Warm feet and cold art: is this the solution? Polychrome wooden ecclesiastical art - climate and dimensional changes

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Abstract

The installation of heating systems in the unheated churches in Norway in the first part of the 20th century was, after a period, thought to be the cause of damage to the polychrome wooden objects in the churches. From the end of the 1970s, localised heating in churches has been seen as a way to minimise the climatic impact on the wooden objects. There were however in the 1990s still a number of unanswered questions concerning the climatic stress put on the painted wooden objects.

In the research project *Ecclesiastical Art – Climate and Dimensional Changes* led by The Norwegian Institute for Cultural Heritage Research, the dimensional changes in the surface of the wood were registered. Two of the results from the project were of special interest: the surface of the wood reacted extremely fast, just a few minutes after a change in the environment (relative humidity or temperature). In addition it appeared that relatively larger dimensional changes occurred over distances of one millimetre than in distances around 100 millimetres. A change in the environment (relative humidity or temperature) seemed to cause both swelling and shrinking in the micro distances while the larger distances seemed to be dominated by either shrinking or swelling.

NIKU is in 2007 starting a cooperation with the Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences, in a project with the aim of finding a method of observing reactions in painted wood when exposed to a varying climate. Documentation of changes in the paint layer by laser vibrometry and direct monitoring using acoustic emission will be tried out, complemented by computer modelling. In 2007, Gotland University and NIKU start a project trying to find out whether intermittent heating really has damaged polychrome wooden objects in the churches. Between one and two hundred objects, placed both in heated, unheated and intermittently heated buildings, are planned to be investigated. Hopefully the two projects will create a basis for defining whether the intermittent heating is damaging the polychrome wooden objects in our churches.

Introduction

For church authorities in a cold country like Norway, the aim is to keep the users warm and the works of religious art cold. As practitioners within the field of cultural heritage conservation, our approach to climate and dimensional changes in painted wood is based on experience in the field and in the conservation laboratory. We have seen paint flake off as a result not only of unsuitable heating in the churches themselves, but also as a result of a breakdown in the laboratory's humidity control system. This has raised the wish to confirm the link between theory and the "real world". Through cooperation with natural scientists we want to try to find some answers to our questions on climate in churches and climate-influenced dimensional changes in painted wood. Norway's Directorate for Cultural Heritage and NIKU have for many years cooperated with scientists at universities, technical institutions and research institutions. In this paper we present the results of this cooperative work and research, leading to the NIKU publication *Ecclesiastical Art – Climate and Dimensional Changes*, together with the planned work in a Polish-Norwegian project and a Swedish-Norwegian cooperation that started this year. The project partners for the Polish-Norwegian project are the Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences (ICSC PAS) and NIKU. Gotland University and NIKU will work together in the Swedish-Norwegian project. Finally we present our thoughts and questions in a discussion.

Climate in churches in Norway

Polychrome (painted) objects made of wood decorate the interiors of most old churches, and Norwegian churches are no exception.

The installation in the early 20th century of heating systems in the previously unheated churches was after a certain period seen to be a threat to the church

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art, as damage to polychrome wood was thought to be related to the heating of the buildings. These damages had not been reported previously, in the period starting around the mid19th century, when some of the churches were locally heated by wood-burning stoves during the hours they were in use in the winter.

Localised heating in churches was thus seen as a way to minimise climatic impact on the wooden objects, and was, from the end of the 1970s, established as the preferred heating system.

In the 1980s the main objective for the climate work – then carried out by the Directorate for Cultural Heritage – was to chart climatic conditions in the churches and to measure the effects of climate on church art in order to implement measures to improve conditions for both the artefacts and the buildings [1]. The measurements confirmed that dramatic changes in relative humidity occurred when churches were heated [1,2]. This has also been observed by, among others, the European project "Friendly heating" [3]. Following a project that confirmed the efficiency of intermittent heating, it is currently recommended that churches in Norway install local heating systems based on radiant heating [4]. Electrical heaters are placed under the benches in the pews, and other radiant heaters are used locally to warm the priest and the organ player when necessary. The heating is activated for the shortest possible period. The Friendly Heating project also improved and refined the localised heating system based on local heaters in the pews and other critical places in the church.

