

A detailed still life painting of a bouquet of flowers in a vase. The bouquet is composed of various flowers, including white and pink roses, blue and white hydrangeas, and other smaller blossoms. The vase is a large, textured, brownish-gold color. The background is a muted, earthy tone. Several butterflies are scattered throughout the scene, adding to the intricate detail of the painting.

The conservation of panel paintings and related objects

Research agenda 2014 -2020

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Abstracts of relevant literature can be found at:
www.nwo.nl/science4arts

Summary

Until the early 17th century almost all portable paintings were created on wood supports, including masterpieces by famous painters, ranging from Giotto to Dürer to Rembrandt. The structural conservation of these paintings requires specific knowledge and skills as the supports are susceptible to damage caused by unstable environmental conditions.

Unfortunately, past structural interventions often caused significant damage due to insufficient knowledge of the behaviour of the wood panels, glue and paint layers. Over the last fifty years, the field has developed treatment strategies based on interdisciplinary collaboration and on the knowledge of specialist conservators. Most current conservation protocols rely on empirical knowledge of conservators and are not necessarily based on a scientific understanding of the nature and behaviour of wood and paint layers.

In order to move the field forward, it is imperative to strengthen scientific research into the production methods, ageing and future behaviour of panel paintings, being an intricate interplay between different materials. A deeper understanding of the processes that adversely affect panel paintings over time will contribute to the improved care and conservation of these artworks.

The Netherlands Organisation for Scientific Research (NWO) and the Rijksmuseum Amsterdam brought together a group of experts from different disciplines to recommend specific areas in the field that would benefit from systematic research. The experts concluded that targeted interdisciplinary research projects are key to understanding the behaviour of panel paintings and help conservators make better informed decisions. Research into chemical and physical properties of wood, glue and paint layers should be combined with an evaluation of past and current conservation treatments. Research should also consider the history of the object, studio practice, conservation history and thoughts on long-term impact of treatments.

Over the next seven to ten years key research topics should include:

- Hydromechanical properties of ageing wood in panels,
- Interlaminar stresses and fractures mechanics, also affecting the paint layers
- Loss of adhesion among the paint layers,
- Adhesives with appropriate chemical and physical properties,
- Non-destructive testing and development of theoretical models.

Successful projects encourage close collaboration between conservators and (conservation) scientists, as each discipline brings a unique perspective to the discussion. This collaboration would include the review of existing literature, the development of a database with population studies, and the establishment of a calibration system between laboratories.

Given the growing need for skilled conservators with a good scientific background, it is imperative that outcomes are widely shared with the conservation community. Wide dissemination can only be achieved with the support of national and international funding organisations, e.g. in the framework of the European Joint Programming Initiative on Cultural Heritage.

Strengthened collaboration among international stakeholders, concerned with the conservation of panel paintings, is vital to the advancement of the field. Existing programmes in a number of countries offer a useful basis, such as the Getty Panel Paintings Initiative and the NWO-programme Science4Arts. Museums, conservation institutes, cultural heritage institutions and universities must play an important role in promoting best practices, knowledge dissemination, and education. These organizations must take the lead to establish an international network of knowledge centres with open access policies that will stimulate knowledge transfer.



1. Introduction



Introduction

CHAPTER 1

Introduction

Nico Kos and Paul van Duin

The conservation of panel paintings and related objects

Research agenda 2014-2020

1. Introduction

1.a. The panel painting

For centuries wood was used as a common material for a variety of artworks, ranging from Egyptian Fayum coffin portraits to Old Master paintings. Unique masterpieces are painted on wooden panels. The Ghent Altarpiece by Van Eyck (1432) is just one fine example, but equally important objects can be found in many countries. Panel paintings are constructed from wooden boards, joined together by glue, dowels, and crosspieces. The painted surface of a panel typically has an interface of fabric and/or gesso that carries the paint layers, on one or both sides of the panel.

While wood can be a long-lasting material, it is unstable material and over time will show signs of deterioration, such as warping, splitting, and cracking. Mechanical and/or chemical degradation often results in damage, such as the detachment of the ground- and paint layers and loss of paint, and are generally the primary impetus for intervention.

Most information on degradation processes is empirical. In the past a lack of knowledge of the consequences of treatments has sometimes led to irreversible damage (e.g. wash boarding). This has been aggravated by the adverse climate conditions under which panels are sometimes kept. There is, as yet, a lack of sufficient scientific research into the properties of ageing wood and its chemical and physical interactions with paint layers. This should deepen the understanding of these processes and the consequences of ageing and of interventions. Also the conservators' knowledge of the production, the studio practice, and previous conservation conditions and treatments of panel paintings needs to be strengthened.

