)
- case (display / storage / long-term visual storage).

Figure 2. Impacts on environmental control: building, room, case.

The building may feature historic architecture or be of more recent construction – modern, or increasingly often, a customised building for the storage needs of cultural heritage materials. Buildings consist of a range of materials with specific properties that may or may not be capable of achieving current environmental standards. There are issues of cost for both the maintenance of the existing structure and the upgrading of the infrastructure and systems. Whether the building can be retrofitted, and the cost of this, often elicits extensive debate when institutions are trying to determine the best option for meeting standards for environmental control. In addition, there are energy costs involved depending on the building type, including those for the installation of humidification and other environmental control systems. These have an impact on the building itself, which is of additional concern when the building is considered to be of cultural significance. The vagaries of mechanical systems in maintaining stable environmental control also need to be considered since mechanical breakdown can create damage to materials. The variation from a tightly controlled temperature and relative humidity (RH) environment to one reflecting the external ambient conditions may be severe, depending on both the seasonal and the geographical location of the collection.

To achieve required set-points and ranges specified in standards, buildings may be customised, zoned or divided into separate components to meet the often conflicting needs of storage, exhibition, research and access, and of collection versus human occupancy requirements. Customised buildings for long-term storage control include the British Library Additional Storage Project (ASP) building at Boston Spa, the Library of Congress (LC) Fort Meade module storage to maintain conditions of reduced temperature and relative humidity (RH), and the Library of Congress National Audio Visual Conservation Centre (NAVCC) building Figure 3.

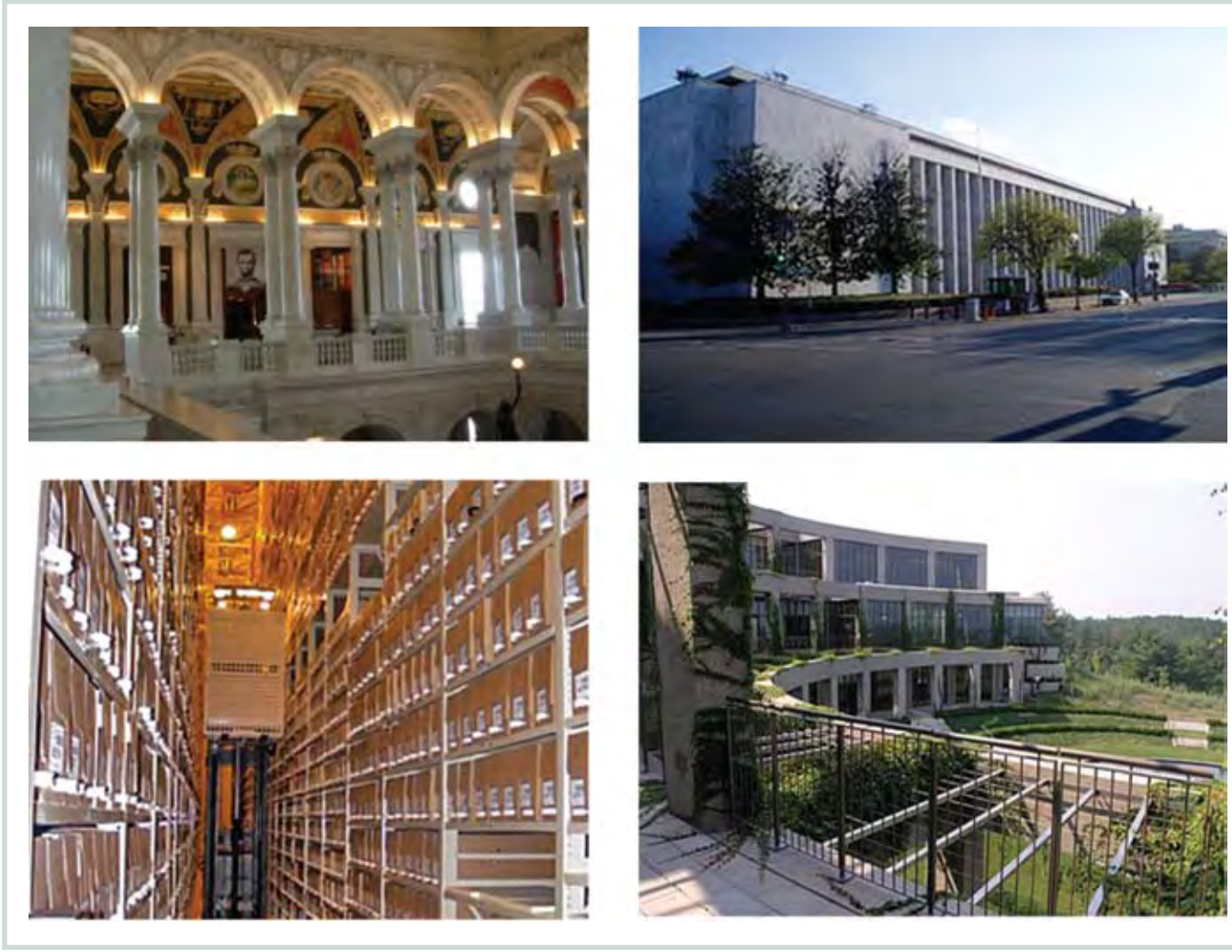


Figure 3. Building structure: historic architecture, modern customised (Library of Congress Fort Meade and NAVCC buildings below).

As noted above, the top level of macro- to micro-environment spectrum is that the building which houses and influences the collection needs to take into account the effect of external factors. These include not only meeting standards, but also the energy costs of controlling the environment, political mandates for reducing energy costs, and climate changes – geographical and local variations that may vary widely within the limits set by standards, as well as global changes in climatic conditions. All these are influenced by economic considerations for individual cultural heritage institutions as they struggle to meet and justify the costs of energy and resources to achieve required environmental standards.

The next level in the macro- to micro-spectrum is the room or defined space within the building. Traditionally, rooms or spaces within cultural heritage buildings are divided on the basis of the required level of access, as well as the specific content of the collection. While the distribution of collections based upon subject may seem logical and simplify cataloguing, whether this adequately addresses the needs of the collection should be considered. A better allocation of resources may be the separation of materials according to their different environmental needs, while also optimising conditions for the control of environmental parameters commensurate with the collection materials' tolerances to minimise damage. Rooms can be modified by adapting the entry (e.g. double sets of doors to reduce fluctuations in RH and temperature) and access to maintain better conditions. Monitoring can establish the level of control within rooms, both with passive and active control, and these levels of control can be related to the material tolerance of collection items.

At the micro-level of control is the exhibit, display or visual (long-term) storage case that is capable of creating and controlling a microclimate for more fragile artefacts and those requiring separate cases. The use of visual storage (encasement for display and storage) helps minimise the potential impact of

handling when an item of significant cultural heritage is moved from storage to display. More importantly, it ensures that the environmental conditions of the local environment remain stable. The challenge in creating efficient visual storage systems is the selection of materials which are capable of achieving the required hermetic seal that can attain a low rate of leakage and tight control of the microclimate. While the initial cost outlay may seem larger than for less controlled spaces, the long-term energy costs of this type of environmental control are greatly reduced since a passive environment is constantly maintained and the stable buffering against external fluctuations minimises the risk of damage for the artefact. In addition, the conditions can be customised to control the specific environmental parameter that is the major cause of deterioration for the material-based needs of the artefact – whether it is RH, temperature, oxygen or pollutants. An example of this is the Waldseemüller 1507 world map, where protection of the map due to the requirement for long-term exhibition necessitated an anoxic and lowered RH encasement. This has been engineered to allow a 150-year seal by using to a truly hermetic seal with lowered energy costs due to passive control of the encasement Figure 4.

Figure 4. Waldseemüller 1507 world map anoxic encasement.

The concept of cases or microclimates can be extended to storage areas where encasing cultural heritage materials helps to buffer the environment to achieve the required material tolerances in relation to external changes, while addressing the need to optimise preservation requirements.

Knowledge

In the 1970s, Garry Thomson's *The Museum Environment* (Thomson 1986) recommended 50 or 55±5% RH and a temperature of 19 or 24 ±1 °C for winter and summer, respectively. This established an overarching requirement for controlling and limiting fluctuating conditions. Continued research in the field further recognised the need for drier and cooler conditions. Standards such as British Standard 5454 state that the temperature and relative humidity should be at fixed points within the range of 13–16 °C and 45–60% respectively, with time for acclimatisation if materials are moved to different conditions. To promote longevity, the LC special storage modules are maintained at a constant 10 °C and 30% RH. There exist a number of standards and guidelines for recommended display and/or storage conditions for archives and libraries; including British Standards (BS), International Organization for Standardization (ISO), National Information Standards Organization (NISO) and

the American National Standards Institute (ANSI). There are also published recommended practices adopted by specific organisations such as the National Archives and Records Administrations (NARA, USA), American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) and the European Committee for Standardization (CEN); and many locally adopted guidelines too. Each organisation setting standards, guidelines and recommendations has different underlying needs and motivations.

These consensus standards and advisory bodies comprise a range of professionals with varying expertise, and their backgrounds mean that there are often fundamental differences in specifications. For example, a preservation scientist will develop recommendations from a materials science background that focus on the structural materials tolerances to specific deterioration factors as well as the rate of change. This emphasis is based on different priorities from those of a mechanical engineer who is basing recommendations on known limits and tolerances of machinery rather than materials.

In terms of the knowledge that currently exists, it is well established in the preservation field that there is a recognised overarching need to control and limit fluctuating conditions for a range of materials. The standards outline the main environmental parameters that require control and attention, such as maintaining temperature at fixed points in a range, controlling levels of visible and ultra-violet light, and pollutants. To promote longevity, customised buildings and specialised storage have evolved (e.g. LC special storage modules maintained at a constant 10 °C and 30% RH), and there are many detailed studies in the literature that investigate and advance the knowledge of changes in materials on the basis of scientific studies. In addition, there have been significant developments in relevant technology and engineering.

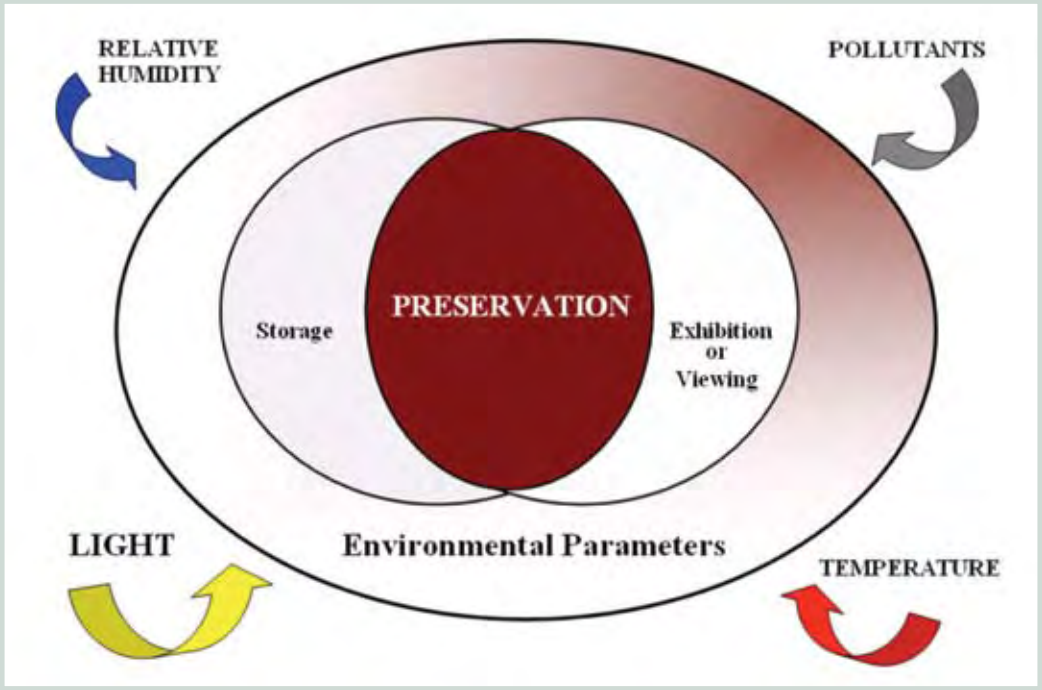


Figure 5. Effect of the environment on preservation.

As illustrated in Figure 5, the deteriorating effects of RH, light, temperature and pollutants – both for storage and exhibition – must be taken into account. There is also recognition that cooler and drier conditions are beneficial, but that the needs of collections and humans often do not coincide, as highlighted in Figure 6. Most institutions raise temperature to address the needs of humans working in or accessing collections and collection areas.

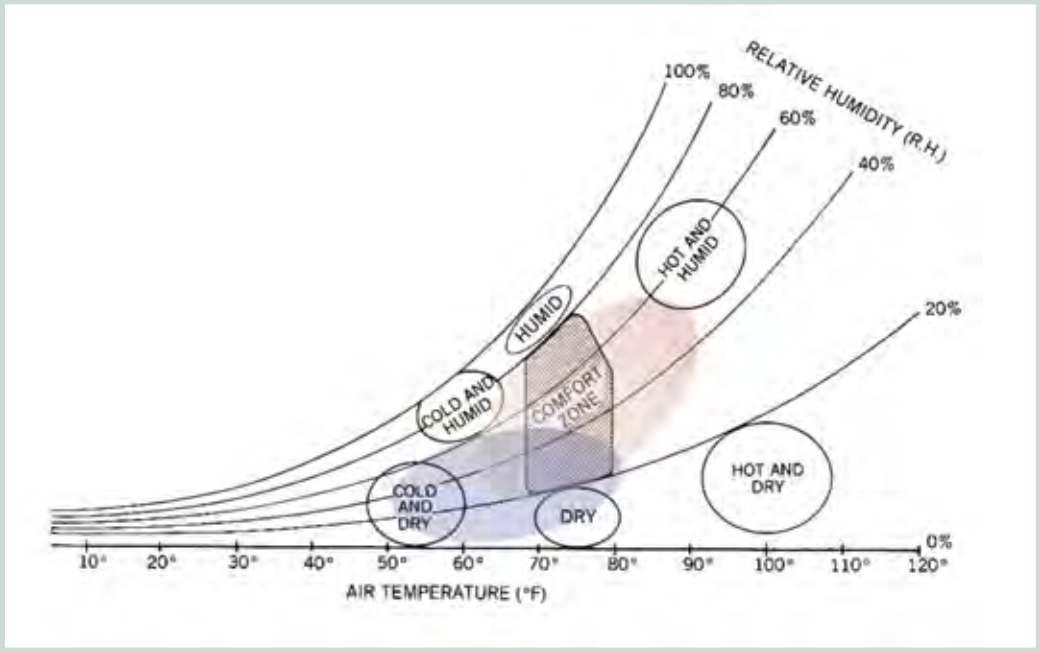


Figure 6. Collection needs and human comfort.

Therefore there is a need both to maintain and to understand better the required environment, while addressing the needs of collections, as opposed to human comfort. The adaptation of current standards and existing knowledge to local environments and circumstances must be managed in order to create stable rather than fluctuating conditions. In order to balance preservation and access, we need to utilise scientific, technology and engineering advances more effectively. There are two areas to be addressed: linking these developments with material properties, and increasing access while preserving the original artefact.

Gaps

The challenge in applying the above standards, guidelines and issues to cultural heritage preservation is that many of the past recommendations and standards adopted for preservation applications were not based upon a true understanding of known changes in cultural heritage artefacts derived from research into cultural materials. Standards should be critically assessed in light of advances in knowledge of changes in cultural materials based on scientific studies. Consideration should be made of specific research into changes in paper and other substrates to define appropriate set-points for specific parameters and safe ranges for specific material requirements. This knowledge needs to be linked with engineering capabilities, building structures (historic or modern), types of collections (including mass treatments) and local climate parameters. Other factors to be considered include the effect and rate of change in the environment, linked with the acclimatisation required for the adaptation of an artefact to changes in environmental parameters while minimising risk of damage.

Gaps in what is known include the effects of fluctuations and cycling for RH responses of specific materials, including the different requirements for materials and material composites for storage, microclimate and display areas. In addition, the buffering necessary in relation to linking these data with building control systems and the levels of control that can be attained and maintained and are required, need to be considered. This should incorporate the impact of local climate adaptations based upon measured material properties and the upper and lower tolerances that can occur without inducing unnecessary damage. The control of levels of light, pollutants and temperature is an area of investigation. Collaborative research efforts between the British Library (BL) and the LC are underway to address some of these issues and their implications for two of the world's largest collections, collectively encompassing over 250 million items. Further research with regard to implementing scenarios for cost-effective solutions and material-specific parameters is also needed.

Further considerations for defining required research include determining the major cause of deterioration for specific materials so that the best utilisation of energy and resources can be made to address the preservation requirements of collection materials. The determination of deterioration from environmental parameters needs to evolve from an understanding of the impact of each damage parameter and how this has an impact on the individual artefact or collection material. Currently we simply control such factors as RH and temperature overall, and a disparity exists in the understanding of what happens at the micro-level in terms of molecular changes that lead to irreversible damage or of acceptable changes that do not adversely affect the mechanical stability of the artefact. By increasing our understanding of the tolerance levels and micro-changes, we can reduce the potential for damage and optimise preservation and long-term accessibility to collections. We must address the extensive materials science needed to define the rate of change, tolerances and range of environmental control for common cultural heritage collection materials Figure 7.

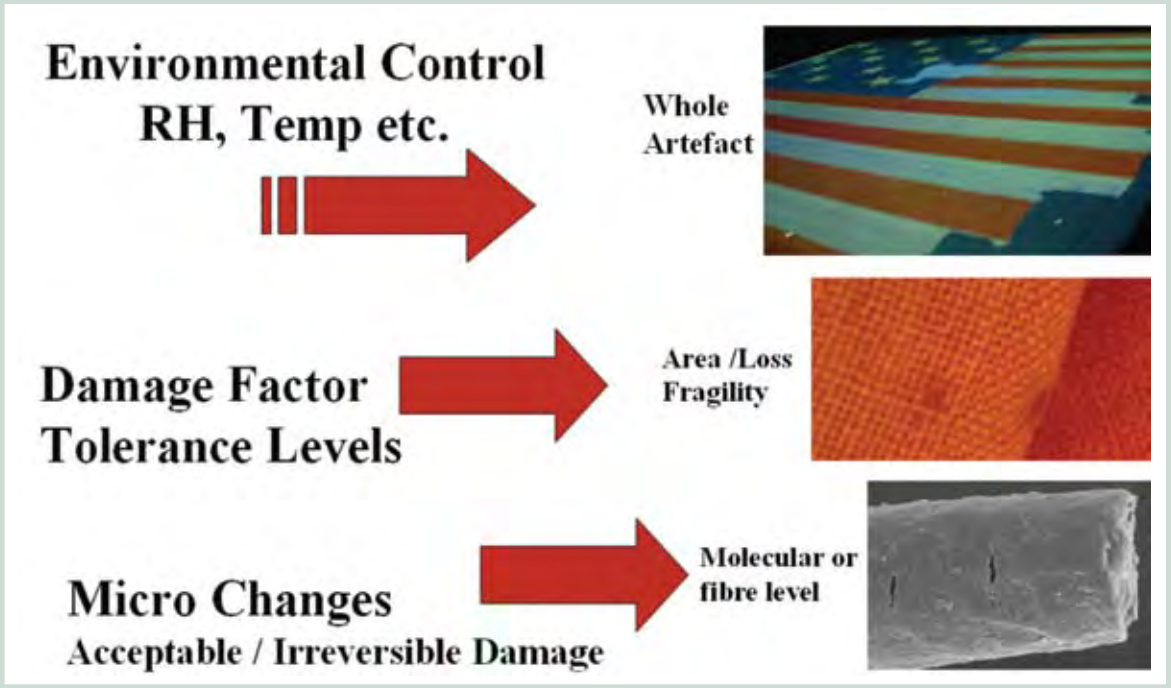


Figure 7. Artefact and material properties: macro to micro.