In a cold climate, the intermittent heating method seemed to improve the climate viewed over the whole year, and as a solution was thought to be better than general heating throughout the cold season. In the 1990s, however, a number of questions arose concerning the climatic stress put on the painted wooden objects.

The project: climate and dimensional changes in painted wood

Further work at the Norwegian Institute for Cultural Heritage Research in the 1990s on climate and dimensional changes was based on the need to know how fast the surface of the wood responded to a climatic change. In addition; how big and how long lasting an environmental (relative humidity or temperature) change might be allowed when heating a church, or, put another way: what size and rate

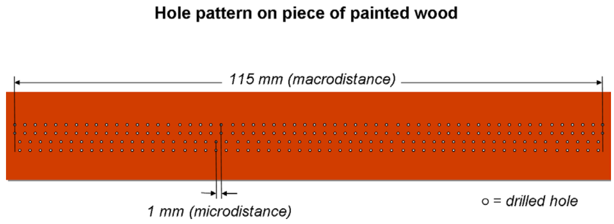

Figure 1. The macro area is 115 mm. It is divided into micro areas. Each micro area is 1 mm and is marked by drilled holes (white dots) in the paint. Two parallel lines of 57 and 58 pairs of holes were drilled. A micro area is the distance between the lines which are formed between the middle of two pairs of drilled holes (white dots). One micro area is the distance between the two black arrows on the figure.

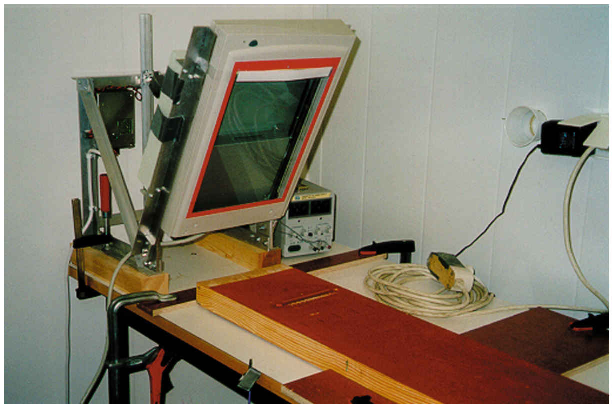

Figure 2. The picture shows the set-up of the climate room with the test piece lying on the workbench. The measurement scale can be seen as a light stripe in the upper part of the plank. The scanner has been moved to the side of the test piece. Photo: Tom-Nils Nilsen

of change were the wooden painted objects able to tolerate before damage occurred?

The project *Climate and dimensional changes in painted wood 1999-2001* [5] used a dummy to test the reaction of painted wood to climatic fluctuations. The test piece was a pine plank measuring 1050 x 215 x 43 mm. It was surface treated on the two largest surfaces in the same way as was standard for medieval wooden painted art. [6]

Of the measurement methods tested in the project, only an optical method based on scanning and data handling was suitable for revealing surface movements over short distances. The method was developed at the Norwegian Building Research Institute. A measurement scale in the form of pairs of holes was drilled into the layer of primer on the test piece. Each pair of holes defined a measurement line and there was about 1 mm between each measurement line. There were116 measurement lines in all, across a total distance of 115 mm, which delimited the total measurement area (see figure 1). The total measurement area is called the macro area, while the small areas delimited by the measurement lines are called the micro areas.

While the test piece lay undisturbed in the climate room (see figure 2), the climate changes were carried out in a predetermined series of climate cycles. The climate cycles were based on, and partly simulated, the climatic changes known from heated churches. The tests were carried out over three periods, with several climate cycles in each one. The first cycle had a constant temperature (5ºC) and changed the relative humidity from 30% to 80% and then back to 30%. In cycles 2 and 3 the relative humidity was unchanged while the temperature was changed from 5ºC to 20ºC and then back to 5ºC. In cycles 4 and 5 the temperature was again held stable at 5ºC and the relative humidity was changed from 30% to 60% and then back to 30%. In cycles 6 and 7 both the temperature and the relative humidity were altered while the water vapour pressure was constant. In cycle 8 the relative humidity was unchanged at 35% while the temperature was altered from 8ºC to 22ºC. In the last cycle, no. 9, the temperature was held stable at 15ºC while the relative humidity was changed from 30% to 80%.