When establishing conservation treatments, conservators rely on their knowledge of materials and, to a large extent, on years of practical experience. This valuable experience has not always been adequately documented and is often transferred by word of mouth or as tacit knowledge (Sennett 2008). But, more generally, knowledge transfer between the two often separated worlds of conservation and restoration and of arts and sciences needs to be strengthened in order that everyone can benefit from the knowledge generated. The results of this further research will also support the conservation of other wood-based artworks, e.g. furniture, musical instruments and historic interiors.

1.b. Background to the report

The recent *Needs Assessment Survey* carried out as part of the Getty Foundation's Panel Paintings Initiative unambiguously points to an urgency for training conservators in the structural conservation of panel paintings, as well as to connect between conservation practice and applied research in wood science, mechanical engineering and chemical science. Steps are already being taken to strengthen the link between conservation and scientific research. The Getty Foundation launched the Panel Paintings Initiative to train the next generation of panel paintings conservators before the current experts retire. Additionally, the Netherlands Organisation for Scientific Research (NWO) launched the Science4Arts programme, in collaboration with the National Science Foundation, U.S.A. Science4Arts funds the Climate4Wood project of the Technical University Eindhoven and the Rijksmuseum Amsterdam. Finally, UCL Centre for Sustainable Heritage and English Heritage are participating in a joint research project funded by the UK AHRC/EPSRC Science and Heritage Programme. A group of scientists has successfully applied for the COST-action Wood science for conservation of cultural heritage.

In January 2011, the Netherlands Organisation for Scientific Research (NWO) and the Rijksmuseum Amsterdam, with grant support from the Getty Foundation, hosted a meeting of 30 international experts, including conservation specialists, art historians, wood scientists, chemists, engineers, and computer scientists. The specialists discussed a variety of essential research topics, that would advance the fields of panel painting conservation. They agreed on the need for: fundamental and applied studies, modelling of behaviour patterns including validation studies, and experimental population studies. Based on the initial outcomes of this meeting a small team further discussed specific research topics, each of which is covered in a separate chapter of this report. We have thus formulated a number of questions that should be addressed in research projects to further our understanding of the making, the composition and (future) behaviour of these robust yet delicate objects. One should be aware that there are of course overlaps. E.g. study of the studio practice or effects of (past) treatments are cross-cutting topics.

The contributors hope that this report will encourage the development of innovative research programmes and projects that will propel the field of panel paintings conservation forward. Compared with the enormous cultural (and economical) value of panel paintings collections throughout the world, this initiative is a relatively small effort to undertake compared with the huge impact it should have on preserving present and future collections. It is vital to ensure that future generations may see unique masterpieces in the best condition achievable.



Figure A+B Albrecht Dürer, Adam and Eve, 1507
Frontside of the painting. For backside see page 16 – 17
© Museo del Prado (Spain)



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nº 72

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B. 228

B. 228

Albrecht Dürer, Adam and Eve, 1507.
Reverse side of the panels.
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2. **The Painted Support: Properties and Behaviour of Wood**

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Behaviour of Wood Properties and The Painted Support:

2. The Painted Support: Properties and Behaviour of Wood

A painting executed on a wooden panel is a complex composite structure consisting not only of a number of layers of different materials with different physical and chemical properties, but often also a number of three-dimensional structural elements with differing mechanical properties. Although problems can be encountered due to degradation of any part of this composite, it has been long identified that most often it is damage or deformation of the wooden support structure that leads to interventions in order to preserve the artwork (Stout 1955). This section looks into the properties, behaviour and conservation treatments of traditional wooden panels. Whilst by no means exhaustive, the topics and references provided should give an overview to individuals of different backgrounds and provide an starting point for in-depth research into a specific topic. Not specifically included in this study are painting supports on manufactured wood boards, however many of the themes in this paper may be relevant to the study and conservation of such supports.

2.a. Construction of a Panel Painting

Many surveys and reviews exist of different types of original panel construction using different species of wood and different reinforcements (Castelli 2006), (Taube 2005), (Uzielli, Veliz, Wadum et al 1998), (Castelli et al 1997), (Verougstraete-Marcq 1989). Numerous case studies in conservation literature document original construction and structural devices. Museum documentation also provides a wealth of information. Between 1990 and 1993 Al Brewer (Royal Collection, UK) undertook a number of international visits surveying panel collections gathering construction and deformation details (Brewer 2000). Ciro Castelli (Opificio delle Pietre Dure (OPD), Italy) fabricated a series of scale ‘modelli’ illustrating construction details of a number of panels and crucifixes worked on at the OPD over a number of years.