The global impact of lack of information translates into ongoing discussions about internationally agreed standards for cultural heritage buildings and collections. Until we can incorporate into material science an understanding of the impact of local, regional and global variations, we shall not be able to arrive at balanced and accurate standards and recommendations that we can use in protecting our collections.

One effective way of increasing our global knowledge base for cultural heritage materials and collections is through the development of a preservation reference materials database and repository. The LC is currently undertaking the development of an open-source software architecture/platform through the utilisation of a customised resource description framework (RDF). Open access would allow international access to data with data interoperability. Enhanced access through attention to the use of standardised file formats would ensure that proprietary software and file format structures do not impose barriers for access to the collection. The reference collection would comprise a wide range of reference materials of new, naturally aged and accelerated aged samples, including but not limited to the following:

- Physical samples:
  - characterised reference papers such as the American Society for the Testing of Materials (ASTM) 100-year study
  - naturally aged mass deacidification paper samples

- naturally aged book collections such as the LC Barrow collection (books from 1500 to 1900)
- pigments
- leather samples
- stone samples
- fibre samples

- Digital files associated with both LC collection objects and the above reference samples (hyperspectral images, FTIR, Raman, XRF, SEM, etc.)

- Extant and associated international database collections.

The availability of well-characterised aged samples that are relevant in terms of measured materials properties is important, since they reflect the changes manifested in actual artefacts, as opposed to starting with material analysis of new and accelerated aged samples. This gives a better understanding of the impact of environmental parameters on aged materials that have already undergone various levels of deterioration as well as exposure to treatments and other effects.

More effective utilisation needs to be made of non-destructive techniques that can enhance the preservation of original artefacts with greater access to the digital object – this can often provide the researcher with more information than can normally be accessed visually from the original. The development of hyperspectral imaging – integrated narrow-band spectral imaging – with low heat, low light exposure LED conservation lighting to reveal information from the ultra-violet, visible and infra-red spectral regions, allows for non-destructive characterisation of inks, colorants, substrates and treatments, while also revealing information not apparent in the visible region. Use of digital images and spectral combination of images allows increased access to objects, while enhancing their preservation through reduced handling and exposure to changing environments Figure 8.

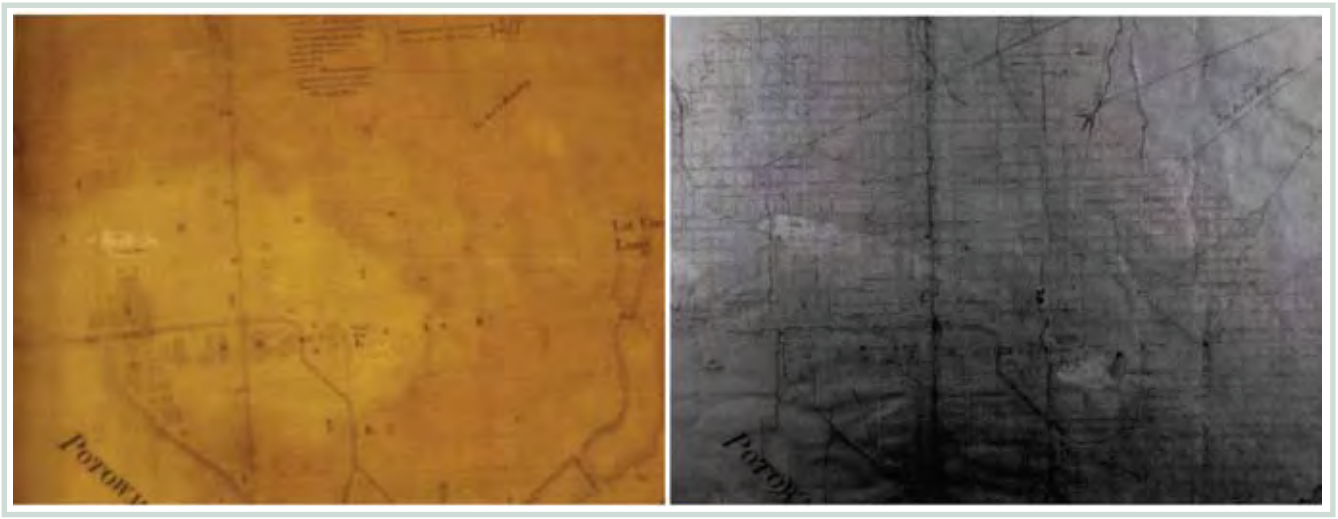


Figure 8. L'Enfant Plan of Washington DC (1791): viewing in visible light and infra-red.

This brief overview demonstrates that there are a number of key issues to be addressed in the review of current standards and future developments. Those include enhanced understanding of material-specific properties and the tolerance and rate changes that should be included in environmental standards for cultural heritage. That needs to be achieved while addressing storage, exhibition and research access requirements and balancing the needs of preservation and access. Monitoring and determining the relevant major deterioration factors that lead to damage should integrate risk factors related to the impact of the local environment – both climatic and cultural. Incorporating energy efficiency in the light of reducing costs and meeting government mandates is another critical component of the current economic and political environment. The overarching need to establish a consensus for international

agreed standards for cultural heritage loans underpins the assessment of risk versus value, and what is acceptable loss that allows access while optimising preservation.

Conclusion

In order to preserve our cultural heritage adequately for future generations is it imperative to establish and apply advanced knowledge of materials science to protect our collections in relation to:

- tolerances and actual damage
- control of deteriorating factors rather than bulk parameter control.

To achieve this we need to focus on international research collaborations that allow the implementation of consensus standards optimised for protection of cultural heritage buildings and collections. This has to be objectively based in economic and political reality – achieving preservation within the current focus on economic, energy and climatic responsibility. This will allow the best allocation of resources and enable us to balance preservation and access, while providing standards that enable international agreement and the best conditions for cultural heritage.

Acknowledgements

Eric Hansen, Chief, Preservation Research and Testing Division, Library of Congress

Velson Horie, Research Project Manager, British Library

Dianne van der Reyden, Director, Preservation Directorate, Library of Congress

Selected related publications

Heating, Ventilation and Air-conditioning Applications, AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC. (ASHRAE) (2003), Chapter 21: Museums, Libraries and Archives.

ANSI/NISO Z39.48-1992 (R2002) ISSN: 1041-5653: Permanence of paper for publications and documents in libraries and archives.

ANSI/NISO Z39.79-2001 ISSN: 1041-5653: Environmental conditions for exhibiting library and archival materials.

BRITISH STANDARD BS5454: Recommendations for the storage and exhibition of archival documents.

CEN STANDARDIZATION COMMITTEE: http://www.cen.eu/cenorm/aboutus/how/index.asp

EMERY, R.D., F.G. FRANCE AND M.B. TOTH (2009 forthcoming), Management of spectral imaging archives for scientific preservation studies. Society for Imaging Science and Technology, Springfield, VA, USA Archiving 2009, May 4 – 7, 2009 pp 137 – 141

FRANCE, F.G. (2005), Andean to banners. *Proceedings of 12th International Wool Research Conference*, Leeds, UK.

FRANCE, F.G. (2007), Managing digital image repositories as key tools in the preservation of cultural objects. *Proceedings of Imaging Science and Technology Archiving Conference*, Arlington, VA.

ISO 11799:2003: Information and documentation – document storage requirements for archive and library materials.

MORRIS, P. (2007), Interpreting published environmental guidelines for preservation in libraries. *Portal: Libraries and the Academy*, Vol. 7, No. 1, 111–122.

MUETHING, G., R. WALLER AND F. GRAHAM (2005), Risk assessment of collections in exhibitions at the Canadian Museum of Nature. *Journal of the American Institute for Conversation,* Vol. 44, No. 3, 233–243.

NARA 1571: Archival Storage Standards.

SHAHANI, C., F. HENGEMIHLE AND N. WEBERG (1989), The effect of variations in relative humidity on the accelerated aging of paper. *Historic Textile and Paper Materials II, American Chemical Society*, 63–79.

THOMSON, G. (1986), *The Museum Environment*, 2nd edition. London.

The Mellon Paper Conservation research project

Velson Horie, Research Project Manager, British Library

Introduction

The Mellon-funded meeting and report *Future Life of Collections* (2004) identified three areas as being of the highest priority for conservation research in this field:

- life-cycle prediction
- storage environment
- assessing damage to materials.

The British Library prepared a collaborative research project to address these issues by the investigation of:

- the condition of identical books in different nationally significant libraries
- the emission of acids by books and paper.

In December 2005, the Andrew W. Mellon Foundation awarded a grant of $695,000 for the development of the conservation research agenda in the UK. The British Library (BL) led the project partnership with the five other legal deposit libraries: Cambridge University Library (CUL), National Library of Scotland (NLS), National Library of Wales (NLW), Oxford University Library (OULS) and Trinity College, Dublin (TCD); and also with The National Archives (TNA) and National Archives of Scotland (NAS). The project was planned to run from January 2006 to May 2009, culminating in an international conference at the British Library.

Project plan and project reality

The project had three overall aims:

- Estimating the effect of the past environment on the condition of library collections in order to predict future likely changes, starting in 2006.
- Measuring the volatile acids produced by ageing books in order to design systems to remove these damaging agents from stores, starting in 2007.
- The project would end with an international conference and a round-table discussion on ways forward.

When the project started, the scope of work and methodologies were reassessed in the light of recent advances in paper science, enabling clarification of the questions to be addressed while keeping within the overall scope. The implementation was split into six strands:

1. Choosing Identical Books: Types of books, choosing books by libraries, long-term use of identified books
2. Measurements by libraries: Methodology, sampling of books
3. Condition assessment: Current state of the art, using external academic researchers as contractors
4. Volatile Organic Compounds (VOCs): Current and novel methodologies, scoping VOCs produced

by books, comparison with condition data, using external academic researchers as contractors

5 Construction of model of paper degradation, correlating environmental with condition data, using external academic researchers as contractors

6 Capacity building: Training conservators (training trainers), building a community of research-aware conservators, building and training external partners.

Category/Date	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	Totals
Art		2	2	3	2	2		2	2		2	17
Atlas	2	1	2	1	2	1	2	2	2		2	17
British Parliamentary Papers	5	6	2	1	2		2	2	2			22
Children's book	1	2	3	2	2	1	1	1	1		1	15
Reference book	1	2	2	2	2	2	2	2	2		2	19
Map	1	1	1	2		1	1	2	2		2	13
Music	2	2	2	2	2	2	2		1	2	2	19
Newspaper	1	1	1	1	1	1	1	1	1		1	10
Novel		1	2	2	2	1	1	2	2		2	15
Academic journal	3	3	3	3	3	3	3	3	3		3	30
Popular journal	3	3	3	3	3	3	3	3	3		3	30
Pulp fiction		2	1	2	1				3		2	11
CURL1905	19	1										20
CURL1915		16										16
CURL1925			19									19
CURL1935				20								20
CURL1945					24							24
CURL1955						22						22
CURL1965							19					19
CURL2005											17	17
Totals	38	43	43	44	46	39	37	20	24	2	39	375

Table 1. Categories of publication chosen to reflect the range of papers used in the 20th century, with the number of items sampled for each decade, and available in every legal deposit library. The CURL categories were randomly chosen monographs from the CURL database, with the search parameters of publication place: London; publication date: **05.

1 Choosing Identical Books

The books to be studied were books published in the UK, 1900–2005. The aim was to investigate the behaviour of the range of types of paper encountered in the collections. As it was not practicable to identify the type of paper in items as part of the choosing processes, the publication category was used as the surrogate measure of paper type, Table 1. The target number of items was 400, derived from the statistical basis of the National Preservation Office's Preservation Assessment Survey (NPO PAS) methodology (Walker 2006). Work on the experimental design for the PaperTreat research project suggests that about 1200 items are needed for a statistically powerful random sample of books.[1] However, after taking advice from epidemiological statisticians, this study deliberately targeted date

1 Dr Jana Kolar (pers. comm.), 2008.

and category series in order to use statistical analysis to identify trends in the data.[2]

The legal deposit libraries are a unique and valuable resource. They hold, indefinitely, published books deposited under the UK copyright acts. Theoretically, therefore, they should receive identical copies of books from UK publishers. Only the BL receives every book by right; the other legal deposit libraries have a right to receive items on request. As a result, the BL's copyright collection has the most complete selection of UK published books, though even this lacks some items. Each library had its own collecting priorities; for example, the academic libraries concentrate efforts of collecting (and cataloguing) on academic publications. In some cases, losses have occurred by flood or fire. We were fortunate that other researchers had carried out investigations into some books published in the UK, particularly a set of British Parliamentary Papers (Sonoda *et al*. 2004), which guided our choice in items to study.

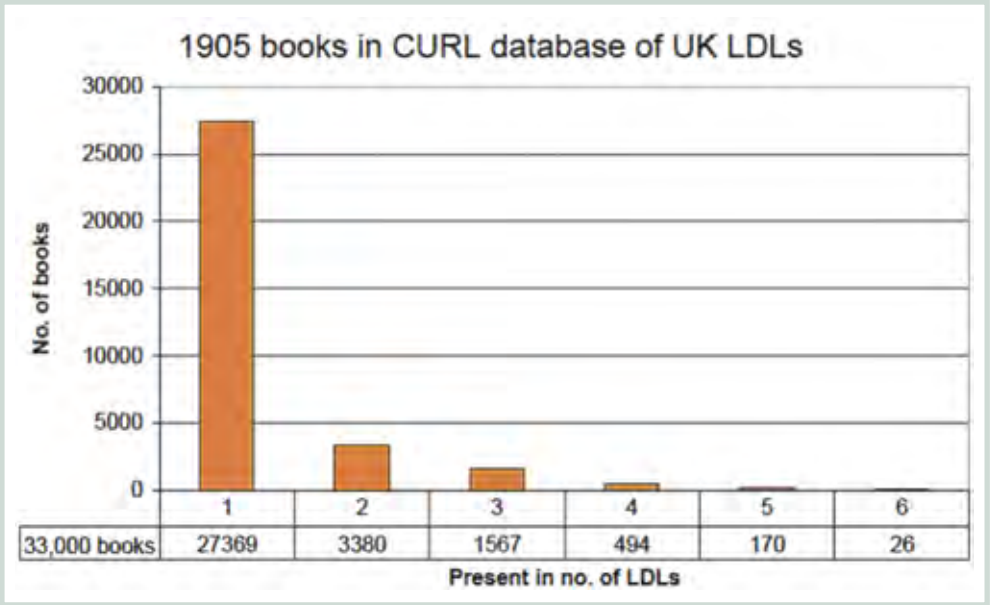


Figure 1. The CURL database was searched for items with publication place: London; publication date: 1905. The resultant output was manually sorted to identify twenty-six items common to all legal deposit libraries. Subsequent sorting of the CURL search outputs for other years was carried out.

The legal deposit libraries have different cataloguing policies and conventions. For instance, the BL has a single catalogue entry for its British Parliamentary Papers, dated 1805, and similarly for other serials. Individual issues are therefore invisible in searches by year. Initial searches of legal deposit library holdings used the computerised union database held on CURL servers.[3] The individual source databases are idiosyncratic. For instance, the NLW is undertaking a major retrospective input of its non-Welsh books on card catalogues onto the computerised database, and had reached 'D' at the time of the Identical Book searches. Almost none of the libraries had externally accessible catalogues of their (large) music and map holdings. The CURL database showed that many of the books are catalogued in only one or two libraries – see Figure 1.

The only practicable way to identify the actual holdings was to enlist the expertise, and time, of specialist curators in each of the libraries. Each library volunteered to create two of the required specialised lists, four items per decade. These were then circulated around the specialists in other libraries, and missing items were deleted and further items added, with the aim of having at least two items per decade in each category, Figure 2. In parallel, the CURL database was searched for items by decade, then manually sorted to identify further items, largely monographs. Some categories proved particularly

2 Dr David Broadhurst (pers. comm.), 2007.
3 We are grateful to Sarah Davanall and colleagues at the Consortium of University and Research Libraries database in Manchester for assistance in interrogating the database in an unconventional manner.

difficult. For instance, a major newspaper has a succession of daily editions and multiple printing sites, making 'identicalness' across libraries unlikely and often impossible to check. Also, copies of newspapers in some libraries had been subjected to conservation treatments.

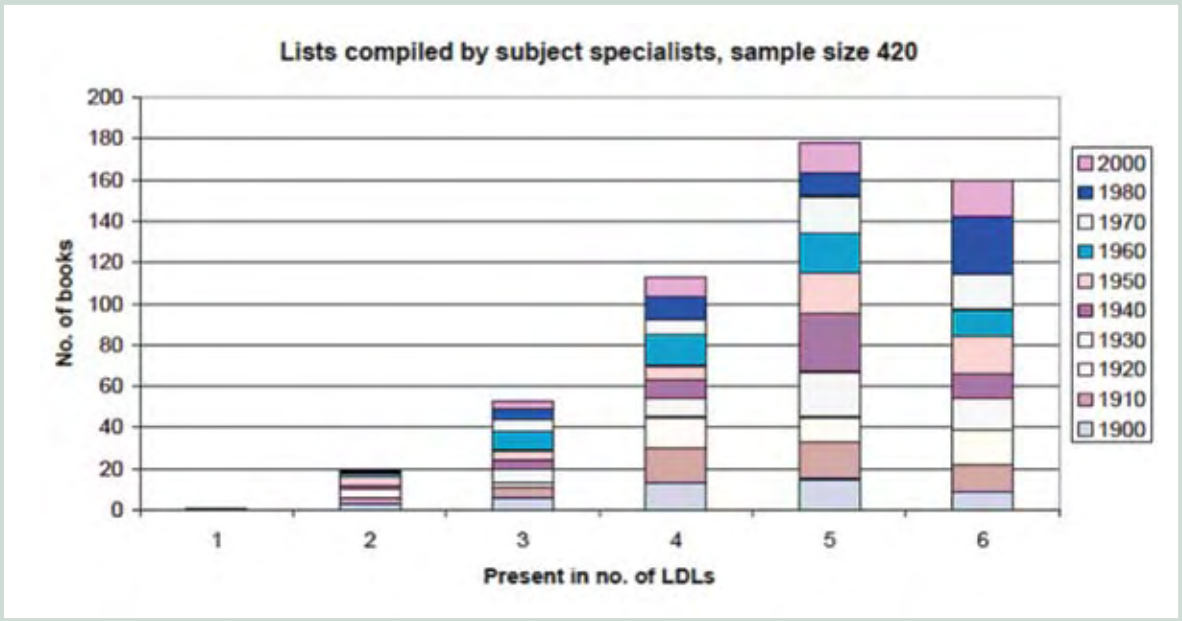


Figure 2. For each publication category, a list was compiled by a subject specialist in one library, four titles per decade. Specialists in the other libraries then checked if these items were present. The graph indicates the success in identifying items.

Much of the initial identification of the books was made using catalogue records. During the next stage of the project, when calling the books to be measured in individual libraries, a number of items was found to be missing or to be variant editions. Although the 'final' list had 376 items, 267 of these were found in all libraries. When a sample of 345 Identical Books at the BL and NLW was examined using the SurveNIR tool, two of the Identical Books pairs were found to be printed on different paper (Lichtblau 2009). Also during the measurement stage, it was discovered that libraries had rebound many items, both serials and monographs. Apart from introducing variability in the materials of binding, rebinding had frequently included trimming of pages. Comparing the Identical Books was made less certain because a legal deposit item cannot be removed from its host library. The Identical Books were compared by photographs of the title pages and the measurement page, and the memory of the travelling researchers.

The choosing process, initially estimated to take five days, lasted seven months, finishing in June 2007.