Scanning was initially carried out every 20 minutes, and thereafter every 10 minutes and then every 5 minutes. In each scan 115 micro areas were calculated.

We recorded the movement in the surface of the wood. The discussion of the results is based on the difference between the dimensional changes in the wood and in the paint layer caused by each of the specific materials' interaction with the climate. The dimensional changes in the wood dominate and might cause damage to the paint layer.

The surface of the wood seemed to react extremely fast: a dimensional change was recorded within a few minutes after a change in climate. We do not know the thickness of the wood layer that was rapidly affected. It also appeared that, relatively speaking, considerably larger movements occur in the micro areas than at macro level. At the micro-level, one millimetre area in the materials seemed to be able to expand while the adjacent area contracted.

But is the micro distance important? To what extent will the movements over such small areas influence the paint layer? Our interpretation is that the movement in the micro areas of the wood might stress the paint layer and cause problems for this layer. Is there local compression and strain in millimetre areas in the paint structure?

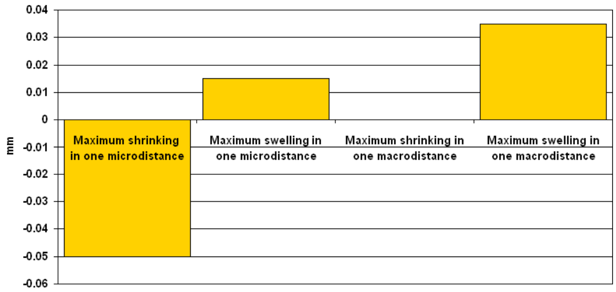

Figure 3. Measured maxima of shrinking and swelling on micro- and macrolevel when the temperature is 15 °C and the relative humidtity is raised from 40% to 80%.

We ended up with results that needed confirmation by further work. A measurement method that keeps human participation to a minimum should be used for further work. Since the previous climate may have influenced the project results, it is also extremely important in further work that the test piece is sufficiently stabilised before a climate series is begun.

MICRO MEASUREMENT AREAS

When we worked on the project described above [5] we found that very few had looked at dimensional changes over small areas. Brewer and Forno had used a type of screen or grid measurement technique (moiré fringe analysis) to measure within millimetre areas [7]. Dreiner, Klein and Zillich had used lasers and created a three-dimensional picture of the panel's surface with a reading after each mm step [8]. For the other published projects we looked at, the minimum distance measured was 20 mm and the largest was 400 mm. [9, 10, 11 &12].

RESPONSE TIME

In the 1990s we saw that there was a lack of agreement in the publications regarding response times following climatic change. Dreiner [13] together with Brewer and Forno [7] stated that changes occur quickly after climatic change. Holmberg, together with Klein and Bröker [11, 12, 9] stated that daily changes can be registered, while the *WARP-experiment* indicated that daily fluctuations may be insignificant [10].

There was in general at that time not much in the literature about response time of the outer layer of the wood. When response time was an issue, the response times were usually not described in numbers, but by using expressions such as immediate, instant or fast, or the opposite: late or slow. Brewer and Forno recorded after five minutes a sharp increase in warping in a test panel as a result of climatic change

[7]. Dreiner clearly thinks that it only takes minutes from the imposition of a climatic load until a change in the moisture content in the layer can be registered. He does not quantify the thickness of the layers [13]. The fast, almost immediate, response time is confirmed by later research [14, 15]. Bratasz and Koslowski have found that a change in temperature gives the fastest response in the materials, while the response to RH is slower [16].

In the project *Climate and dimensional changes in painted wood* the response time was shortest at micro-level: under 10 minutes for changes in both relative humidity and temperature. At macro level, however, the response time was shorter for changes in the temperature than for changes in the relative humidity.

It seems as if research during the last 20 years confirms that heating the church even for a short time will influence the objects, at least if the change in temperature, with the consequent change in RH, also reaches the area where the objects are located.