Many large collections have holdings exemplifying works of Italian and Northern Renaissance painters, therefore the most common wood species discussed in literature and amongst conservators are poplar (*Populus alba*) and oak (*Quercus sp.*),

however many other types of wood are used for painting supports and panelling within other objects of cultural heritage. Most paintings have been executed on timber derived either locally or from common trade sources (Rief 2006) (Altamura et al 2005). Softwoods found as painting supports are pine, fir, larch and spruce, (Hoadley 1998). Hoadley also lists common hardwood species along with oak and poplar as maple, chestnut, beech, ash, walnut, cherry, pear, willow, mahogany, lime and elm.

For the purposes of this paper, a panel painting is constructed from one or more boards of wood of varying sizes, which may be butt-joined, lap-joined or have tongue-and-groove joints, with either vertical or horizontal grain orientation, or in some cases, both. Reinforcements may be present such as wooden or metal dowels, pegs or tongues, or strips of canvas or un-woven fibres across the joints beneath or within the ground layer (Bisacca et al 2011), (Skaug 2006). Rigid supports such as cross-battens may have been fabricated, attached to the reverse using nails, metal or wooden bridges or other devices, allowing for lateral movement in some cases. In Italian poplar panels, tapered cross-battens were frequently dovetailed into the wooden support. Panel paintings may be executed within engaged frames, or be rigidly attached to framing elements. Whilst not all panels are coated (painted) on one side only, most are asymmetric, and many that were intended to have decorative surfaces on both sides have been subsequently altered (cut within the thickness of the board¹) to become coated on one side only¹. In this asymmetry lies a correlation with other objects such as wooden furniture or panelling which may also be constructed from planks of wood, coated on one side with varying restraints on the reverse.

2.b. Fundamentals of Wood Structure

A variety of different types of cell of particular chemical composition produce the complex biological structure of wood, formed not as a structural engineering material but as tissue designed to meet the needs of a growing tree. The biochemistry of the wood in a living tree defines the properties it extends to us as a material and the deformations we encounter in the structural conservation treatment of wooden objects such as panel paintings. Insight into how to best treat those deformations requires understanding of the microscopic structure.

¹ For example: *Van Eyck, The Adoration of the Mystic Lamb, Saint Bavo, Ghent*. The side panels of the Ghent Altarpiece were cut longitudinally to allow both sides of the painted panels to be seen simultaneously. This was not an uncommon occurrence, and has occurred in many altarpiece panels in many collections worldwide.

Anatomy, Cellular and Chemical Structure

Investigation of timber structures for panel paintings can be limited to those cut radially or tangentially from the trunks of trees as solid planks or boards. Anatomically, the structure of wood is well researched (Bergman et al 2010), (Dinwoodie 2000), (Hoadley 1978, 1998). The wood in panel paintings tends to be cut from the heartwood of a tree. Sapwood has usually been limited or selected against by panel makers when employing more temperate hardwood species, though it has been noted in many artworks, usually in relation to insect damage at board edges (Wadum 1998a). On occasion lengths of pith might also be found. Knots are a more common occurrence, sometimes covered with canvas or fibres beneath the ground or cut out and replaced with wood of higher quality (Uzielli 1998).

The seasoned timber dealt with in panel paintings is made up from mature cells consisting of the cell walls and the lumina. Cells within wood are typically many times longer than they are wide and are orientated axially (parallel to the trunk) and / or radially, across the growth rings of the tree. The bulk of strength and the main water transport system is provided by the axial system, interconnected to the radial cells providing lateral transport. In all types and species of wood, the cell wall is highly regular with regard to constituents of cellulose, hemicellulose and lignin. The cell wall is composed of the lignified middle lamella, the primary wall and the triple layered secondary wall. These are fabricated from cellulose polymers covalently bonded together, hence their high strength in the axial direction. The polymers are collected into microfibrils of indeterminate length by hydrogen bonding and Van der Waals forces between the chains. The hydroxyl groups providing the hydrogen bonding sites also provide cellulose with its characteristic affinity for water. Hemicelluloses link the cellulose microfibrils². A brittle matrix of hydrophobic lignin, responsible for much of the stiffness of both green and seasoned timber is provided as a protective sheath to the hydrophilic cellulositic material which can lose significant mechanical strength when wet. For simplicity these components can be compared to the structural components of concrete; lignin mimics the stone element providing strength in compression, cellulose can be compared to the steel reinforcement providing strength in tension and hemicellulose provides the bond, much like the cement in concrete.