2 Measurements and sampling by libraries

The primary data gathering was carried out by nominated conservators in the libraries. A large amount of data was gathered in order to characterise the Identical Books.

Identification: The shelf number or other unique identifier of the Identical Book was recorded in order to distinguish between multiple holdings of a title. Photographs were taken of the title page and the measured page, before and after sampling. In retrospect, a photograph of the cover and measurements of the text block would have been useful. The storage location was recorded. Each Identical Book was given a unique identifier – for example, *Whitaker's Almanack* (1903) was BL211, the letters indicating the library and the number being the same across all the libraries. In order to reduce variability between measurements, the following protocols were used.

The same page in each of the Identical Book sets was used, with the page on the right when the volume was opened. A page was chosen to be at least fifteen leaves from the endpapers, to reduce the

effect of contamination from the binding case.[4] For some of the items with few pages such as music or pamphlets, this was not possible.

PAS: Part of the NPO PAS methodology was used to carry out a visual evaluation of individual volumes, condition of the bindings and text block. Categories of damage are physical, biological, chemical and result of repairs, measured on a scale of 0 (minor) to 2 (severe).

Colour: Measurements were made at two locations on one page, using a Konica 2600 reflection spectrophotometer.

Samples: For most of the libraries a sample was taken at two locations on one page, while for the BL and NLW an additional two samples were taken adjacently. For many of the libraries, the taking of samples from collection items was unprecedented. We are grateful for their acceptance of the principle and cooperation in developing the criteria and methods for sampling.

Samples were taken from the page in the gutter, near the top edge and near the middle, designated like BL211-T and BL211-M. The samples were taken with a sharpened hypodermic needle, creating a sample and hole about 1 mm in diameter. The samples were placed in labelled centrifuge sample tubes, Simport T330-7N ClikLok 1.5ml tubes. One (aborted) research line addressed the take-up of sulphur by the paper in the books. A duplicate set of samples for this study was taken from the BL and NLW Identical Books, using the templates.

Templates were constructed for each page to be measured[5]. A sheet of Melinex (transparent polyethylene terephthalate) had holes punched to locate the positions of colour measurement (6 mm diameter) and sampling (3 mm diameter). Initially the sheet was located on the page by folding the sheet so that it fitted snugly over the top and fore-edges. Unfortunately, this system of location failed for books whose edges had been trimmed. The template sheet was modified by marks locating text blocks so that it could be lined up with significant text on the page.

A measurement kit and instructions were constructed to send round the libraries. This included the templates, the Konica, computer, camera, sampling materials and pH measuring equipment.

Conservators were nominated from each library to carry out the measurement. These conservators were trained together (February 2007) in the project procedures and the techniques of measurement. They were also trained to take micro-pH measurements, but this technique proved too delicate and difficult to carry out in multiple sites. There were relatively few changes in the conservators involved during the process.

Each library in turn collected together their Identical Books. When the measurement kit arrived, the procedures were revisited, and lessons learned from previous measurements and any difficulties were sorted out. These interlibrary visits proved very valuable in discovering different curatorial practices and the history of collections that affected their condition.

The main campaign of measurements started in May 2007, finishing in January 2008, with final measurements of missing items in February 2009.

4 We are grateful to Dr Matija Strlič for this advice.
5 Giordana Santoro of the NLS ably prepared the templates and visited each library for their measurement campaign.

3 Condition assessment

Three measures of the state of the paper were evaluated: the fibre make-up of the paper (the furnish), the pH of a micro-sample, and the molecular weight of the sample. The original plan was for trained conservators to carry out the pH measurements on the micro-samples. Unfortunately, this proved impracticable. Most of the samples were assessed for pH, a pair of Identical Book collections were assessed for furnish and, because of cost limitations, only three sets (BL, NLW, TCD) of Identical Book samples were measured for cellulose molecular weight.

Preliminary experiments on the sulfur distribution across a book page indicated that levels fell from a maximum to background levels within 5 mm from the external surface. Unfortunately, trimming of the edges at an unknown date and consequent ambiguity of the sampling position meant that sulfur measurements in the samples could not be correlated with position. These measurements were therefore not carried out.

Towards the end of the measuring period, the SurveNIR measuring tool (Trafela *et al*. 2007; Lichtblau *et al*. 2008) became available. Spectra and derived estimates of furnish, pH, molecular weight and so on were obtained for the BL and NLW Identical Books, with measurement positions at the top right corner and middle of the page.

4 VOCs

The original proposal was to carry out an innovative survey of stores in the institutions, alongside some measurements of the VOC emissions from books. During the recasting of the project, the emphasis was reversed to focus on quantifying VOC emissions from the Identical Books. This work was led by Dr Lorraine Gibson of the University of Strathclyde.

Each institution chose two storage areas and an internal circulation area for study. Strathclyde developed a VOC-collection kit that could be deployed without a specialist analyst being present. The kit comprised diffusion tubes to collect organic acid and aldehydes, and a pumped Tenax tube. Conservators were trained in the techniques, deploying and returning the tubes for analysis.

Previous researchers had shown that the emissions of VOCs from papers and books showed differences. It was postulated that the pattern of VOCs from an item can be correlated with its composition, history, age and condition. If the correlation can be established, measurements of VOCs might be used to establish the condition of an item or collection, using completely non-contact methods, perhaps automatically.

Methods for quantifying VOCs from books were developed, as described more fully in other contributions to these proceedings. Previously used methods had included collecting VOCs on a number of absorbing chemicals, such as solid phase microextraction (SPME) fibres and Tenax tubes, then analysing using gas chromatography-mass spectrometry (GC-MS). All these are selective absorbers and are difficult to tie to absolute concentrations in a book or in air. Methods were sought that could quantify the VOC concentrations in order to establish significant markers for the evaluation of the books.

Using sub-ambient thermal volatalisation analysis (SATVA), all the VOCs present in a book were extracted and partially separated. This is enabling the quantification of the VOCs in total and individually. In parallel, two emerging technologies were explored for potential for assessing items within a few seconds. Field Asymmetric Ion Mobility Spectrometry (FAIMS)[6] is available as a portable device which provides a fingerprint of VOCs. Selected Ion Flow Tube Mass Spectrometry (SIFT-MS)[7] provides absolute concentrations of VOCs in air samples. Both require calibration of the analytes of

6 http://www.owlstonenanotech.com/site.php
7 http://www.syft.com/

interest for book and paper conservation and, as with other techniques, have different strengths and weaknesses. They can quantify analytes that are not accessible with GC-MS.

The VOC work attracted a Natural Environment Research Council grant to access the Molecular Spectroscopy Facility at the Rutherford Appleton Laboratory. The aim was to investigate laser spectroscopy to identify low levels of VOCs. However, preliminary investigations revealed and quantified emissions of carbon monoxide from books, which had not been found previously.

5 Environmental modelling

The environmental modelling was carried out by the Centre for Sustainable Heritage, University College London.

The original proposal was to correlate the current condition of the Identical Books with their environmental history. A preliminary survey of the legal deposit libraries would reveal which had the most useful historical data on the internal and external environments, and which had building changes. Unfortunately, few surviving environmental records were more than fifteen years old and there were few records of building changes that would enable estimations of the resulting changed response to the external environment, which itself was poorly documented for periods more than thirty years ago. Even if it had been possible to reconstruct the environmental history of individual library buildings, the normal, unrecorded, movement of collections around libraries made a coherent environmental history of an individual item impossible to unravel. To provide data for the current project and to start the process of data collection for the future, year-long surveys of RH and temperature distributions were measured in stores and circulation areas in the BL and NLW.

It is known that a major cause of damage to paper is historic exposure to sulfur dioxide. A study of the short-term and year-long concentrations of sulphur dioxide, nitrous oxides and ozone was therefore established in the same stores in the BL and NLW. These libraries had been subject to pollution research as part of the British Leather Manufacturers' Research Association 1930s long-term study into leather book binding deterioration, followed up by the ENVIRONMENT project (Brimblecombe 1996). These results were to be calibrated with the sulphur analyses of items from those areas. Although sulfur analyses of paper from the Identical Books would not have been valid, the pollution measurements provide a valuable additional record of the long-term conditions of storage.

There is considerable interest in the BL's Additional Storage Building at Boston Spa, which uses a low oxygen atmosphere to stop combustion. Accelerated ageing experiments on a variety of papers at low oxygen were carried out to help judgements about the difference in rate of change due to the new storage conditions.

6 Capacity building

A major purpose of the project was to improve the capability for use and understanding of research in the libraries and archive sector. The Mellon project built upon a network of connections established over a number of years. The NPO and related initiatives had brought the libraries and archives together in order to build mechanisms for collection care that are wider than individual institutions or sectors. The BL was a collaborator in the major European Union PaperTreat[8] and SurveNIR[9] research projects. The redesign and implementation of this project benefited considerably from these contacts, their expertise and enthusiastic support. The input of an international expert advisory panel was significant in ensuring that the aims and methods were current and relevant.

8 http://www.infosrvr.nuk.uni-lj.si/jana/papertreat/index.htm
9 http://www.science4heritage.org/survenir/

The BL's research strategy for conservation research is to develop long-term partnerships with high-quality academic (and other) researchers at the forefront of their subjects. The number of such partnerships is limited by the number of initiatives that can be accommodated with the internal priorities of the BL. Two such partnerships (with the University of Strathclyde and University College London) were included in the original proposal. Others were explored during the project, with successful collaboration achieved with three small enterprises: Morana, Owlstone Nanotechnology and Syft Technologies. The resulting technical insights and methods of approaching problems have improved conservation science at the BL and the other partners.

Within the libraries and archives, the scientific input has added considerably to knowledge of collections and their care. The work has highlighted the importance of the material aspects of the collections and demonstrated the methods of analysing these aspects, using both non-destructive and sampling techniques. Staff in all parts of the libraries enthusiastically participated in this project, from bench conservators to curators to facilities managers. There is considerable will to carry scientific collaboration forward.

The extensive, successful collaboration both between the partners and the researchers has attracted attention from the overseas library and archive community, resulting in invitations to speak at conferences at La Bibliothèque nationale de France and the Library of Congress (LC), the latter being followed up with a week at the LC to develop a joint research strategy. Similar invitations have been received from within the UK.

Researchers outside the library field have shown interest. A presentation has been made at a sensors knowledge transfer seminar and a poster will be given at the major International Union of Pure and Applied Chemistry Congress in Glasgow.

The project has demonstrated research excellence with the library and archives and the wider cultural fields, at a time when the relationship between science and heritage in the UK has received considerable attention and funding.

Conclusions

The research results are already proving useful. Methods being developed for VOC analysis are being applied in the development of protective packaging for the BL's Newspaper Project. Knowledge about the (lack of) effect of reduced oxygen on paper deterioration rates is useful in developing alternative strategies to increase the lifetime of collections.

The final conference brought together some of the main players in the field, who put the results and achievements of the project in a wider context. Although the scientific papers arising from the project will take the topic forward considerably, the mass of collected data will be mined for years to come, with new questions and concerns in mind. We shall be making the data available on the BL website.

Acknowledgements

This project would not have been possible without the active involvement of a large number of people. It has truly been a multi-disciplinary, multi-author effort, challenging and immensely rewarding because of the enthusiasm of the participants. Contributors to the initial discussions led to the publication of *Future Life of Collections*.

The partners developed the project proposal and oversaw its fulfilment: Helen Shenton, Barry Knight (BL), Alan Farrant, Brian Jenkins (CUL), Linda Ramsay (NAS), Iwan Meical Jones, Alan Vaughan Hughes (NLW), Rab Jackson (NLS), David Howell (OULS), Suzie Bioletti (TCD), Nancy Bell, Kostas Ntanos (TNA).

Staff in the partners' institutions put in far more time and energy than could be expected: Giordana Santoro, Almut Boehme (NLS), Richard Price, Caroline De Stafani, Stephen Seargeant, John Tuck,

Andra Patterson, John Lowery, Clive Billenness (BL), Deborah Farndell, Jim Bloxham, Andrew Alexander (CUL), Saho Arakawa (NAS), Huw Bonner, Dilwyn Williams, Brian Dafis (NLW), Kristie Short-Taxlor, Sandrine Decoux (OULS), Andrew Megaw, Matt Hatton, Barbara McDonald, Charles Benson (TCD).

Members of the International Advisory Panel were essential in testing and refining our developing ideas: Nels Olson, Eric Hansen (LC), Gerhardt Banik (Staatliche Akademie der Bildenden Künste Stuttgart), John Havermans (TNO, The Netherlands), Henk Porck (National Library of The Netherlands).

The number of scientific collaborators grew during the project, adding to the richness of the input and outputs: Jana Kolar (Morana RTD, Slovenia), Matija Strlič, Nigel Blades, Phil Biddulph, May Cassar (Centre for Sustainable Heritage, UCL), Lorraine Gibson, Jim Lewicki, Claire Robinson, Kirstie Shields (University of Strathclyde), Greg Francis, Stephen Guilfoyle (SYFT UK), Max Allsworth, Chris Prior-Jones, Billy Boyle (Owlstone Nanotechnologies), Andy Smith, Robert McPheat, Pavel Matousek (Rutherford Appleton Laboratory), Dirk Lichtblau (ZFB, Leipizig).

Interns from University of Texas at Austin: René Payne, Rebecca Holte.

We received help and advice from many external sources: Naoko Sonoda (National Museum of Ethnology, Osaka), Chris Pond (House of Commons Library), Alison Walker (NPO), Olga Tolstikova (Library for Foreign Literature, Moscow), H.K. Kaul (Delnet-Developing Library Network, New Delhi), Sarah Davenall (Consortium of University and Research Libraries), Peter Brimblecombe (University of East Anglia), Chris Calnan (National Trust), Christiane Baryla (IFLA-PAC), David Broadhurst, Chris Carr (University of Manchester), Robin Higgons (Sensors and Instrumentation Knowledge Transfer Network), participants in the SurveNIR and PaperTreat projects, Tim Padfield, Philip Eden, Tom French.

References

BRIMBLECOMBE, P. (1996), Pollution studies. In R. Larsen (ed.), *Environment Leather Project: deterioration and conservation of vegetable tanned leather*, Copenhagen, Royal Danish Academy of Fine Arts, 25–31.

LICHTBLAU, D. (2009), The surveys at the National Library of Wales (NLW) and at the British Library (BL). Unpublished report, ZFB.

LICHTBLAU, D., M. STRLIČ *et al.* (2008), Determination of mechanical properties of historical paper based on NIR spectroscopy and chemometrics – a new instrument. *Applied Physics A – Materials Science and Processing*, Vol. 92**,** No. 1, 191–195.

SONODA, N., S. HIDAKA *et al*. (2004), New evaluation methods of paper deterioration: study of British Parliamentary Papers in the collection of National Museum of Ethnology, Japan. In J. Kolar, *Durability of Paper and Writing*, Lubljana, National and University Library, Ljubljana, 92–94.

TRAFELA, T., AND M. STRLIČ *et al*. (2007), Nondestructive analysis and dating of historical paper based on IR spectroscopy and chemometric data evaluation. *Analytical Chemistry*, Vol. 79, No. 16, 6319–6323.

WALKER, A. (2006). *Preservation Assessment Survey for Libraries and Archives*. London, National Preservation Office, British Library.

Are the Identical Books still identical?

Matija Strlič,[1] May Cassar,[1] Jana Kolar,[2] Alan Vaughan Hughes,[3] Velson Horie[4] and Barry Knight[4]

Introduction

The purpose of the Identical Books research strand of the Mellon research project was 1) to investigate the differences between the microclimate and pollution of library environments; 2) to establish whether there are any differences between books in the UK legal deposit libraries; and 3) to carry out a lifetime prediction study. This abstract presents interim findings of points 1) and 2).

Study of microclimates

Microclimates in three repositories – the National Library of Wales (Aberystwyth) (NLW), British Library (St Pancras, London) and the British Library (Colindale, London) – were investigated in detail. Temperature (T) and relative humidity (RH) were logged at ten different locations in each repository for a period of one year during 2008–9. The purpose of this study was to examine whether the differences in microclimates within a repository are comparable to the differences in average microclimates among different repositories.

While the BL (St Pancras) repository is an extremely stable (mechanically climatised) environment, the microenvironments in the BL (Colindale) and the NLW are more variable. The maximum difference between two micro-locations in the same repository was 12 °C. One should note that an increase in the average storage temperature of 4–5 °C results in the doubling of the rate of degradation of acidic paper. Furthermore, the difference in the annual average temperature between NLW and BL (St Pancras) is lower than the maximum difference within the BL (St Pancras) repository. Since the microclimatic history of individual objects is unknown, it is not possible to correlate the condition of individual objects with microclimatic data.

Pollution study

Research into past concentrations of SO_2 showed 5–15x higher concentrations in central London than in Wales. Nowadays, the concentrations of exogenous pollutants (SO_2, NOx, O_3) are similar in Aberystwyth, St Pancras and Colindale.

Studies in 2008–9 demonstrated that the indoor environment in the BL (St Pancras) repository is particularly clean, while the external atmosphere had higher concentrations, particularly of NO_2 (25 ppb) and O_3 (25 ppb) The external concentrations of O_3 in Colindale are slightly higher (~40 ppb), which may be due to lower concentrations of NO_2 (10 ppb), which is an ozone scavenger. This is especially evident in the case of NLW data, where external concentrations of O_3 are the highest (50 ppb), while the concentrations of NO_2 are lower (2.5 ppb) in comparison with the London sites.

1 University College London, Centre for Sustainable Heritage, The Bartlett School of Graduate Studies, Gower Street, London WC1E 6BT
2 Morana RTD, Ivancna Gorica, Slovenia
3 National Library of Wales, Aberystwyth, Ceredigion, Wales SY23 3BU
4 British Library, St Pancras, 96 Euston Road, London NW1 2DB

Indoor concentrations of SO_2 are comparable at all sites (<0.5 ppb), while the indoor concentrations of O_3 are 2–10x higher and the concentrations of NO_2 are 5–10x higher in Colindale and Aberystwyth than at the St Pancras site (0.25 ppb and 0.2 ppb, respectively).

Characterisation of Identical Book collections at the BL and NLW

Using micro-samples extracted from paper with a hollow needle of 0.8 mm diameter, we were able to determine the following properties: pH, molar mass and fibre furnish, both in the centres and margins of identical pages in Identical Books of the two collections, so that an evaluation of differences was possible. Samples, in which pH has been determined, were dried after analysis and then forwarded for determination of molecular weight using size exclusion chromatography.

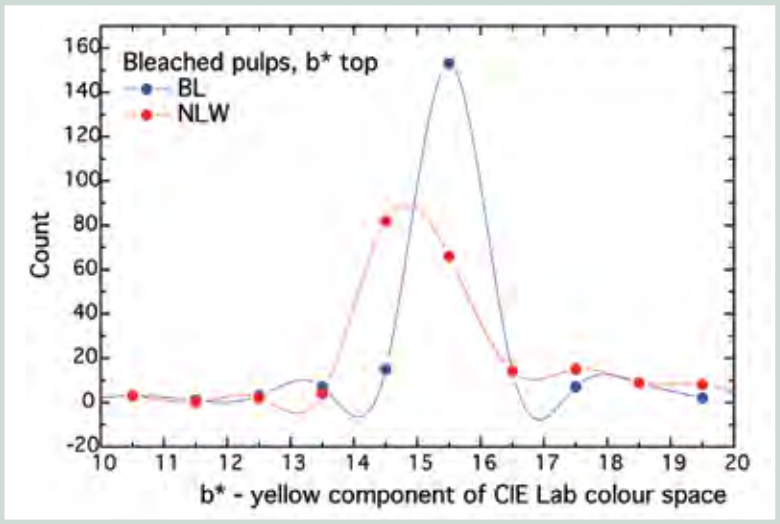


Figure 1. Frequency plot for b* (yellowness) of the margins of the BL and NLW Identical Book collections. The margins in the BL collection are on average more yellow.