RH and temperature as environmental influences

During our work we saw that the wood reacted to changes in both temperature and in RH. The scientists at The Smithsonian Center For Materials Research and Education (SCMRE) considered RH the most important climatic factor. All their tests were done with a fixed temperature and fluctuating RH. Bratasz and Koslowski regard the RH as the most important stress-creating and potentially damaging factor with regard to wooden objects. This is because a change in temperature affects the wood right through, while a change in RH first affects the outer layer of the wood [14]. The stress gradient in wood caused by RH change is discussed also by other scientists. [Among others 17, 13, 18] The stress in the wood may cause it to crack. If the wood cracks the paint will also be damaged. A change in temperature affects the underlying wood, including the surface layer, so a temperature change might cause stress in the paint layer.

Because the RH impact moves inwards through the wood, layer by layer so to speak, the duration of an unwanted climatic condition must be of importance. Short climatic fluctuations will constantly influence the surface of the wood, while the longer the same RH lasts, the thicker the layer of wood that will be influenced by the new climate. However, the thickness of wood influenced is probably not of importance for the condition of the decorative layer, if the paint is already influenced by movements in the upper layer of the wood.

During the Friendly Heating project the Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences (ICSC PAS) did tests on three different heating episodes and found that the fast changes from 70% to 30% RH lasting from 10 minutes till 24 hours, created unacceptable internal stress in the wooden structure. Rate and duration is of importance for the stress created in the wood, but of what importance is that to the paint layer, as long as the wood does not crack?

Another question is the climatic starting point for the object when exposed to a climatic impact. The scientists at SCMRE did find that there was a significant difference in the allowable RH-fluctuations if the materials were equilibrated to 50% RH in the air, or to a higher or lower RH, when they were exposed to a climatic change. The range of the allowable fluctuation of RH was widest for the materials adjusted to 50% RH. This was later partly confirmed by the research done at ICSC PAS [14].

There always will be gradients of moisture content inside a wooden painted object in a church. It may take months to establish equilibrium moisture content in large masses of wood. How long depends on the thickness of the object. In a church there will constantly be fluctuations in the climate and one climatic situation will most often not last long enough to allow for uniformity of water content to be established throughout the object. Since one can't avoid climatic fluctuations, the aim is to find the allowable microclimatic variations for polychrome wood.

Another problem is that the objects are probably very seldom adjusted to 50% RH when exposed to a change in interior climate.

Future work

In the future the following questions need to be answered:

- Is damage in the paint layer related to micro movements in the wood caused by fluctuations in climate?
- Are visible damages in the paint layers related to intermittent heating?
- Is it significant if the values of RH or T rise or fall?

These are simple questions that demand more research to find the more complex answers. There is a need to systematise collected experience, to have more knowledge of materials, and to monitor the wooden polychrome structure while RH/T is being changed. If monitoring is difficult, one possibility is to establish a method to document at micro-level any eventual changes in the structure, before and after a climatic impact.

The first question will be studied in the Polish-Norwegian project *establishing standards for allowable microclimatic variations for polychrome wood* and the second in the Swedish-Norwegian project *Polychrome wood in intermittently heated churches in Scandinavia.*

The project "Establishing standards for allowable microclimatic variations for polychrome wood"

From 2007 the Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences: ICSC PAS, and NIKU will be partners in a project whose final aim is to establish precisely and quantitatively the variance limits of air parameters, RH and T, which are safe for the painted wooden surfaces. The main idea of the project is to find a method to detect what happens to the painted wood when exposed to varying climate. This method will then be the tool used when trying to define the possible fluctuations the painted wood may sustain without damage. We are looking for a method that enables us to see the earliest stage of the damage process caused by movements in the wood due to climatic changes, which means long before the paint falls off and the damage is irreparable.

The work in the project is based upon the research done at SMRCE in the 1990s by Mecklenburg, Tumosa and Erhardt [19, 20, 21 & 22], the research done by ICSC PAS in the Friendly Heating Project, and the idea that the micro areas are important. Both NIKU [5] and ICSC PAS in their research projects [14] have chosen to use a definition of damage which is based on research carried out by SCMRE, and which states that damage can occur when the structure is loaded beyond the yield point. This definition will also act as the damage definition in the running project.

The main research tool in the project will be direct monitoring of decohesion of the decorative layers from the wooden support and their mechanical damage using laser vibrometry and acoustic emission, when the object is exposed to certain climatic conditions.

Laser vibrometry will be used to survey the condition of the test piece before and after the climatic tests.