Softwoods have a simple structure possessing only two cell types with very little variation. Ninety percent of the cells are axial tracheids, often 100 times longer than they are wide, formed radially in rows being both conductive and mechanical.

² The acidity of wood is caused by the hydrolysis of the acetyl groups within the hemicellulose in the presence of moisture, forming acetic acid. This is particularly significant as it can produce severe corrosion of metal fixings, particularly at high relative humidity.

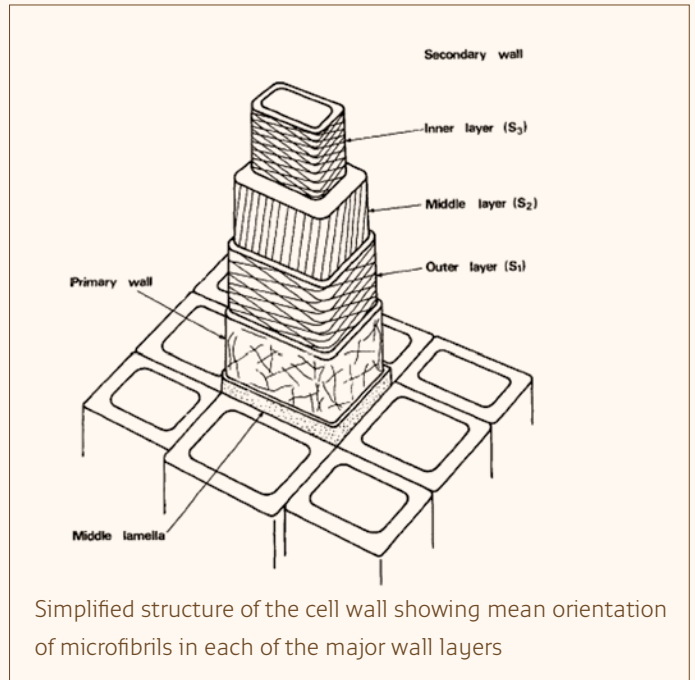


Figure 1 The primary wall is characterised by the random orientation of cellulose microfibrils. Within the secondary wall the microfibrils are organised directionally. The first of the layers (S1) is thin and the cellulose laid helically with an angle of 50-70 degrees between the microfibrils and the long cell axis. The second layer (S2) is the thickest and, with a low microfibril angle between 5 and 30 degrees making the fibres almost parallel to the axis of the cell, makes the greatest mechanical contribution to the properties of the cell wall. The thinner third layer (S3), is made up from microfibrils with an angle of over 70 degrees, almost perpendicular to the axis of the cell. (Copyright BRE, reproduced by permission)

They overlap at each end and are linked by pits allowing the conductive properties to continue throughout the height of the trunk. The brick-shaped ray parenchyma cells collectively appear as dark lines radiating out perpendicular to the growth rings, generally around 2 cells wide and 50 cells high. Resin canals may also be present in some softwoods, tending to be orientated in the axial direction, surrounded by parenchyma cells that specialise in the production of resins.

The greater number of basic cell types in hardwoods have greater degree of variability and complexity, including a 'vessel' or 'pore' element. There is a huge diversity of hardwood anatomy. The axial system is composed of mechanically supportive fibrous elements, vessel elements and axial parenchyma all in different sizes and arrangements. The radial system is comprised of the rays, with a variety of cell size and shape. Vessels are shorter than softwood tracheids and stack on top of each other linked by perforation plates. Vessel diameters can vary considerably as can their number and distribution. Pits link vessels and ray cells tangentially. The thickness of the fibre cell wall determines the density and mechanical strength of the timber of each hardwood (Dinwoodie 2000).