Acidification of paper can be the result of paper degradation or absorption of acidic gases from the environment. Yellowing of book margins could be the result of oxidation (e.g. lignin) or extensive hydrolysis due to absorption of, for example, SO_2. Degradation of paper was assessed on the basis of differences in molar mass of cellulose.

Book margins in NLW are in general less degraded and less yellow than in the BL (Figure 1), while pH is on average very similar. Interesting differences in the behaviour of ground wood containing paper and bleached wood pulp containing paper were established. The differences may be the result of different pollution levels, although differences in storage conditions cannot be ruled out, as discussed earlier.

Conclusions

The study of two Identical Book collections and repositories from the BL and the NLW showed the following:

- The microclimatic differences within a repository are comparable to average differences in the indoor climate between the three observed sites: BL (St Pancras), BL (Colindale) and NLW (Aberystwyth).
- The BL collection was exposed to 5–15x higher historical concentrations of SO_2 than the NLW collection .
- Book margins in the NLW are in general less degraded and less yellow than in the BL, while pH is on average very similar. This could be due to different pollution levels, although differences in microclimatic conditions cannot be ruled out.

The well-characterised Identical Book collections represent a significant result of this research, and will undoubtedly prove to be a very important reference sample database for future research.

Identical Books: predicting their future from their current condition

Jana Kolar,[1] Aneta Balažic,[1] Dusan Koleša,[1] Matija Strlič,[2] Velson Horie,[3] Barry Knight,[3] and Alan Vaughan Hughes[4]

Introduction

The purpose of the Identical Books research strand of the Mellon research project was to investigate the differences between the microclimate and pollution of library environments, to establish whether there are any differences between the books in the UK legal deposit libraries, and to carry out a lifetime prediction study. This abstract focuses on the third objective.

Characterisation of identical book collections at the British Library and the National Library of Wales

Using micro-samples extracted from paper with a hollow needle of 0.8 mm diameter, we were able to determine the following properties: pH, molar mass and fibre furnish – both in the centres and margins of identical pages in Identical Books of the two collections – so that an evaluation of differences was possible. Samples, in which pH has been determined, were dried after analyses and then forwarded for determination of molecular weight using size exclusion chromatography of carbanilated cellulose (Kolar et al. 2006a).

Lifetime prediction study

Results of the size exclusion chromatography of carbanilated cellulose and the results of pH were used to predict the remaining useful lifetime of the selected identical books, using the methodology developed within the recently completed PaperTreat project.[5] The following were used to calculate the predicted useful lifetime of paper in identical books:

- average molar mass of carbanilated cellulose correlates with mechanical strength of paper and degree of polymerisation (DP) of cellulose (Kolar et al. 2006a, 2006b)
- rates of degradation of paper at certain pH at ambient conditions (about 21 °C, 50% RH) were used to calculate the remaining useful lifetime of paper – i.e. the time in which the paper within the book will become unusable, if stored from now on in identical ambient conditions
- DP 200 was used as the threshold below which paper was considered unusable – i.e. too fragile to be delivered to general readers.

Using this approach, the rate of loss of the collection of 313 identical books was predicted (Figure 1).

1 Morana RTD, Ivancna Gorica, Slovenia
2 University College London, Centre for Sustainable Heritage, The Bartlett School of Graduate Studies, Gower Street, London, WC1E 6BT
3 British Library, St Pancras, 96 Euston Road, London, NW1 2DB
4 National Library of Wales, Aberystwyth, Ceredigion, Wales, SY23 3BU
5 http://www.infosrvr.nuk.uni-lj.si/jana/papertreat/index.htm

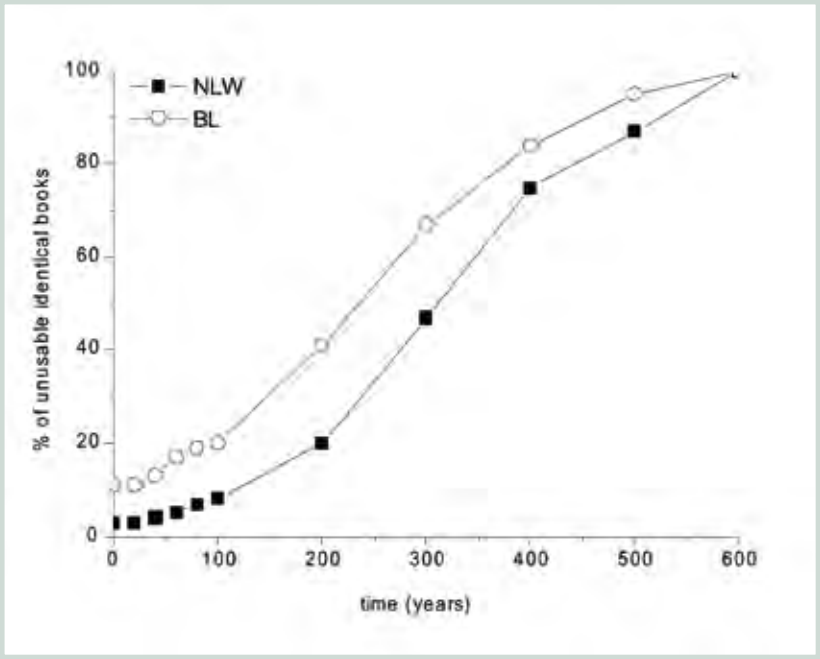


Figure 1. Predicted rate of loss of collection of Identical Books, when stored at similar ambient conditions.

Conclusions

The study of two identical book collections and repositories from the National Library of Wales (NLW) and the British Library (BL) showed the following:

At present, the papers close to the margins in Identical Books from the BL are significantly more degraded (10% unusable) than the papers in identical books at NLW (3% unusable). This corresponds well with colour measurements, where it was demonstrated that the book margins in NLW are in general less yellow than in the BL.

Using the approach described, it can be predicted that the number of unusable identical books in both libraries will double in approximately one hundred years.

References

KOLAR, J., A. BALAŽIC, M. STRLIČ AND D. KOCAR (2006a), Micro-destructive evaluation of paper degradation. Extended Abstracts: Belonging to the Oral and Poster Presentations of the Final MIP Conference [and] 2nd International Iron Gall Ink Meeting, 24–27 January 2006, Newcastle upon Tyne, UK, 87–89.

KOLAR, J., M. STRLIČ, A. BALAŽIC, T. LOJEWSKI, D. KOCAR (2006b), Chromatographic techniques for evaluation of the condition of historical paper. In M. Strlič and W. Buchberger (eds.), 12th International Symposium on Separation Sciences, Lipica, Slovenia, 27–29 September 2006, Book of abstracts. Lipica. Ljubljana, Slovensko kemijsko društvo, 2006, 64–66.

Analysing smelly old books

L.T. Gibson and C. Robertson, Department of Pure and Applied Chemistry, WestCHEM, University of Strathclyde, 295 Cathedral Street, Glasgow, Scotland

Volatile organic compounds survey

A sampling campaign was undertaken in 2008 to assess the typical concentration of indoor air pollutants in eight national libraries and archives across the UK and Ireland. Partners involved in the study included the National Archives of Scotland (NAS), National Library of Scotland (NLS), British Library (BL), Cambridge University Library (CUL), The National Archives (TNA), Trinity College Dublin Library (TCL), National Library of Wales (NLW) and Oxford University Libraries (OUL). At each site, two locations were chosen that contained various objects in the collection (paper, parchment, microfilm, photographic material, etc.) and one location was chosen to act as a sampling blank (a corridor or entrance hallway).

Sampling techniques

A combination of sampling techniques (passive and active) was used to determine the concentration of organic acids, aldehydes and other volatile organic compounds (VOCs) in the indoor air environment. Palmes diffusion tubes used in passive sampling campaigns – for acetic acid (Gibson *et al.* 1997), formic acid (Gibson *et al.* 1997), formaldehyde (Gibson & Brokerhof 2001) and sulfuric acid determination – were deployed for twenty-eight days. Active sampling pumps connected to sampling tubes containing Tenax TA were used to trap a wide range of VOCs in a twenty-four-hour period. Curators were trained to deploy sampling tubes and activate sampling pumps to collect air samples on-site.

During this survey it was observed that the locations differed in the type of building housing the collection and the air-handling systems used, as well as in the items stored within selected sampling sites. Some locations were known to hold approximately a quarter of a million documents consisting of different types of material in addition to paper (microfilm, parchment, photographic material, etc.). Additionally, access within sampling locations was allowed (and necessary) during sampling.

Summary of sampling results

At each location surveyed no measurable concentration of sulphur dioxide (< 1 μgm^{-3}) and low formaldehyde vapour concentration (< 18 μgm^{-3}) were detected regardless of sampling location. In contrast, acetic and formic acid vapours were detected in all locations with, for the most part, higher acetic acid levels in sampled areas containing objects (locations A or B) compared to background locations (location C); see Figure 1.

The active sampling results indicated that a number of analytes were consistently observed in all locations (A–C) at low concentration, regardless of sampling location: heptane, toluene, ethylbenzene, o-xylene, p-xylene, nonane, benzaldehyde and decane. In contrast, other analytes (cyclohexanone, 4-ethyl toluene, 1,3,5-trimethyl benzene, 2-ethyl toluene, 1,2,4-trimethyl benzene, limonene acetophenone and camphor) were observed in some, but not all, locations. It was therefore recognised that determination of actual analyte concentrations was not the best use of the data collected; rather examination of chemical profiles (or chemical signatures) might help to relate combinations of VOC patterns to locations with stored objects. As an example see Figure 3, which illustrates the similarities

of analyte peaks in the chromatograms collected at one site each at the BL and CUL. To examine such correlations in more detail, multivariate analysis was performed on the full data matrix, and Figure 2 illustrates just one example of analyte correlations which indicate an association with storage locations compared to background locations. The sampling locations along the x-axis are in the order of location: A, B, C (coloured red for visual aid). Points that lie close to the zero line have similar (average) concentrations of acetic acid, furfural, heptane and toluene. Points that lie above the zero line have similar correlations to these four analytes: low acetic acid, low furfural, high heptane and high toluene. Notably, most of the points above the line were taken at the background location where no objects had been stored. Points that lie below the zero line are also correlated with high concentrations of acetic acid and furfural, with low concentrations of heptane and toluene; most of these points are associated with locations B or C where objects were stored. Thus both acetic acid and furfural appear to be measured at their highest concentration when objects are stored in the sampling location. Are they therefore indicators of paper degradation? Full analytical results relating analyte correlations to sampling locations will be published in the near future.

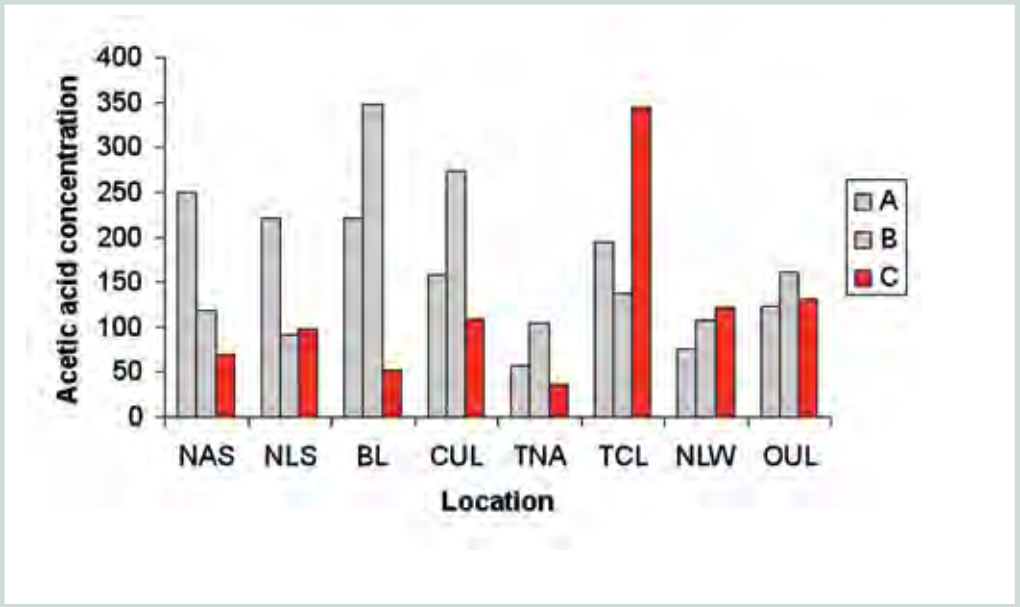


Figure 1. Concentration of acetic acid (μgm^{-3}) measured at various sampling sites.

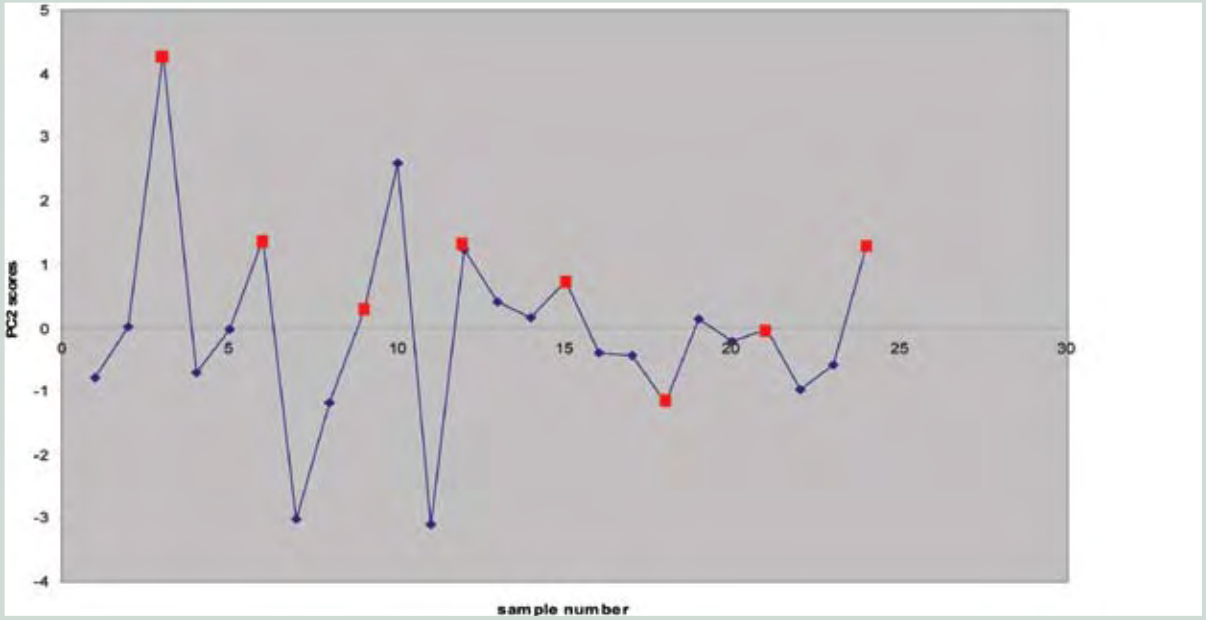


Figure 2. Results of multivariate data analysis illustrating the trend of PC2 with sample number.

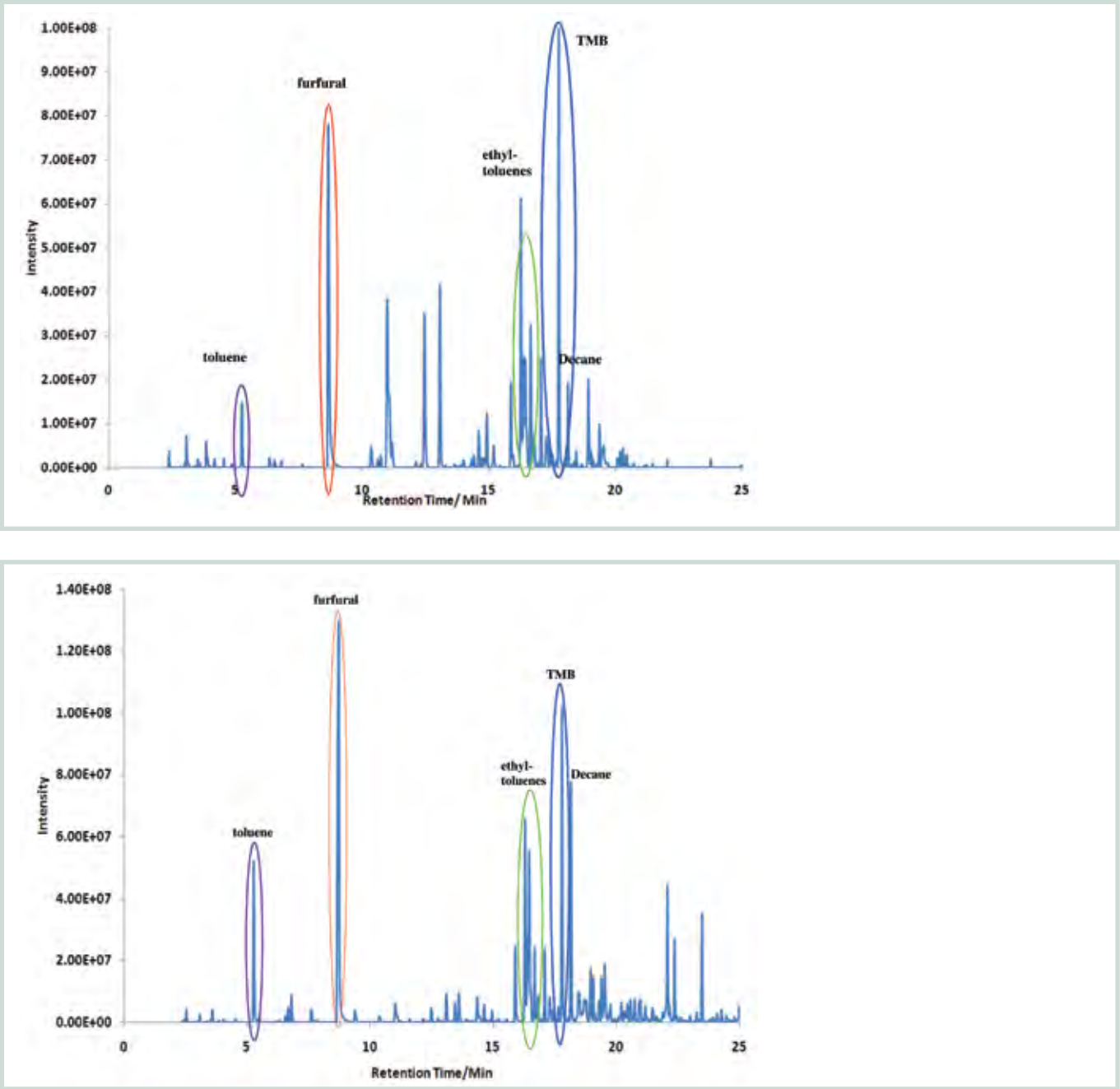


Figure 3. VOC profiles of locations at BL (top profile) and CUL (bottom profile).

References

GIBSON, L.T., AND A. BROKERHOF (2001), A passive tube-type sampler for the determination of formaldehyde vapours in museum enclosures. *Studies in Conservation*, Vol. 46, 289–303.

GIBSON, L.T., B.G. COOKSEY, D. LITTLEJOHN AND N.H. TENNENT (1997), A diffusion tube sampler for the determination of acetic acid and formic acid vapours in ambient air. *Analytica Chimica Acta*, Vol. 341, 11–19.

Scissors, paper, rock – a study of the Old Library at Trinity College, Dublin

Robbie Goodhue[1] and Susie Bioletti[2]

Extended abstract

Keywords: environmental monitoring, dust, VOCs, NO_2, SO_2

This presentation focuses on investigations into dust and volatile organic compound (VOC) levels in the Old Library at Trinity College, Dublin (TCD), which forms part of a multifaceted study of the building, the collections and the environment.