The monitoring of the test pieces during the imposed drying and heating episodes modelled on patterns from real world situations will be done by recording acoustic emissions from the test pieces. Earlier monitoring of acoustic emission done by ICSC PAS has allowed direct tracing of the fracturing intensity in wooden cultural objects exposed to variations in temperature (T) and relative humidity (RH) in their environment [23].

Parallel to the experimental work, there will be computer modelling of mechanical stress appearing at the wood-paint interface. The modelling will be based on the laboratory measurements of physical parameters of materials in the individual layers of the composite polychrome structure.

The measurement methods established in the first laboratory phase of the project is planned to be used on-site in churches in Poland and Norway. This part of the project might be connected to the Swedish-Norwegian project described below.

The project "Polychrome wood in intermittently heated churches in Scandinavia"

The Swedish - Norwegian project has been established in cooperation with Gotland University and will start in 2007 as a preliminary study. The main objective is to find out if intermittent heating really has damaged the existing polychrome wooden artefacts. The project plans to study between one and two hundred objects in situ. Materials and painting techniques should preferably be the same for most of the objects in the survey, but in reality it will probably be necessary to note the differences between them.

Information on the conservation and treatment history of the objects will be collected together with information on the building acting as a storage or show case for the objects. The condition for the objects will be defined by the building construction, by historical meteorological data, by heating information and information on the environmental conditions today.

Today's state of the investigated furnishing and wooden objects, will be related to the collected historical information and the climate of today, the aim being to find connections between the climate and the development of damages.

The survey will hopefully create a basis for defining whether it is possible to observe visible damages due to intermittent heating.

Discussion

Wood is a complex material and a wooden painted object comes in many variations. For how many of these objects will research based general rules about suitable preservation climate apply?

Polychrome wooden objects have survived huge climatic impact caused by the natural environment through centuries, by transport from one country to another, from church to church, from church to museum, and between museums, and the impact caused by heating of buildings. The objects still in the churches are in a way objects in use, and have to accommodate to the demands of comfort from people using the churches. The same kind of climatic impact is resisted quite well by some objects , others suffer. The climatic conditions are not the only damaging factor, even if it is important. Maybe further work will show us that we have to make climatic conservation categories that correspond to the structure and materials of the object. Size, shape and paint structure will be parameters in such a division into groups. The practitioner's collection of information from the objects in situ and in museums will have to be used together with the scientists' results from laboratory work.

The climatic history of the objects is also an important parameter for the ideal conservation climate. The same kind of objects, made in the same period, with the same kind of wood and the same painting technique, might have survived better if they had remained in an unsuitable climate in an intermittently heated building, than if they had been moved to a conservation climate for the last few centuries.

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Literature:

1 Marstein, N. & M. Stein. 1987. Advanced measuring of the climatic conditions in the mediaeval wooden churches in Norway. - ICOM Committee for Conservation, 8th triennial meeting, Sydney. pp. 889 -895.
2 Olstad, T. M. 1994. Mediaeval wooden churches in a cold climate – Parish churches or museums? - Roy, A & Smith, P. Preventive Conservation. Practice, Theory and Research. Preprints of the Contributions to the IIC Ottawa Congress, 1994. London. pp. 99 -103.
3 Camuffo, D. et al.2006. Church Heating and the Preservation of the Cultural Heritage. Guide to the Analysis of the Pros and Cons of Various Heating Systems. Milan.
4 Olstad, T. M. & A. Haugen. 1997. Klima i stavkirker: Lokal klimatisering av menigheten i Kaupanger stavkirke, Sogndal kommune. - NIKU Fagrapport 004. Oslo
5 Olstad, T.M, Haugen, A. & Nilsen, T. N. 2001. Polychrome wooden ecclesiastical art –Climate and dimensional changes. NIKU Publications 110. 24 p
6 Surface treatment of the test piece:

Layer	Materials
Topcoat / decorative layer	Boiled linseed oil / English red pigment
Insulation layer	Egg white
Chalk-glue ground	8 coats rabbit glue / water / chalk
Sizing	Rabbit glue / water
Base	Pine