Both softwoods and hardwoods may exhibit abrupt transition, gradual transition or no apparent transition between the earlywood and latewood in the growth rings. Most softwoods used in panel paintings have an abrupt or gradual transition. In hardwoods the difference in transition is classed as diffuse-porous (no transition), semi-ring-porous or ring-porous (abrupt transition) relating to the relative size and distribution of the vessels in the earlywood and latewood. Of the common species of wood used in panel paintings, poplar is diffuse porous and oak is ring porous. The structure of the wood will determine the wood density; the greater the proportion of thick cell walls, the more dense the wood. Therefore the density is also directly related to the relative proportions of the different cells; where there is a greater proportion of latewood, the density increases. Noted in the Grabner et al (2010) study of softwood from pith to bark, was that the density and therefore the strength of the wood increased with increasing cambial age (tree rings) due to the increase in the percentage of latewood, however in ring porous woods such as oak, the opposite is true.



Figure 2 Wood sections, X: cross section, R: radial, T: tangential (Wolfgang Gard)

Sectional planes

The transverse plane or cross section is the face exposed when the cut stump of a tree is viewed, or when a cut is made across the grain (across the direction of the fibres or trachieds). The radial plane runs from pith to bark, parallel to the axis of the tree, it is the face exposed when a plank is ‘quarter sawn’ or split along its length. The tangential plane is a face cut at right angles to the radial plane. Each of these three planes, when cut as a board of wood and used as a support structure, exposes a different part of the cellular structure and has different mechanical and rheological properties. In practical terms, unless it is split, wood does not tend to be converted into a true radial section, the exposed wood in many panel paintings exhibit a ring structure incorporating both radial and tangential regions. [See fig 2](#)

The cellular orientation of a piece of wood leads to anisotropy in dimensional change. It shrinks / swells most in the direction of the annual growth rings (tangentially), approximately half as much across the rings (radially), and only slightly along the grain (longitudinally). Even in wood with uniform growth, the combined effects of radial and tangential shrinkage can distort the shape of wood pieces because of the difference in shrinkage and the curvature of annual rings.

Wood technology literature provides information on the longitudinal characteristics of wooden beams, or on different sections of green wood and timber oven-dried to an moisture content (MC) of 12% (Kretschmann 2010). Recently Mazzanti et al (2010) performed cross-grain compression and tension experiments on blocks of radial, part-radial and tangential poplar at differing relative humidity (RH) and therefore MC values as part of a larger study of the mechanical properties of poplar used in panel paintings. Although they found the radially cut blocks and those with the lowest MC to be strongest and stiffest in tension and compression, the conclusion was drawn that neither the MC nor the cut of the wood greatly influence the strength or modulus of elasticity (MOE), although the MOE is somewhat higher in compression than in tension. However, results of this kind of research depend very much on the test method applied, the selected specimens, the size and the number of samples, therefore comparison may be deceptive.

Anomalies in Wood Structure Causing Deformations

The assumption is often made that wood grain runs straight up and down the trunk of a tree, however this is not always the case. In some logs, a spiral grain is evident, due to the gentle slope of the cellular overlap during the tangential division of the cambial cells. A spiral grain can lead to a loss of strength and increase in twisting upon drying. In other logs the grain may run initially in a clockwise helix, then a few years later run counter clockwise forming an interlocked grain. In both these

cases it is impossible to cut a straight-grained plank, regardless of the skill of the craftsman. However, when a log is straight-grained, it is possible to make a cut in which the long edge is not parallel with the grain. A plank cut with such a diagonal grain can also lead to atypical deformations in response to changes in MC. Around knots the growth rings or grain can become deformed.

Certain regions of a tree form slightly different cell structures leading to different mechanical characteristics. Primarily, the earliest formed wood of a tree, those rings (10-20) closest to the pith are known as juvenile wood. In softwoods this is characterised by a higher microfibril angle in the S₂ layer of the cell wall. This correlates to a much higher rate of longitudinal shrinkage of these cells when seasoned for use. Consequently a board of wood containing juvenile wood will have a much greater tendency to warp, cup or check. The morphology of the cells is often altered so that cells become short and angled or twisted and bent. The wood outside this core is known as mature wood and has a greater strength and dimensional stability.