The Library at TCD (now termed the Old Library) was built between 1712 and 1732. It retains its original function as a library and a research space, but also houses office space, an exhibition space and a retail area. In the past fifteen years visitor numbers have increased to over 500,000 per annum, and their impact and that of the modern urban environment are being assessed through the study of the indoor environment. The internal design of the building has over the decades undergone significant changes due to the need for extra storage and in order to provide access to visitors, which may have resulted in the loss of a protective environmental buffer for the collection. In a balance to this, external events such as the end of coal burning by Dublin Town Gas in 1968 and the Air Pollution Act 1987 may have resulted in improvements in the internal air quality.

Since 2004, a significant amount of environmental monitoring has been undertaken under the leadership of the Preservation and Conservation Department, and a summary of some of these data is presented here. Monitoring of environmental parameters is vital in order to establish a baseline that can then be compared with standards available and with studies of other archives. The results will feed into the development of the preservation plan for the building and the collection. Continuous monitoring in the future will allow comparison with baseline conditions as further modifications to the building occur and with future climate change.

The data from the environmental monitoring will be stored within LibViz, a 3-D interactive model of the building that has been designed in a parallel project. The model acts as a numerical and graphical database, allowing the correlation of a wide range of parameters, including temperature, relative humidity (RH), visitor numbers, dust accumulation, VOCs, SO_2, NO_2 and weather conditions in a spatial context and over time.

Dust

In the first study existing macroscopic dust in the Old Library was characterised in terms of its component types by mass. The microscopic dust was investigated with x-ray diffraction and x-ray fluorescence. A visual 'rough and dirty' estimation of dust levels in the Long Room according to a three-point scale (slight, moderate and severe) was conducted in 2007 to record levels and look for a pattern in distribution, and dust from different spaces within the building was analysed to cross-compare content over location.

1 Dr Robbie Goodhue, Department of Geology, Trinity College, Dublin
2 Susie Bioletti, Preservation and Conservation Department, Library, Trinity College, Dublin

In order to determine the current dust accumulation rates and distribution, the loss of gloss technique of Adams (1997) was employed in 2008 on forty sites in the Long Room and five in locked storage areas over a nine-month period. The results show that significantly lower rates of accumulation exist in the locked storage areas which are out of bounds to the visitors. Second, the gap from the head of the book to the overlying shelf is a key factor in the accumulation of dust – those shelves with a gap exceeding 40 mm showed significantly higher levels than those with gaps from 5 to 40 mm.

The distribution of the dust in the Long Room shows influence from the central stairwell used by visitors exiting the room. It is believed that a chimney effect brings particles from the shop and exhibition space, and possibly outside into the Long Room, which deposit close to the stairwell.

SEM ED-XRF examination of the material showed that the particle-size distribution is heavily biased towards the >10µm fraction and that the <2.5µm fraction, which is considered as a health hazard (Tétreault 2003), makes up less than 5% of the dust and is largely inorganic.

Gaseous pollutants

A survey of twenty-nine sites with passive diffusion tubes for SO_2 and NO_2 and Tenax tubes for VOCs was conducted in November 2008, following on from three site measurements by the University of Strathclyde for the British Library / Mellon VOC study. In the more extensive survey, the equipment and analyses were supplied by Gradko International Ltd. Preliminary results from passive sampling of VOCs show the presence of compounds such as furfural, which is diagnostic of acid hydrolysis of cellulosic paper and seen in many other similar collections. Thirty different VOCs were detected in the study, including several alkanes which have not yet been linked to degradation pathways of the collection but show promise as indicators of air exchange. Overall, VOC concentrations are low (average summed values <10ppb) across all sample sites.

Low SO_2 concentrations (<0.4ppb) are seen in all except one site and NO_2 concentrations are typically in the 0.4–0.6 ppb range. Comparisons of observed levels with recommended guidelines (Grzywacz 2006) suggest that, with the exception of NO_2, the levels for the collection are acceptable. The urban location of TCD and its proximity to a >30ppb off-peak NO_2 concentration in the streets that surround campus make obtaining low concentrations unlikely.

Conclusions

The high numbers of visitors to the Old Library and urban situation of TCD create significant environmental pressure on the storage conditions within the 277-year-old building. Preliminary results suggest that dust accumulation is a significant problem, but further study is needed to assess the impact of it and of other environmental conditions on the collection.

References

ADAMS, S.J. (1997), Dust deposition and measurement: a modified approach. *Environmental Technology*, Vol. 18, 345–350.

GRZYWACZ, C.M. (2006), Monitoring for gaseous pollutants in museum environments. Tools for conservation. *The Getty Conservation Institute,* 176.

TÉTREAULT, J. (2003) Airborne pollutants in museums, galleries, and archives: risk assessment, control strategies, and preservation management. *Canadian Conservation Institute,* 168.

Comparative methods of volatile organic compound measurement and characterisation from individual books

Claire Robertson, James P. Lewicki, Kirsty Shields, Gemma Mitchell, Deborah Todd and Lorraine T. Gibson; University of Strathclyde, WestChem, Department of Pure and Applied Chemistry, 295 Cathedral Street, Glasgow

In this work, we report on a comparative study between three differing, minimally invasive analytical methods of sampling volatile organic compounds (VOCs) from a selection of individual books. The techniques are compared in terms of their ability to sample the ppm and ppb levels of a number of organic compounds associated with cellulose degradation. The ultimate goal is the identification of what are considered to be 'key' marker compounds, common to the majority of cellulose-based books and manuscripts.

The sampling techniques that have been employed in this study are solid phase micro-extraction (SPME), silicone elastomer passive VOC uptake and thermal volatilisation analysis (TVA). Both SPME and the silicone uptake sampling methods rely on pre-concentration of VOCs onto an adsorbing substrate (either a SPME fibre or the surface of a silicone strip). Each of these methods subsequently involves thermal desorption of adsorbed VOC species directly into a gas chromatography-mass spectrometry (GC-MS) system where the collected VOCs are identified and the relative quantities of each VOC compared. Passive adsorption-desorption methods such as these (when coupled with GC-MS), offer a truly non-invasive and high sensitivity method of detecting and characterising VOCs from cellulose-based materials. Figures 1 and 2 are examples of SPME and silicone strip elastomer methods employed in the sampling of books.

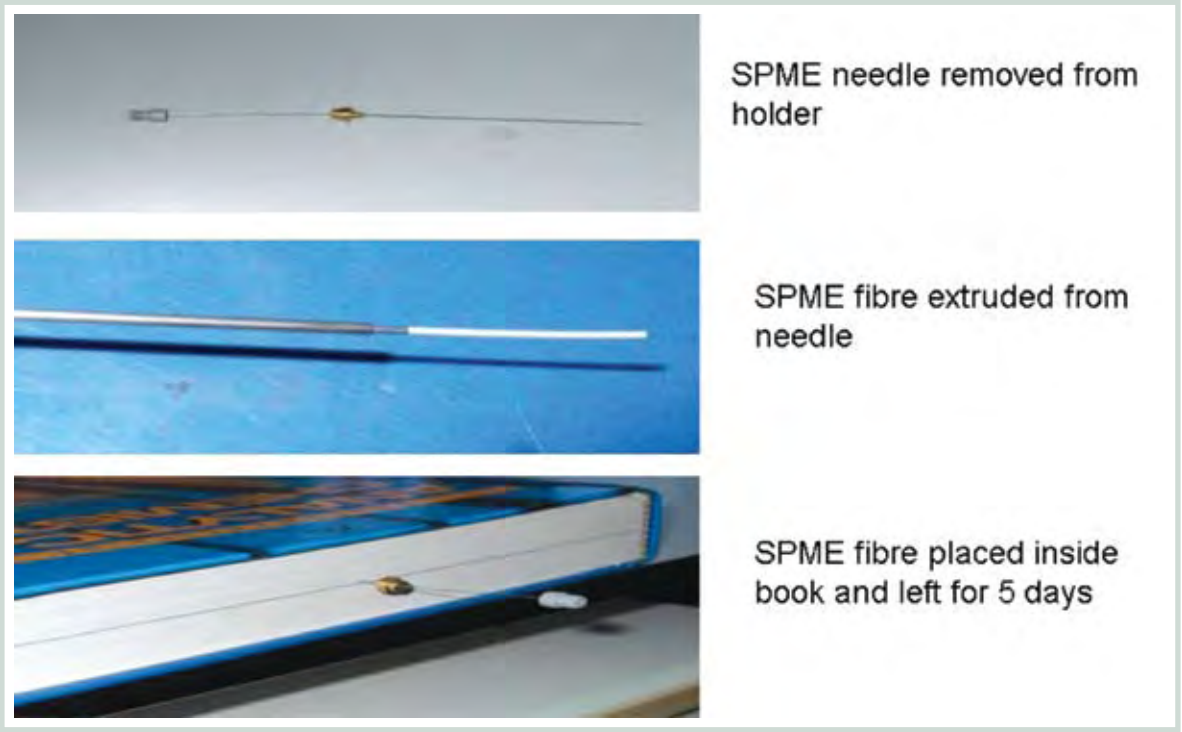


Figure 1. SPME sampling for a model book.

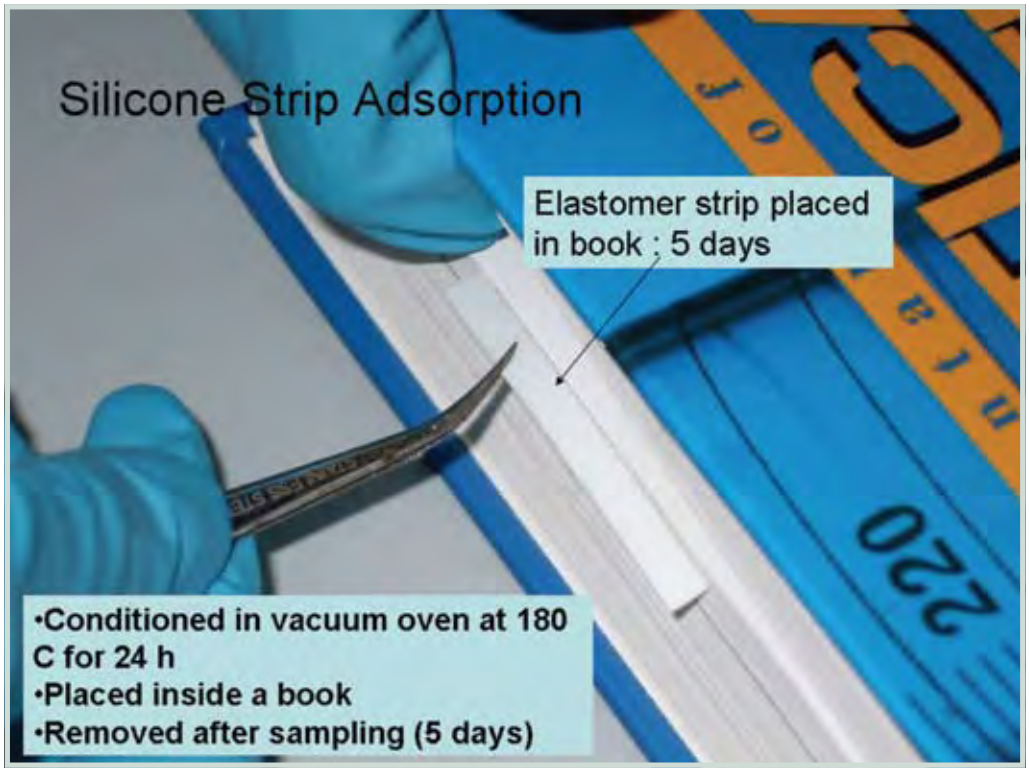


Figure 2. Silicone strip sampling for a model book.

However, passive adsorption methods have a major drawback in terms of their inherent selectivity. Different substrates with differing affinities for chemical species may introduce a bias into any quantitative assay of the 'spectrum' of VOCs from any given sample. Furthermore, GC-MS has a low mass range limit, meaning that compounds typically below 100 amu are not observed.

As such, we have compared these methods with the TVA developmental technique. The TVA method is a high-vacuum sampling technique which employs cryo-trapping to pre-concentrate analyte species. Figures 3 and 4 illustrate some aspects of the principle of the TVA system and the experimental set-up employed to sample from books.

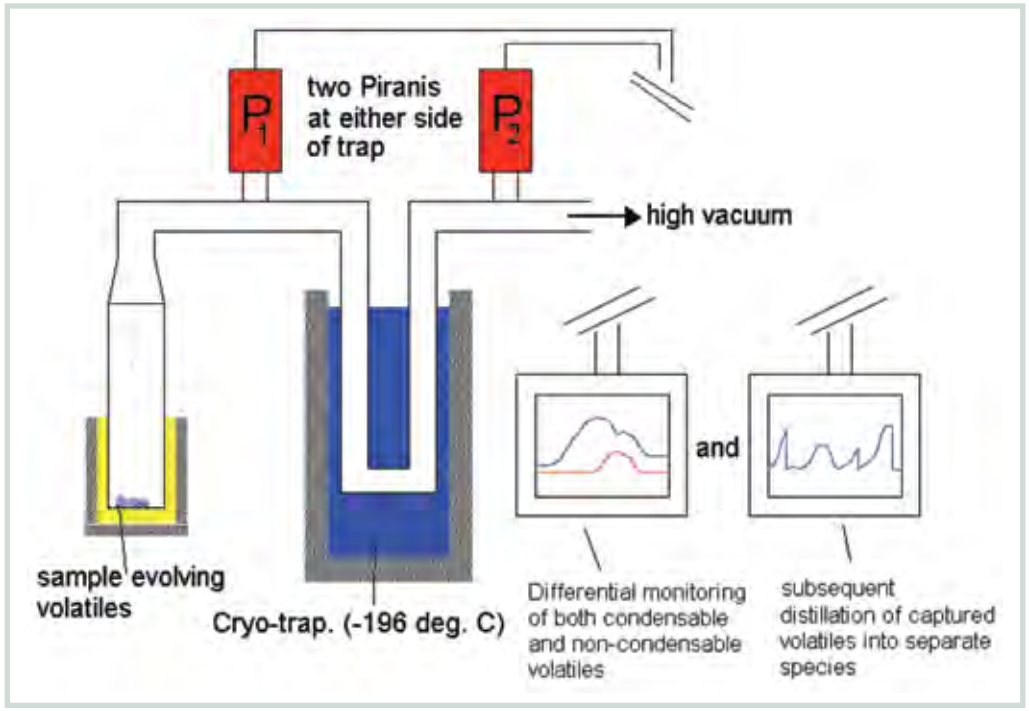


Figure 3. Principle of operation of the TVA technique

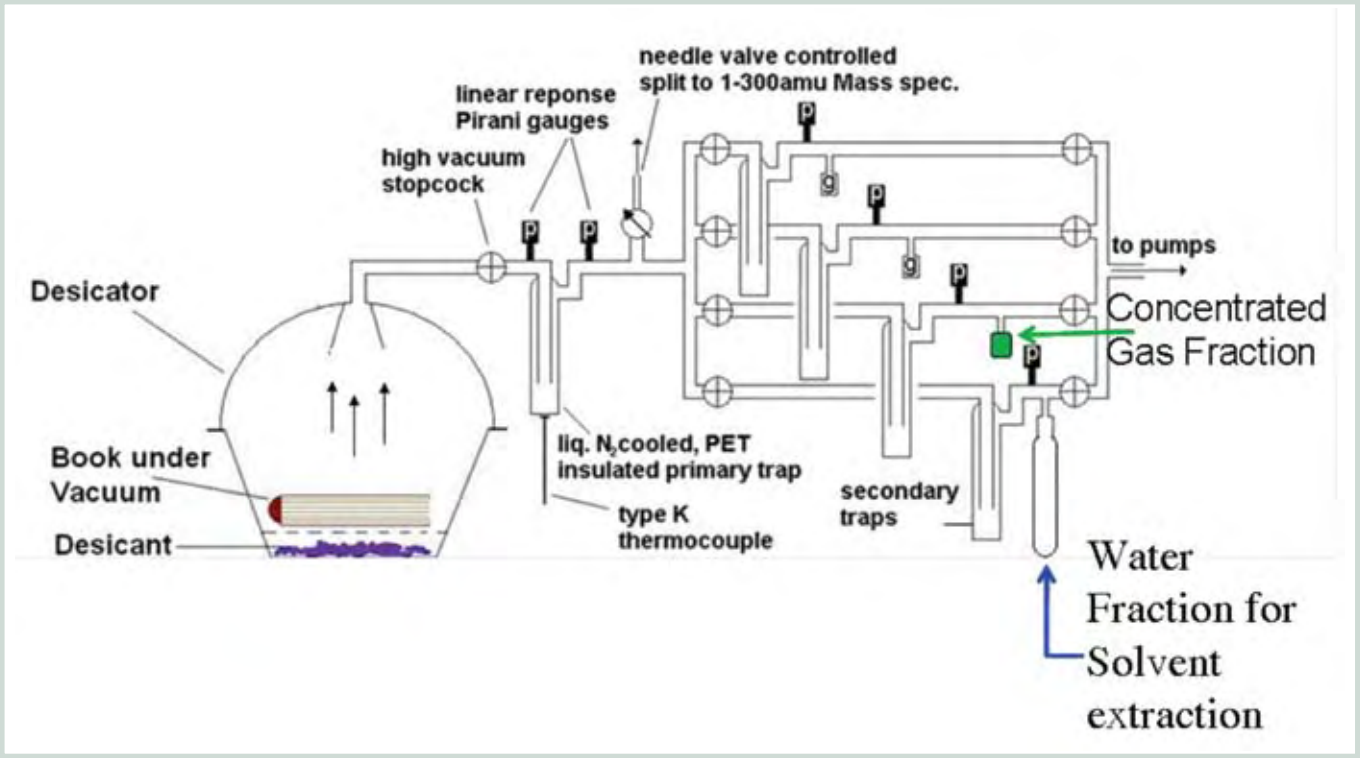


Figure 4. The experimental set-up used to sample books – a volume is placed inside a vacuum chamber and the volatiles evolved are pumped through a cryo-trap at –196 °C. VOCs and water are collected. The condensed material is then distilled into a low boiling gas-phase fraction and a high boiling water fraction.

Whilst this technique is not truly non-destructive, it is inherently non-selective, has no low mass range limitations and offers the possibility of obtaining a full and unbiased assay of the VOCs evolved from a book, manuscript or other sample.

The results of our comparative studies of these methods on sampling from three books of differing source and age have yielded interesting results. Both SPME and silicone strip sampling methods have detected significant levels of the furan family of compounds in differing ratios between books. There is generally good correlation between both techniques. Experimental TVA sampling, although complex in its implementation, has demonstrated the detection of small molecule species such as methanol and carbon monoxide not observed by SPME. TVA also has detected a limited number of furans.

The comparison of these sampling methods has confirmed in many cases what has long been suspected about both the strengths and weaknesses of differing analytical sampling techniques, and provides valuable insight into the development of reliable, repeatable and quantitative methods of VOC sampling from library collections.

Volatile organic compound testing for books, papers and cellulose acetate laminated documents

Stephen C. Hobaica, Supervisory Physical Scientist, Preservation Research and Testing Division, Library of Congress, Washington, DC

This paper discusses planned research on volatile organic compounds (VOCs) off-gassing from paper, cellulose acetate laminated documents and other collection objects at the Library of Congress (LC). The objective of this research is to 1) identify VOCs and their emission rate; 2) identify specific VOC chemical markers that can be related to the physical condition of the paper and other materials in the book; 3) identify the chemical reactions that produce VOC markers; and 4) characterise the material condition of the book's paper and other components (cover, ink, adhesives, etc.). This research begins at a fundamental level by measuring compounds being off-gassed from an internal research collection of generally well-characterised books (Barrow Books Collection) and mass deacidification control books and papers. The Barrow Books Collection has over 900 books from the 15th to 19th centuries and was partially characterised by W.J. Barrow Research Laboratory (W.J. Barrow Research Laboratory 1974) for tear resistance, pH, calcium carbonate content, alum, rosin, ground wood and fibre length. Other books that will be used are the LC mass deacidification programme's quality control books with twenty different types of paper without any printing ink. Other well-characterised collections such as the British Library's (BL) Identical Book Project collection may also be investigated, depending on availability.