7 Brewer, A. & C. Forno. 1997. ‘Moiré Fringe Analysis of Cradled Panel Paintings’. - Studies in Conservation 42 (1997). - London. pp. 211-230.
8 Dreiner, K., Klein, P.& Zillich, I.1996. ‚Investigation into the deformations of Panel Paintings‘. - ICOM Committee for Conservation (ICOM-CC). - 11th Triennial Meeting, Edinburgh. 1996. Preprints. - Volume 1. pp. 268 – 270
9 Klein, P. & Bröker, F.-W.1990. ‘Investigation into the deformations of Panel Paintings’. ICOM Committee for Conservation (ICOM-CC). - 9th Triennial Meeting, Preprints. Volume 1. Dresden. pp.41-43.
10 Ashley-Smith, J., Umney, N. & Ford, D. 1994. Let’s be honest – realistic environmental parameters for loaned objects. - Roy, A & Smith, P. Preventive Conservation. Practice, Theory and Research. - Preprints of the Contributions to the IIC Ottawa Congress, 1994. London. s. 28-31.
11 Holmberg, J. 1996. Relative Humidity, RH, in historic houses, museums and museum storage rooms, a literature study. - Projektburo EUREKA EU 1383 - PREVENT, Report No. 1 from Swedish partners. Stockholm
12 Holmberg, J. G. and B. Kylsberg (1999). Final report on results from measurements at Skokloster palace of: indoor climate; time dependent moisture sorption in old wood; surface deterioration and cupping of old wood; presence of mould; outdoor air filtration. Stockholm. Projektburo EUREKA EU 1383 - PREVENT, Report No. 10 from Swedish partners. Stockholm
13 Dreiner, K. 1996. Untersuchungen zur Reduzierung Klimabedingter Belastungen für das Aschaffenburger Tafelbild. - I: Emmerling, E. & Ringer, C. red. Das Aschaffenburger Tafelbild. - Arbeitshefte des Bayerische Landesamtes für Denkmalpflege, Band 89. - München. pp. 283-291.
14 Bratasz L., Jakiela S., Kozlowski R., 2005 - ‘Allowable thresholds in dynamic changes of microclimate for wooden cultural objects: monitoring in situ and modeling’. In 14th Triennial Meeting of ICOM Committee for Conservation, the Hague, 12-16 September 2005: Preprints, James & James, London, vol.2, 582-589.
15 Dionisi Vici P., Mazzanti P., Uzielli L., 2006 – ‚Mechanical response of wooden boards subjected to humidity step variations: climatic chamber measurements and fitted mathematical models‘. Journal of Cultural Heritage,Vol 7 (1), 37-48.
16 Bratasz L., Kozlowski R., 2005 - ‚Laser sensors for continuous monitoring of dimensional response of wooden objects in situ‘. Studies in Conservation, vol.50, 307-315.
17 Uzielli, L. & Casazza, O. 1992. Conservazione dei dipinti su tavola. Firenze 1992.
18 Padield, T. www.padfield.org/tim/cfys/
19 Mecklenburg, M.F.& C.S Tumosa. 1991. ‘Mechanical behavior of paintings subjected to changes in temperature and relative humidity’. - In:
Art in Transit. Studies in the Transport of Paintings. - International Conference on the packing and Transportation of Paintings. London 1991. -Washington.
20 Erhardt, D. and Mecklenburg, M. 1994. “Relative Humidity Re-examined”. - IIC Ottawa Congress. Preprint. London. Roy, A & Smith, P. Preventive Conservation. Practice, Theory and Research. - Preprints of the Contributions to the IIC Ottawa Congress, 1994. London. s.32-37.
21 Erhardt, D., Mecklenburg, M., Tumosa, C.S & McCormick-Goodhart, M. 1997. The determination of appropriate museum environment. Bradley,S. - ‘The Interface between Science and Conservation’. - British Museum, Occasional paper. Number 116. London. pp 1 53 –163.
22 Richard, M., Mecklenburg,M. & C.S. Tumosa. 1998. ‘Technical Considerations for the Transport of Panel Paintings’. I: Art in Transit. Studies in the Transport of Paintings. - International Conference on the packing and Transportation of Paintings. London 1991. -Washington.
23 S. Jakiela, L. Bratasz, R. Kozlowski, ‘Acoustic emission for tracing the evolution of damage in wooden objects’, in print, Studies in Conservation (2007).