The purpose of using these well-characterised books is to allow tracking of VOCs being generated and relate the emissions to the physical condition of the books over an extended period of time. These naturally aged books offer two advantages. First, there is no need for accelerated ageing, which may lead to erroneous predictions on the condition of the books (paper) and their expected lifetime. For example, a recent review indicated that accelerated ageing based on the Arrhenius relationship does not allow for a reliable prediction of paper life expectancy (Calvini & Gorassinin 2006). Second, the information gained by the analysis is available to future investigators since the books will remain part of the collection and, third, this collection can be shared with other investigators (e.g. BL and others) to undertake a range of complementary analyses.

VOCs being off-gassed are an important indicator of the condition of the book and paper. Books and papers are degraded by chemical reactions (hydrolysis and oxidation) and environmental activity (biological reactions, humidity– Shahani *et al*. 1989 – and light). The reactions have been shown to off-gas a variety of compounds including acetic, formic and carboxylic acids, aldehydes, alcohols, aromatic and aliphatic hydrocarbons (Lattuati-Deieux *et al*. 2004; Buchbauer *et al*. 1995). Books are composite structures that absorb and deabsorb VOCs (such as pollutants) and VOCs produced from other objects such as building and collection housing materials. In addition, parts of the book may react differently and absorb VOCs at different rates and quantities. Each book is a composite of unique materials such as the cover (possibly parchment, leather or paper), paper (type and chemical composition), adhesive, inks and colorants, and each of these materials may contribute to VOC emissions.

To separate the paper emissions from these other materials, samples of different materials in the book may be taken and analysed with the Agilent head space unit attached to a GC-MS. Once head space GC-MS analysis is complete, a mass balance of VOCs in the books and air will be calculated to determine the VOCs from the paper. Another goal of the head space analysis is to yield information

on other VOC markers for books (inks, adhesives, leather, vellum, colorants, etc.). Studying the rate at which paper absorbs VOCs (pollutants and from surrounding objects), environmental factors such as light and humidity (Shahani *et al*. 1989) will also assist in understanding their roles in VOC emissions from paper.

Specific VOC markers related to paper and cellulose degradation will be identified. A recent paper identified a relationship between furfural and paper pH. Other VOC emissions such as toluene, vanillin and formaldehyde were thought to have a statistical correlation with the carbonyl group in the cellulose structure (Strlič *et al.* 2008). The rate of off-gassing in LC experiments will be measured and characterised at room (68–72 °F) and higher temperature conditions. LC keeps many collections at room conditions and this information could be used with a future mobile mass spectrometer brought into collection spaces to measure VOCs in the space. Paper composition materials such as fibres, buffers (pH control) and degradation products (condition of the paper) will also be related to VOC emissions. VOC markers for other materials in books (inks, adhesives, leather, vellum, etc.) will be related to their physical condition.

The initial work with the Barrow Books Collection will characterise pH of the paper, tear resistance, ground wood and fold endurance. These tests will be repeated along with molecular weight determination, elemental analysis (Stephens *et al.* 2008), by inductively coupled plasma optical emissions spectrometry (ICP-OES) or environmental scanning electron microscope (ESEM), water content of the paper, fibre analysis, Fourier transform infra-red (FTIR) spectra of the paper and tensile strength testing. Then the VOCs being off-gassed will be measured by multiple mass spectrometric and instrumental methods.

The specific instruments used will include, but not be limited to, the Agilent 5890N gas chromatograph, Jeol GC-mate, direct analysis in real time (DART), Agilent 5975 quadrupole mass spectrometers and Agilent head-space sampling unit. Specific VOC markers will be related to the physical and chemical properties of the paper and cellulose acetate laminates (molecular weight, pH, chemical composition, and water content, fold endurance) for the purpose of determining the condition of the paper and what treatment is needed. The Agilent 5890N/5975 GC-MS can be used for routine testing as well as research. The DART MS can be used to analyse solids (such as paper) directly at room and elevated temperatures and the Jeol GC-Mate can be used not only to measure compounds being off-gassed but also the breakdown these compounds further to characterise their structures (MS-MS) better. Other goals of this research are to develop a reliable and repeatable methodology to study VOC emissions and the condition of the books and will include cellulose acetate laminated documents (Ormsby 2005) and work to study VOC emissions from housing materials.

This research will also serve to build a database of compounds that are present in books and paper with each of the three mass spectrometers. This work is presently underway with the DART MS that characterises volatiles and semi-volatiles from paper directly (without taking an air sample) and will continue with the Jeol GC-Mate mass spectrometer. For example, DART MS work is characterising fifteen papers from the ASTM's 100-year paper ageing research project (ASTM's Paper Aging Research Program 2002). This information will be part of the repository of reference samples to build upon for future work and made available to other VOC investigators. The repository will have specific information related to the GC-MS spectra produced by each instrument for various papers as well as instrumental methods used in the analysis (oven temperatures, MS setting, GC conditions, etc.).

In summary, this research will measure the VOCs from collections of books, paper and cellulose acetate laminates and chemically characterise VOCs. VOC markers for other parts of the book (inks, adhesives, leather and vellum) will also be investigated. Specific chemical markers will be identified and related to cellulose degradation, and the condition of the book and the chemistry of these markers will be studied. This work will begin to build a repository of VOC information with physical samples, spectrometric information and experimental methods.

References

ASTM'S PAPER AGING RESEARCH PROGRAM (2002), Research Report (RR#) D06-1006: ASTM International; West Conshohocken, PA.

BUCHBAUER, G., L. JIROVETZ, M. WASICKY AND A. NIKIFOROV (1995), Research note: on the odor of old books. *Journal of Pulp and Paper Science*, 1995, Vol. 21, No. 11, J398–399.

CALVINI, P., AND A. GORASSININ (2006), On the rate of paper degradation: lessons learned from the past. *Restaurator*, Vol. 27, 275–290.

LATTUATI-DERIEUX, A., S. BONNASSIES-TERMES AND B. LAVEDRINE (2004), *Journal of Chromatography, Part A.*, Vol. 1026, 9–18.

ORMSBY, M. (2005) Analysis of laminated documents using solid-phase microextraction. *Journal of the American Institute of Conservation,* Vol. 44, No. 1, 13–26.

SHAHANI, C., F. HENGEMIHLE AND N. WEBERG (1989), The effect of variations in relative humidity on the accelerated aging of paper. *Historic Textile and Paper Materials II, American Chemical Society*, 63–79.

STEPHENS, C., T. BARRETT, P. WHITMORE, J. WADE, J. MAZUREK AND M. SCHILLING (2008), Composition and condition of naturally aged papers. *Journal of the American Institute for Conservation*, Vol. 47, No. 3, 201–215.

STRLIČ, M., I. CIGIC, J. KOLAR, G. DE BRUIN AND T. STEEMERS (2008), The role of volatile organic compounds in paper degradation, Durability of paper and writing 2. *2nd International Symposium and Workshop, Book of Abstracts*, Ljubljana, Slovenia, 7–9 July, 28–29.

W.J. BARROW RESEARCH LABORATORY (1974), Permanence/Durability of the Book, volume VII, physical and chemical properties of book papers, 1507–1949. W.J. Barrow Research Laboratory, Inc., Richmond, VA.

The Identical Books Project at the National Library of Scotland

Giordana Santoro, Assistant Conservator, National Library of Scotland

Abstract: The Identical Books Project involves the six legal deposit libraries of the United Kingdom and aims to produce a unique record of the condition of a large, broadly based selection of identical items. Identifying the final 380 Identical Books has been a long and challenging process since many differences in the format of the copies were encountered. The National Library of Scotland has been heavily involved at the early stage of the preparation of the Identical Books. Here is described my personal experience of the collection of the 380 Identical Books and the finalisation of a practical method of sampling. The paper also describes the wonderful opportunity I had of assisting with the training in the other institutions and my first-hand experience of the benefits of collaboration with other institutions, both local and national.

The Andrew W. Mellon Foundation awarded a grant in December 2005 to study the deterioration of paper and books in libraries: the Mellon Conservation Research Project (MCRP). It ran from October 2006 to March 2009 and was headed by the British Library (BL). My involvement in the project arose because the National Library of Scotland (NLS) is one of the partners. I have taken part in two sections of the project: the Identical Books Project (IBP) and the Volatile Organic Compounds survey (VOCs), but my work concentrated mostly on the IBP.

The IBP involves the six legal deposit libraries of UK and Ireland and aims to record and compare the condition of a large broadly based selection of 20th-century items. It is based on four different methods of assessment: photographs, preservation assessment survey, colour measurement by Konica CM-2600 and micro-sampling of 1 mm of diameter for pH and molecular weight (MW).

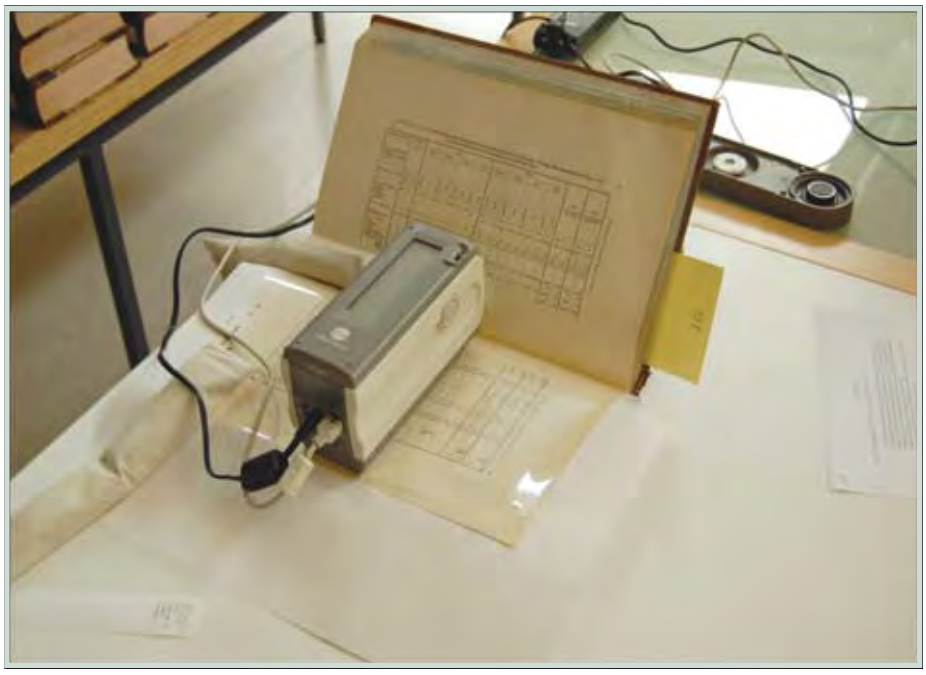
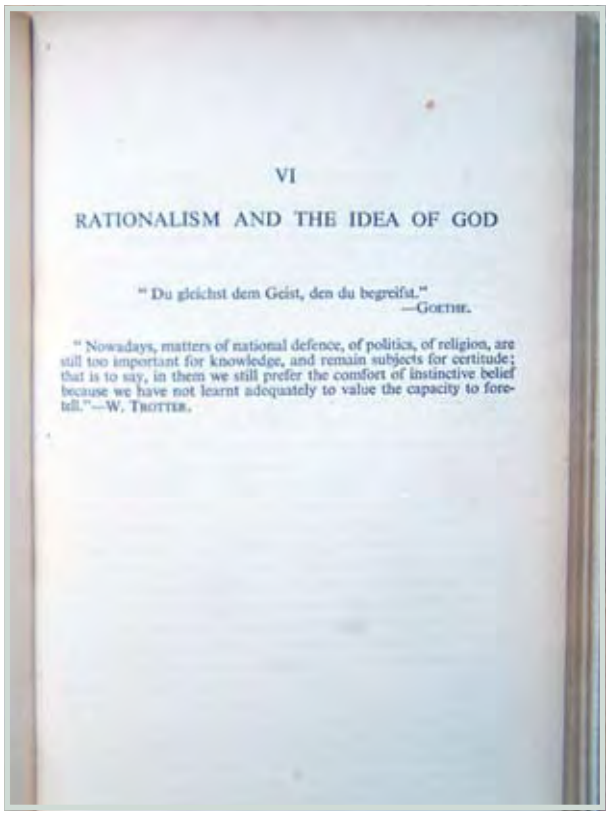


Figure 1. Konica CM-2600.

The NLS was heavily involved at the early stage of the preparation of the Identical Books. The identification of the 380 identical items has been a long and challenging process because many differences in the format of the copies were encountered. The meaning of 'Identical Books' has evolved since I have started their collection at the NLS. I learned that even if the books were produced at the same time and in the same place, they would probably look very different from each other now. First, they have been rebound in many different ways in each library and, second, their conditions may vary depending on how and where they have been stored and how they have been used.

During this period I worked with Velson Horie (Research Project Manager, BL) to develop a simple and inexpensive methodology to ensure that the samples would be taken in identical positions in each collection. A polyester template, marking the page text, indicated the exact position for the samples. I familiarised myself with the equipment and set what I thought was the best procedure for the testing to be able to provide training for the other partners. The NLS collection was tested between December 2007 and January 2008.


VI

RATIONALISM AND THE IDEA OF GOD

"Du gleichst dem Geist, den du begreifst."
—Goethe.

"Nowadays, matters of national defence, of politics, of religion, are still too important for knowledge, and remain subjects for certitude; that is to say, in them we still prefer the comfort of instinctive belief because we have not learnt adequately to value the capacity to foretell."—W. Trotter.

Figure 2. Samples taken with hypodermic needle.

The final result of the IBP is a database that records, for the first time in Europe, a wide range of information on the conditions of the Identical Books in the different libraries. This sets a standard for a monitoring project that will develop in the years to come. Working on the IBP also raised awareness of the new technologies used in conservation research and gave to the conservators the opportunity to learn how to use the new equipment. The secondary, not less important, benefit of the IBP has been the interaction and collaboration developed between the institutions, both local and national. The periodical meetings and the travelling to the various partners gave me the opportunity to meet their conservators, visit their workshops and learn about new conservation projects.

For further information:

www.nls.uk
www.bl.uk
http://www.science4heritage.org/survenir/
www.bl.uk/npo

SurveNIR project – a dedicated instrument for collection surveys

Matija Strlič,[1] Dirk Lichtblau,[2] Jana Kolar,[3] Tanja Trafela,[4] Linda Cséfalvayová,[4] Manfred Anders,[3] Gerrit de Bruin,[5] Barry Knight,[6] Graham Martin,[7] Jonas Palm,[8] Nikša Selmani[9] and Mads Chr. Christensen[10]

Collection surveys are necessary in order to reveal the condition of a collection and the general conservation needs, and in order to plan preservation activities. For such a task, a simple instrument that allows us to survey a collection in a non-destructive, non-invasive and chemical-free manner is necessary.

In the frame of the SurveNIR project, co-funded by the European Commission 6th Framework Programme (2005–8), a consortium of research institutions and end-users built a dedicated NIR spectroscopic instrument which enables the user to determine a variety of chemical and mechanical properties of paper, including naturally aged paper. The approach has been validated in several European collections in the British Library (London), Victoria and Albert Museum (London), National Archives (The Hague), National Archives (Stockholm), National Museum of Denmark (Copenhagen), National and University Library (Ljubljana) and State Archives of Dubrovnik.

Traditionally, the condition of a paper-based object or a whole collection is assessed visually, and simple physical and chemical tests are performed, such as the folding test (Buchanan & Coleman 1987), or determination of pH of paper using pH-indicator pens. The folding test is performed in such a way that a paper corner is actually torn away; the pens leave some of the dye used as a pH indicator on the object. Neither of the two tests can be described as non- or micro-destructive. Even determination of paper pH using flat surface electrode, which is probably the methodology most often used in paper conservation workshops, is destructive as an area of paper has to be wetted in order that the measurement can take place at all. In addition, traditional surveying methods are also highly subjective (Taylor & Stevenson 1999).

Based on the chemical and spectroscopic analysis of more than 1500 historical samples from AD 1650 onwards, we developed a non-destructive method which enables us to characterise historical paper by gelatine content, mechanical properties, lignin content, pH, degree of polymerisation of cellulose and other properties (Trafela *et al*. 2007; Lichtblau *et al*. 2008). A lightweight and portable instrument has been developed and designed in cooperation with conservators and curators (Figure 1; Lichtblau *et al*. 2008). The approach provides museums, libraries and archives with a non-destructive chemical-free low-cost surveying tool that provides more in-depth information than the traditional methods and is at the same time also user friendly and does not require extensive technical knowledge by the surveyor.[11]

1 University College London, Centre for Sustainable Heritage, The Bartlett School of Graduate Studies, Gower Street (Torrington Place site), London, WC1E 6BT; m.strlic@ucl.ac.uk
2 Zentrum für Bucherhaltung GmbH, Mommsenstraße 7, 04329 Leipzig, Germany
3 National and University Library, Turjaška 1, 1000 Ljubljana, Slovenia
4 University of Ljubljana, Faculty of Chemistry and Chemical Technology, Aškerčeva 5, 1000 Ljubljana, Slovenia
5 Het Nationaal Archief, Prins Willem Alexanderhof 20, The Hague, The Netherlands
6 British Library, St Pancras, 96 Euston Road, London, NW1 2DB
7 Victoria and Albert Museum, South Kensington, London, SW7 2RL
8 Riksarkivet, PO Box 12541, S-102 29 Stockholm, Sweden
9 State Archives of Dubrovnik, Sv. Dominika 1, 20000 Dubrovnik, Croatia
10 National Museum of Denmark, Brede, Postboks 260, 2800 Kgs. Lyngby, Denmark
11 SurveNIR webpage, http://www.science4heritage.org/survenir/

Figure 1. The SurveNIR instrument for non-destructive evaluation of paper chemical and mechanical properties for collection surveying, based on chemometric evaluation of NIR spectra.

Additionally, software has been developed which allows the surveyor to work in three different modes:

- Single item assessment: for condition assessment of an individual item, where chemical and physical data are needed for several locations on the same object.
- Random collection survey: for surveys of large collections, where a subset of a collection is first pre-selected and, on the basis of condition assessment of the subset, the condition of the whole collection is deduced (with a pre-calculated confidence interval and a level of significance).
- Total collection survey: for smaller collections, where all objects in a collection can be surveyed.

The software provides methods for the assessment of chemical and physical properties of paper for single sheets (graphical or archival documents) as well as for books. In addition to providing the data on the paper, the software also enables the user to build a survey questionnaire based on a set of descriptive criteria, which can be freely defined – for example, binding condition, evidence of mechanical damage – however, these need to be evaluated visually.

Acknowledgement

The authors gratefully acknowledge the support of the European Community, 6th Framework Energy, Environment and Sustainable Development Programme, contract no. SSPI-006594 (SurveNIR).

References

BUCHANAN, S., AND S. COLEMAN (1987), Deterioration survey on the Stanford University Libraries Green Library stack collection. *College and Research Libraries*, Vol. 48, 102–147.

LICHTBLAU, D., M. STRLIČ, T. TRAFELA, J. KOLAR AND M. ANDERS (2008), Determination of mechanical properties of historical paper based on NIR spectroscopy and chemometrics – a new instrument. *Applied Physics A*, Vol. 92, 191–195.

TAYLOR, J., AND S. STEVENSON (1999), Investigating subjectivity within collection condition surveys, *Museum Management and Curatorship*, Vol. 18, 19–42.

TRAFELA, T., M. STRLI00, J. KOLAR, D.A. LICHTBLAU, M. ANDERS, D. PUCKO MENCIGAR AND B. PIHLAR (2007), Nondestructive analysis and dating of historical paper based on IR spectroscopy and chemometric data evaluation. *Analytical Chemisty*, Vol. 79, 6319–6363.

Paper 18

SurveNIR – Non-destructive Surveying of Paper Collections

Dirk Lichtblau, Leiter Forschung & Entwicklung, Zentrum für Bucherhaltung, Leipzig, Germany

Introduction

For almost two millennia, paper has served as the most easily accessible and readable medium to communicate ideas. Countless works of art, manuscripts and books bear witness to the development of humanity. We are responsible for preserving our cultural heritage in good condition. Fulfilling the long-term care of the collection, efficiently with relatively limited resources, requires a robust decision-making process based on a large amount of reliable data.

The conservator needs data in order to take informed decisions on whether and how to treat an object and whether an object can be displayed. A collection manager needs to know what proportion of a collection is likely to degrade faster and what proportion of a collection is inaccessible to the general public due to low mechanical stability of paper. And the funding bodies need authoritative forecasts to plan budgets. In summary, it is important to know the overall situation as well as the particular state of a single object. In a collection of several million items, how can this information be collected and how reliable are the data?

Paper was made over the centuries from a wide variety of different sources – for example, rags, straw, cotton, pulp, ground wood and bleached cellulose. For a long time the papers were made by hand and, even in this industrial age, each producer has its own secrets. The technology of paper production has constantly changed. For example, surface sizing began by using gelatine, later changed to rosin/alum, and two decades ago involved synthetic sizing or even no sizing. Hundreds of different papers are produced for different purposes. Even if the paper was produced with the same specification, there would still be variation in starting materials and process.

Inhomogeneous composition, a consequence of using natural materials with natural ageing processes in different storage and environmental conditions, leads to a different behaviour over time. The intensity of use will also influence the condition. Overall, the characterisation of paper in archives and libraries presents an enormous challenge.

Until recently, methods of analysing the condition of paper have been destructive, or at least micro-destructive, needing technical knowledge and equipment and a laborious sample preparation. It is often time consuming. The costs of analysing one item are high and material from the items will be destroyed. As a result, instead of using reliable but expensive methods, archives and libraries have used a limited number of simple techniques to assess the condition of their collections.

Visual assessment can be used to describe the appearance. Commonly one looks for yellowing, but how can be the yellowness be defined if the paper itself is coloured (e.g. drawings)? Are human eyes objective observers under different light sources, able to make an assessment of condition based on the colour of paper? At least the method is non-destructive.

The acidity of paper can be assessed using pH electrodes or acid-base colour indicators. This, together with the date of publication, gives an indication of the paper state. However, a decision about the urgency for deacidification can not be made on the basis of the pH measurement alone. Unfortunately, these techniques result in water stains or coloured marks on the items.

It is important to gain information about the mechanical properties of the paper. The low-technology, simple method is still the double fold. Repeatedly folding a corner of a page until it breaks off and counting the number of folds is highly destructive and doesn't correspond to modern standards in conservation. This technique is not suitable for valuable objects. In the assessment of cultural heritage objects, destructive analysis is rarely acceptable.

Development of non-destructive methods

In contrast to traditional methods, spectroscopic methods can be reagent-free, fast and non-destructive. The SurveNIR team chose to combine near infra-red spectrometry (NIR) with chemometrics (advanced statistical data analysis) to obtain a powerful multi-analytical tool.[1,2]

The expectations for such a tool are enormous. The user wants information about the physical condition of the paper as well as decisions about the accessibility of the item. Short-term preservation needs should be deduced and the tool should deliver reliable data to set up long-term preservation strategies. Finally, evidence for budget plans and funding is required.

In preliminary studies, NIR was chosen as the most promising spectroscopic method (Lichtblau 2004; Lichtblau & Anders 2004). NIR is an objective method which delivers reproducible results. NIR does not need a sample pre-treatment, can work with solid materials like paper, can be extremely fast, and is now available in portable instruments. It is totally non-destructive.

The absorption bands in NIR spectra are broader and have a lower intensity than longer wave-length infra-red spectra. The molecular absorption in NIR spectra interfere with each other. A simple mapping of discrete peaks in NIR to molecular vibrations is not usually possible for paper. Since an NIR band contains a lot of overlapping information, mathematical and statistical methods are used to extract the required information. Multivariate analysis by modern computers can extract information from NIR spectra with chemometrical models in a second.

Calibrating the spectra

The question to be solved was: Can information about paper condition be deduced from NIR spectra of paper?

To answer the question, a large collection of almost 1400 historical paper samples was well characterised. Up to fifteen properties per sample were determined: fibre furnish, acidity (pH), degree of polymerisation, cellulose molecular weight, tensile strength and tensile strength after folding, lignin content, gelatine content, rosin content, aluminium content, reducing carbonyl group content, ash content, presence of optical brighteners and grammage. From all these samples, more then 120,000 NIR spectra were taken and then correlated with the reference data to obtain chemometric models, see Figure 1 (Lichtblau 2004; Lichtblau & Anders 2004).

1 Near Infrared Spectroscopy Tool for Collection Surveying (EC 6th framework program SSPI-006594).
2 SurveNIR webpage, http://www.science4heritage.org/survenir/

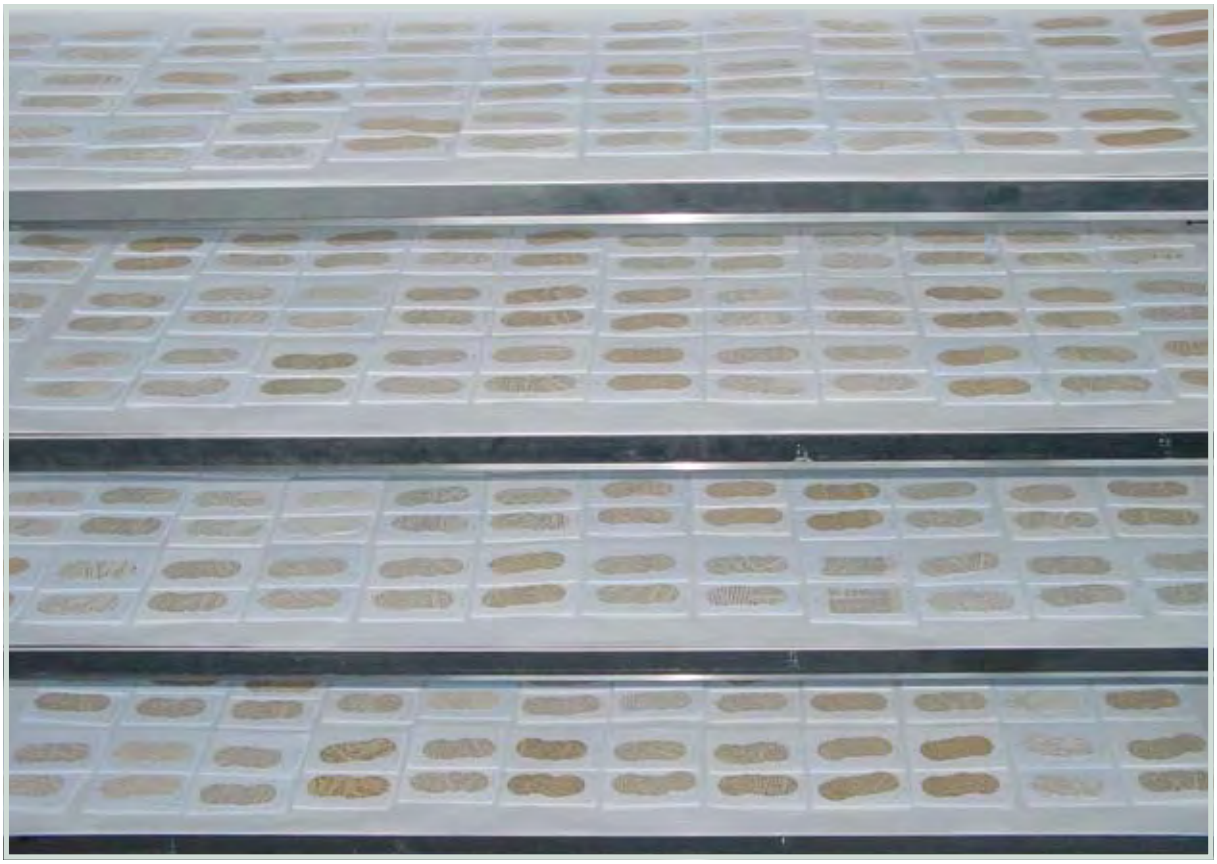


Figure 1. SurveNIR samples prepared for spectra measurement (the picture shows less than 10% of the sample set).

Uncountable numbers of hours were spent collecting data and NIR spectra to create a unique database. After calibration and validation of the chemometric models, SurveNIR is able to measure books (stack mode) as well as single items (single mode). Initially, SurveNIR identifies the type of the paper. Four types of paper can be studied: rag, bleached pulp, coated and ground wood papers, enabling SurveNIR's use on a broad range of different items. Books, drawings, newspapers, archival materials and documents and posters can be evaluated.

For each paper type, up to nine additional chemical physical parameters can be derived: acidity (pH), degree of polymerisation, molecular weight, tensile strength and tensile strength after folding, contents of lignin, protein, and rosin, as well as the presence of optical brighteners.

The spectrometer is attached to user-friendly software. The programme contains database functions to plan, execute and interpret surveys. Data can be imported and exported. The software has a number of modes – for example, classifying scientific data into categories chosen by each user, see Figure 2.

In addition, the SurveNIR software can be used to record visual assessments. The user can configure the software to provide up to fifty descriptive criteria, each categorised into four levels. The software will combine all data and inputs obtained, from the survey based on NIR spectra and from the visual assessment.

The software provides a number of options for reporting the results. They can be exported to Excel or calculated within SurveNIR. It is also possible to print separate evaluations for each measured item.

Because of the fragility of the historical documents, the design of the SurveNIR spectrometer ensures the safety of the items being evaluated. Since instruments available cause warming-up of the sample, evaporation of water and light interference, the SurveNIR spectrometer was designed to avoid any possible side effects; see Figure 3.

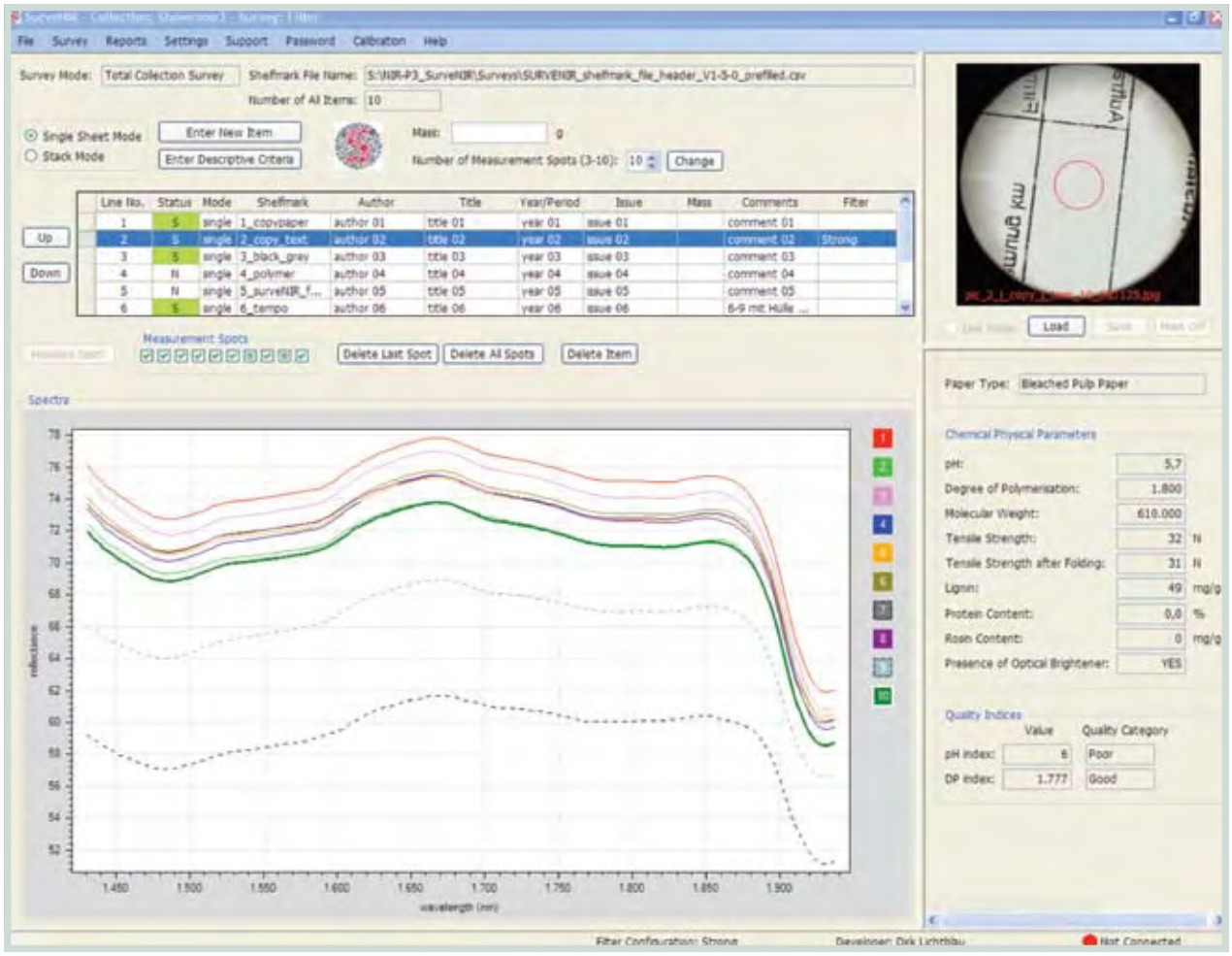


Figure 2. Screen output from SurveNIR, showing the measured NIR spectrum, the data gathered for each item, an image of the measuring spot (live video view; the red circle marks the measurement spot, an image can be saved with each spectrum), the derived chemical and physical properties of the paper, and the quality indices including quality categories.

Figure 3. The SurveNIR spectrometer, which is controlled by a computer (not shown). The paper is rested on the top plate above the spectrometer case and measured at the lighted star point. Light exposure is only one second for a measurement. A book holder for safe handling of bound material is available.

The SurveNIR tool was trialled in a number of significant European collections to demonstrate the value of the hardware and software. SurveNIR can evaluate large collections within a reasonable timeframe and on an objective basis. It enables a collection manager to plan efficient preservation strategies, combining scientific data with individual expertise and criteria. Since the structure of the software is flexible, the tool can be used for a number of tasks.

The tool was used to support the research Identical Books Project funded by the Mellon Foundation. The Identical Books were evaluated with SurveNIR at the National Library of Wales (NLW) in Aberystwyth and at the British Library (BL) in London. Comparison of the lignin determination of the Identical Books in both libraries showed a good agreement between the collections, enabling the identification of two exceptions, nominally identical but printed on different papers.

A comparison of the margins of the identical books at NLW and BL showed no significant difference of acidity or degree of polymerisation since the differences are within the standard deviation. However, the margins at NLW are a little less degraded and less acidic.

The NIR development was initiated by ZFB Zentrum für Bucherhaltung GmbH Leipzig in 2002. Within two regional projects, the first prototype NIR-paper rating tool was developed. From 2005 to 2008, nine partners extended the idea of creating a usable tool within the SurveNIR project. The success of the 6th EC Framework Project SurveNIR prompted ZFB to decide on a new marketing strategy in order to optimise the exploitation of the tool. This strategy involves the establishment of a spin-off company to commercialise the SurveNIR product. Dr Dirk Lichtblau, who was the director of research and development at ZFB, founded the company Lichtblau e.K. to market SurveNIR as a product and as a service, providing SurveNIR as a fully integrated collection-surveying service including preparation, measurement and reporting.

References

LICHTBLAU, D. (2004), Analyse des Alterungszustandes von Papier mit Nah-Infrarot. *PapierRestaurierung*, Vol. 5, No. 3, 5–60.

LICHTBLAU, D., AND M. ANDERS (2004), Characterization of paper by near infrared spectroscopy. *Proceedings of Durability of Paper and Writing*, Ljubljana, 28–30.

Measurements of Identical Books in the legal deposit libraries

Velson Horie, Research Project Manager, British Library

Introduction

The process of identifying the Identical Books and the gathering of the measurements are described in a paper (Horie) in these proceedings. Most of the Identical Book collection at the British Library (BL) is shown in Figure 1. The term 'Identical Book' includes a number of collection categories that are not books, such as maps, musical scores and pamphlets. A photomontage of one set of identical books (Figure 2) illustrates the difficulty in ensuring 'identicalness'. These books were never seen together, so differences in issue and binding or post-acquisition changes could easily be missed.

Figure 1. The majority of the collection of Identical Books at the British Library, omitting the maps and larger atlases. Similar collections were brought together at all the legal deposit libraries.

Figure 2. Photomontage of all the copies of IB211, *Whitaker's Almanack* (1903). The only method of comparison between the different libraries' copies was by juxtaposing their photographs or instrumental values.

In February 2007, two nominated conservators from each institution were trained at a workshop in the purpose and methodologies of the various measurements by Dr Jana Kolar, Dr Matija Strlič and myself. The overall measurement process was managed by Giordana Santoro of the National Library of Scotland (NLS; see her paper in these proceedings) working with conservators at the libraries, who carried out the measurements. A measurement kit was transferred between the libraries from May 2007 to January 2008, with additional measurements in early 2009. Having gathered together the set of Identical Books at NLS, she prepared, and modified as necessary, over 380 templates (Figure 3) used to locate the measurement points and samples on each page.

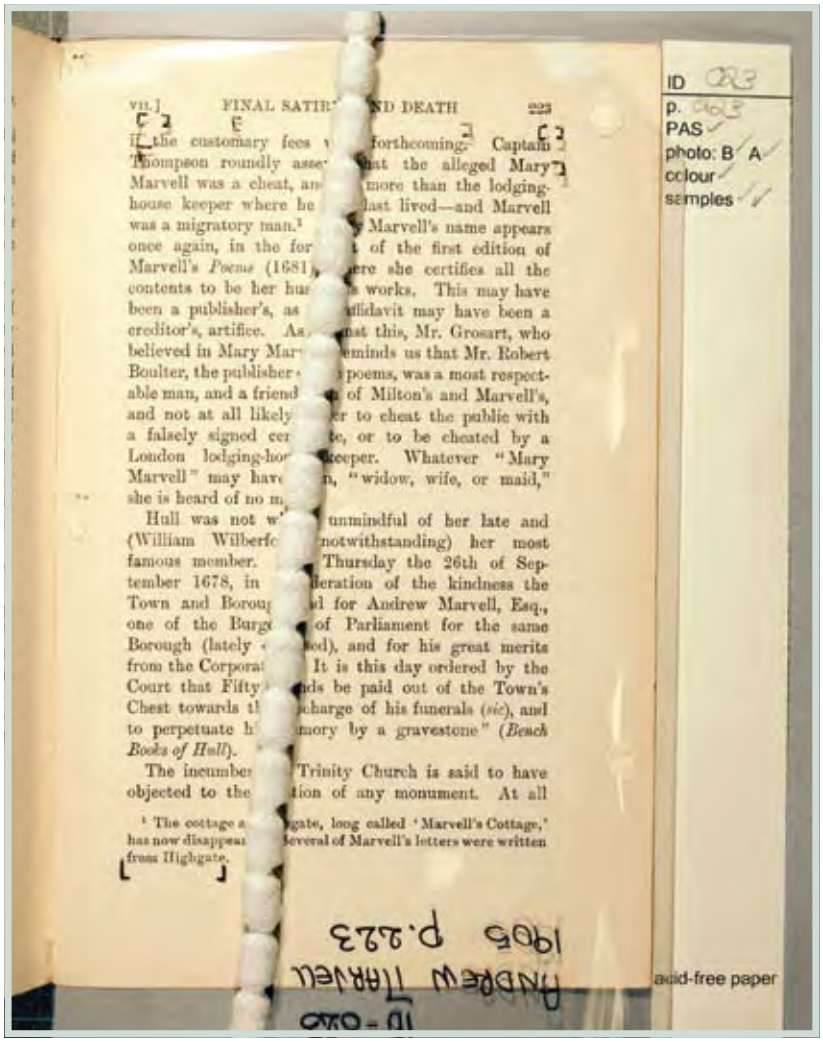


Figure 3. Melinex template over p. 233 of BL023, showing the text alignment marks at the top and bottom of the page. This book had been trimmed and rebound, so the template (prepared with a book in another library) did not fit this page. The colour measuring points are the holes on the top right and centre of the sheet. The sampling positions are holes along the gutter at the top and middle.

Conservators were trained to carry out micro-pH measurements in their libraries. Unfortunately, the equipment and technique proved too delicate for multi-user application, so the measurements were carried out in a single laboratory.

As the BL's contribution to testing in the SurveNIR project,[1] the Identical Books at the BL and NLW were measured by the SurveNIR tool in April–May 2008.

Methods used

Preservation Assessment Survey: The National Preservation Office Preservation Assessment Survey (PAS; Walker 2006) is widely used in the UK for informing judgements about the state of a library collection and recommendations for improvements. The PAS guidelines for the assessment of an individual item were followed. Each item was visually assessed over eight aspects (physical, chemical, biological damage and damaging repairs, separately for the binding and the body of the item) using a set of criteria, grading damage from 0 (minimal) to 2 (severe). Subsequent analysis has focused on chemical damage to the text block.

Colour measurements: Measurements were made at two locations on one page, using a Konica CM-2600d reflection spectrophotometer controlled by SpectraMagic software on a laptop computer (Figure 4).

Colour measurements were taken close to the external top right corner (e.g. BL211-T) and at a position in the middle of the page (e.g. BL211-M) with no printing on either side of the leaf. A backing sheet of paper was used to reduce the effect of underlying leaves. Each measurement was the average of three small area replicate measurements (3 mm diameter) at each position by raising and replacing the Konica over the hole in the template. The software recorded the measurement reference, date and time, reflection measurements 360–740 nm, CIELAB (D65, 10° observer), hue, chroma, lightness values for both Specular Component Included (SCI) and Excluded (SCE) modes in Konica format in one file for each library. These full datasets are archived. Subsequent analysis has focused on SCE b* measurements.

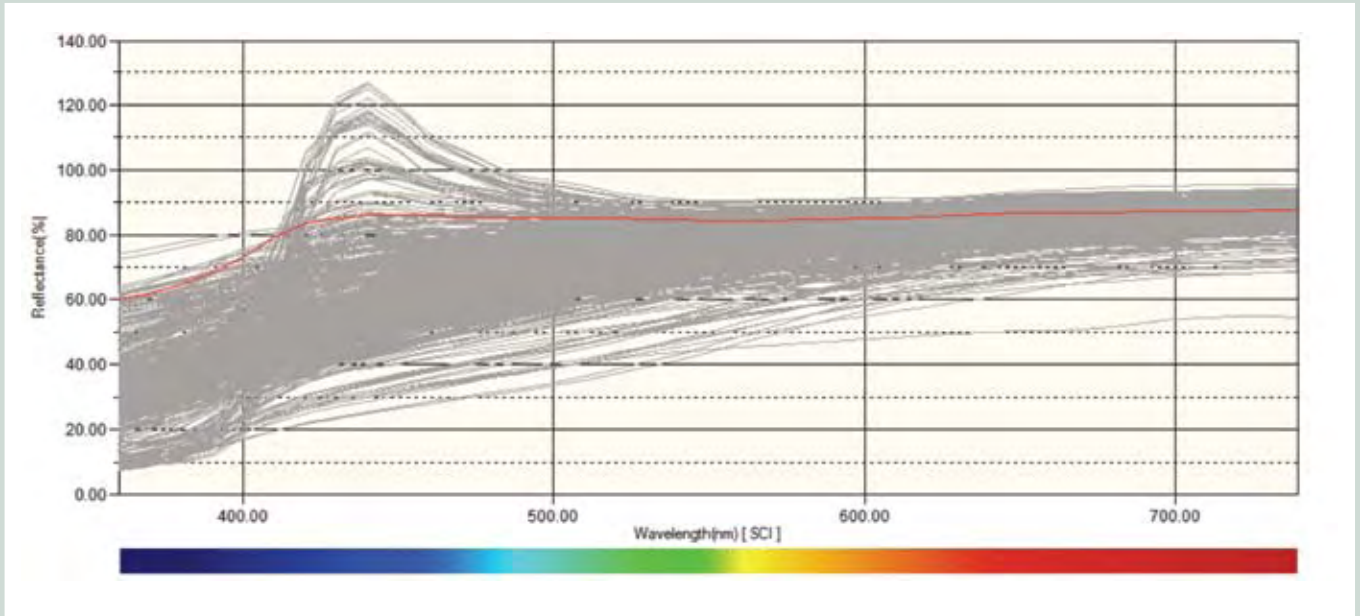


Figure 4. Combined reflectance spectra of the BL Identical Books, taken from the middle of the page. Data from one item, BL456M: Ordnance Survey Landranger series 2004, have been highlighted. Although all nominally 'white', many of the (older) papers show severe yellowness (absorption in the blue region). Some of the (modern) papers also show enhanced reflection in the blue region, due to the presence of fluorescent 'brightening' chemicals.

1 http://www.science4heritage.org/survenir/

SurveNIR measurements: The SurveNIR tool was trialled at the NLW and BL on the Identical Book collections. Infra-red spectra were taken from two positions on the identified page, as near as possible to the colour measurement positions. Each measurement was the result of five to seven replicates, which were assessed for suitability for inclusion in the data analysis by later filtering. The usual reason for rejection of a replicate was the presence of ink in the stack of paper (up to 7 sheets deep) from which the near infra-red radiation is reflected. Where possible, the spectra were taken by laying the volume on the measuring head in order to ensure that a stack of paper sheets could be measured. However, where there was ink on underlying pages or where the item was made up of an insufficient number of sheets (e.g. a map), the measurement was made in single-sheet mode using a calibrated reflector as a backing sheet. A single spectrum sampled a 2 mm diameter spot. The top right positions were taken 5 mm below the top edge (using a guide), while the ones in the middle of the page were positioned by eye and a quick evaluation of the reflection spectrum.

The spectra for Identical Books in the National Library of Wales (NLW) were taken by Dirk Lichtblau (ZFB) and those in the BL by Tanja Trafela (University of Ljubljana), with considerable local assistance, during the weeks 22 April to 1 May 2008.

Post-processing of the data demonstrated that there were 345 items in common, and that half the spectra taken from the middle of the pages were not useable, leaving 293 items with useful data. This analysis has led to improvement to the tool and technique. Papers of two of the Identical Books, 216 (*Whitaker's Almanack*, 1955) and 299 (*Snoopy Parade*, C.M. Schultz, 1983), were shown to have significantly different amounts of lignin, so are unlikely to be identical.

Results

Comparisons between the measurements from the various libraries are incomplete and will be further developed. The comparisons of colour measurements are made here.

Colour: Figure 4 demonstrates the range of measurements obtained from the BL Identical Books. Measurements from the other libraries show a similar distribution. There is considerable scatter of yellowness as a function of age (Figure 5). However, Figure 6 shows a consistent difference between the edge and middle of the pages at the BL.

Figure 7 demonstrates that there are small but significant differences in colour between the books held in the different libraries.

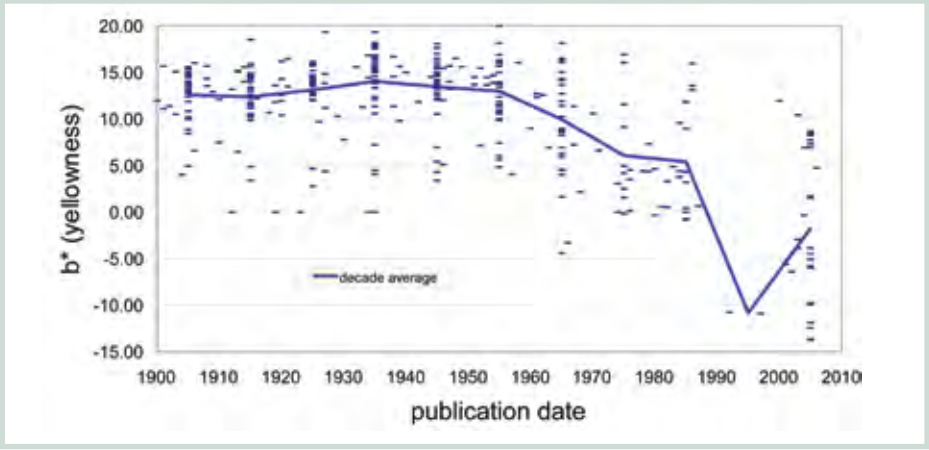


Figure 5 The yellowness of BL Identical Books, measurements at the middle of page, BL-M. There is considerable scatter across the sample chosen. More modern books are less yellow, even after the paper containing fluorescent additives is discounted. The average for the 1990s is probably distorted because of the few (2) books in the sample. It appears that paper is increasingly yellow as it gets older, then the trend plateaus after fifty years. This may be the result of ageing, or of the yellower paper being made in the past, or both.

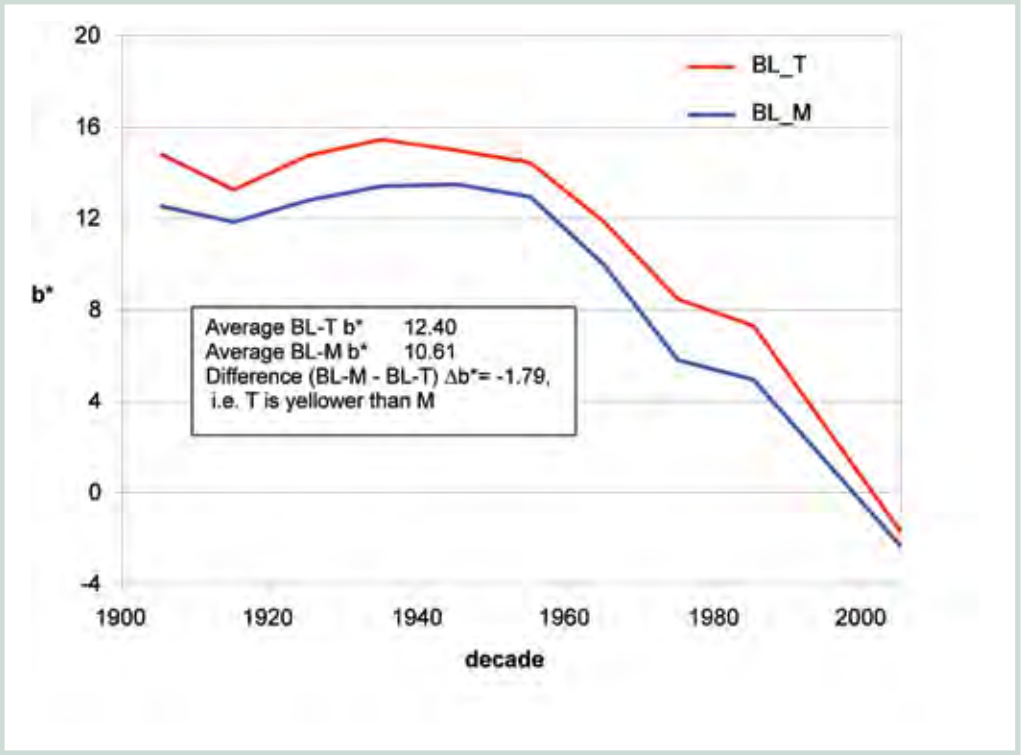


Figure 6. Difference in yellowness between the top edge and middle of the Identical Books. On average, the top right corners of the BL Identical Books are yellower than the middle of the pages. The difference appears to become established and constant after a couple of decades.

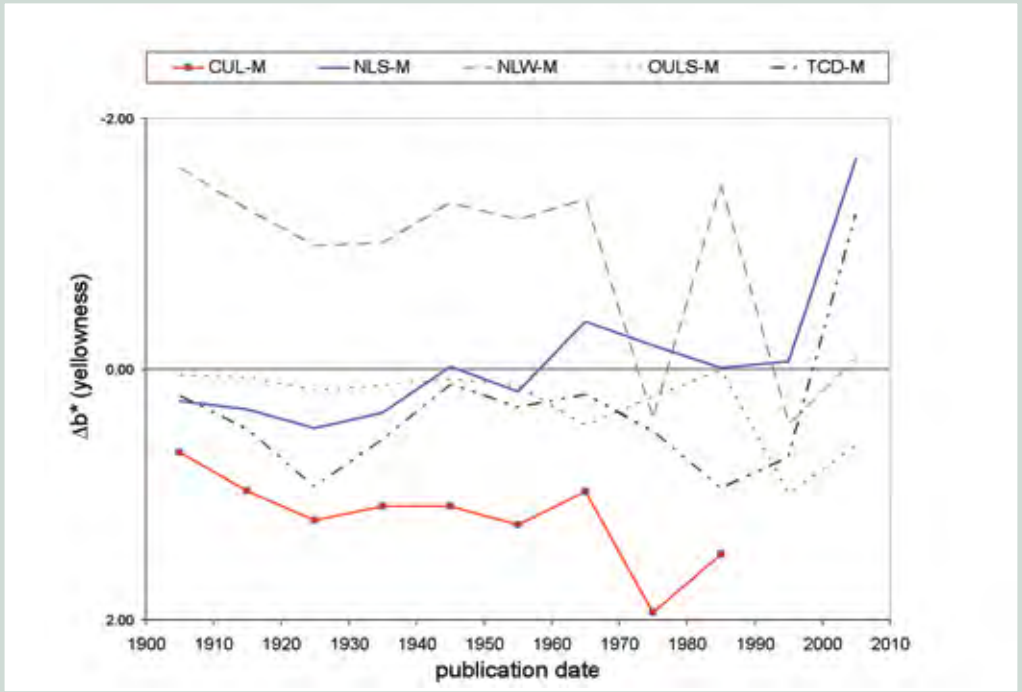


Figure 7. Comparison of yellowness between the Identical Books in the legal deposit libraries. The yellowness of the Identical Books, middle measurements, were averaged by decade, then subtracted from the BL values. Books which are yellower than the BL (e.g. NLW) are at the top of the chart.

Δb*between	BL-M – LDL-M	BL-T – LDL-T
CUL	0.722	1.228
NLS	0.102 (not statistically significant)	0.465
NLW	-0.952	-0.167 (ns)
OULS	0.162	0.457
TCD	0.400	0.626

Conclusions

The 'distributed national collection' held in the UK legal deposit libraries provides considerable redundancy, enabling copies to survive that were not collected or destroyed elsewhere. Distribution of responsibilities has led to a variety of curatorial practices. For instance, the BL, having the greatest usage rate and therefore wear and tear, appears to have bound and rebound items, backed maps and so on far more frequently than the other legal deposit libraries.

Considerable difficulties in first choosing, then sampling, the items were created by the emerging differences between nominally identical items. These difficulties were well managed, but could not be eliminated by the conservators in the libraries. It was not possible to bring the Identical Books from the legal deposit libraries together. Lack of direct comparison between the Identical Books led to variation in the details of sampling, reducing the power of the comparison. A close visual comparison is inadequate for identifying 'identical' books, with differences in paper types revealed by the SurveNIR tool. Choosing Identical Books for comparison is likely to be a separate, major research strand in any similar project.

Developing a cadre of conservators to undertake and carry forward this research has been rewarding. Ensuring that they formed a coherent team that communicated without restraint internally and with the external experts was essential. Bringing the group together for joint training sessions helped in this, as did enabling them to travel to each others' libraries and to research laboratories. Turnover of library staff has reduced the reinforcement of the learning and transmission of lessons to other staff in the institutions. This was helped, but not eliminated, by including two conservators from each institution.

The project introduced state-of-the-art measurement techniques into the libraries' work. For colour measurement, this worked well because it was adapting a well-developed method and technology from other established fields. However, the use of micro-samples and micro-pH sensor required considerably more training and experience than was anticipated or could be provided in the project. This aspect therefore had to be outsourced to experienced researchers. The limited application of the new tool, SurveNIR, demonstrated the advantages of a rapid, non-destructive evaluation of paper.

It is likely that the differences in colour are due to conditions of storage and use in the various legal deposit libraries, but making connections between the effects on the books and the potential causes is impossible in the current state of knowledge. Standards of librarianship and thus collection care, environmental control and so on, were fairly uniform across the legal deposit libraries for much of the 20th century. Differences in storage and usage conditions will therefore have been small, resulting in marginal differences in the current state of collections.

These Identical Book collections are now some of the best characterised books in collections. They are therefore a valuable resource for future researchers and measurements following the changes in the future. Their value will be increased considerably as their conditions and usage are also recorded.

Reference

WALKER, A. (2006), *Preservation Assessment Survey for libraries and archives*. London, National Preservation Office, British Library.

Round-table discussion

Panellists: Dr Fenella France, Dr Henk Porck, Dr Matija Strlič, Velson Horie, Dr Barry Knight and Helen Shenton

Introduction

Helen Shenton summarised the key points of the conference in the context of the British Library (BL) and heritage science. The strategy for conservation research at the BL has proved sound, validated by the conclusions of the Science and Technology Sub-committee of the House of Lords and the timeliness and success of its first grant-funded projects: the Identical Books Project (IBP) and the Volatile Organic Compounds in Books Project.

Next steps

- Embed collaboration by engaging UK and international libraries – i.e. BL, Library of Congress, Royal Library Copenhagen, Trinity College Dublin, National Library of Scotland, National Library of Wales, Oxford University Libraries, Cambridge University Library, The National Archives, etc. and confirm commitments from conference audience.
- Support volatile organic compounds (VOCs) as non-destructive characterisation of books, including development of the 'nose' by applying for AHRC/EPSRC grants or setting up studentships.
- Explore what can be learned from all characterised collections – i.e. Barrow, SurveNIR, IDB and ASTM 100-year survey – by metadata analysis, sharing of research data using the Library of Congress tool and long-term commitment by holding institutions.

Discussion points

- There is a growing need for and expectation of collaboration within the conservation research sector.
- Collaboration works on issues. What does the conservation research sector want from collaboration? What type of projects can only be done by sharing?
- Institutions need to be sure of the benefits of collaboration. It is important to address the what, how and why, and to be both retrospective and forward looking.
- Reputational risks to sharing information were considered and the importance of knowledge was emphasised.
- Large amounts of data are generated on a daily basis; an agreement on standards for how to share data is needed. Standards should be applicable to a wide variety of material. The audience was encouraged to engage with the process of standardisation.
- Tracking the data of moving collections was debated.
- The Time-Weighted Preservation Index (TWPI) appears to be a valuable tool, but needs to be further developed.
- The sustainability of project outputs must be addressed and their value communicated to funding bodies.
- Data are needed in order to ask valuable questions. The IBP is a prime example of data informing a question that could not have been thought of before – e.g. why is there a difference in colour in the books tested?
- There was considerable audience enthusiasm for developing further collaboration. A number of members from major institutions pledged their support in sharing information and developing new strands of conservation research – e.g. on the environment in collecting institutions.