Reaction wood, formed when the growing tree is deflected from the vertical by more than one or two degrees, can also produce misshapen cells. In softwoods, reaction wood is formed on the underside of the leaning branch or trunk and is known as compression wood. Here the tracheids are shorter and misshapen with a large S₂ angle, high longitudinal shrinkage and high lignin content, leading to embrittlement. In hardwoods, the reaction wood is formed on the upper side of the leaning branch or trunk and is known as tension wood. Here the fibres fail to form a proper secondary wall and instead form a highly cellulosic gelatinous layer (the G layer) making the resulting regions more rubbery. Dinh et al (2010) obtained experimental data on the mechanical properties of tension wood in poplar, demonstrating the higher density and longitudinal stiffness, but lower transverse stiffness in comparison to normal and 'opposite' wood. This was concluded to be due to thicker cell walls with slight differences in chemical composition and microfibre orientation coupled with a lack of cohesion of the G layer with the rest of the cell wall. Although some panels are likely to contain these tissues and have different localised rheological properties, in reality, the number of panel paintings containing juvenile or reaction wood is likely to be low, bearing in mind the wood is most likely to be cut from the heartwood of a straight tree trunk, and selected for quality by an experienced panel maker. However, poplar is known to contain tension wood in mature tissue³, and this may have a bearing on its rheological

³ Conversation with Wolfgang Gard.

properties. Brommelle (1963) discusses a mahogany panel from the Victoria and Albert Museum which exhibits bands of reaction wood which have formed crack deformations across the grain. The importance of the quality of the wood is clearly intrinsic to the stability of a panel painting. The tall straight grained oak from the Baltic forests have produced some of the most stable cuts of wood used for panel paintings.

Hygromechanical Behaviour of Wood

The most significant characteristic in the conservation of panel paintings is the hygromechanical behaviour of wood. Timber is a hygroscopic material and so will absorb and release moisture from the atmosphere in order to remain in equilibrium with its surroundings, the cells within the structure will alter their dimensions accordingly, swelling as the moisture content increases and shrinking as it decreases. Acclimatising within a stable temperature and water vapour pressure, or RH in the atmosphere, a piece of wood will reach an equilibrium moisture content (EMC). The adsorption and desorption of moisture by wood follows a hysteresis function. This means that the amount of moisture that is adsorbed from a dry condition to equilibrium with any (higher) RH is always less than the amount retained in the process of drying from a wetter condition to equilibrium with that same RH. Work has been carried out to determine average EMC for many species of wood experimentally during drying of green timber (Dinwoodie 2000) however work more relevant to the conservation of panel paintings are figures related to the dimensional change in response to changes in MC in dried timber (Farmer 1972, 1977), (Rijsdijk et al 1994).

Green timber obviously has a higher MC than seasoned timber due to the high sap content still within the cell cavities, however the occasions in which timber with a moisture content above its fibre saturation point (FSP) might be encountered, are rare. The aftermath of the 1966 flood in Florence, Italy saw an enormous number of paintings and other objects of cultural heritage severely water damaged. Work on repairing some of these objects is still ongoing. Dimensions taken of poplar panel paintings as they dried showed that whilst the mass of the objects decreased steadily as they lost moisture, it was not until the panels reached a moisture content of approximately 30% that the panels began to shrink (Casaccia 2006). This is a clear demonstration of the loss of 'free' water within the cell cavities followed by the loss of the water within the cell walls affecting the dimensions of the cell walls.

Although wood can also exhibit thermally induced dimensional change, these movements are not as significant as those relating to moisture. As in other materials, thermal expansion will occur in wood due to the increase in distance between molecules as they increase in oscillation, more significantly in the transverse grain direction. However, the net result of thermal expansion tends to cause a negative dimensional change, the increase in temperature drives out moisture, resulting in moisture related shrinkage. In a benign sealed environment temperature fluctuations can be problematic due to changes in RH. Much work has been done on thermal and hygro-dimensional changes in wood to inform the transport and microclimate display of works of art (Richard 2011, 2007; Fuesers et al 2005; Richard et al 1998; Wadum 2000, 1998). The resultant recommendation has been to seal the wooden object in a minimal air space in order that any change in RH caused by fluctuations in atmospheric temperature will be accommodated by the object itself with only a very low variation in EMC, and therefore a very small dimensional change, within 'safe' parameters. Many panel paintings travelling due to loan requirements are now packaged in Marvelseal envelopes (Miller 2011). This measure is effective in buffering any climate fluctuations of temperature and relative humidity outside the package (depending on the leakage rate of the enclosure), however infra-red (IR) radiation from lighting sources can cause local heating of the surface. This is likely to cause local emission of moisture and a localised moisture gradient. Work has been done on evaluating sudden temperature increases within microclimate boxes containing pastel drawings (Ankersmit et al 2011), however this needs to be extended to panel paintings as the buffering effect of the wood may give different results. Observation of panel movements, incurred by an increase in temperature, appear to indicate a loss of moisture in a panel even in a stable RH⁴. Similarly an increase in temperature can result in an increased rate of moisture loss during a reducing RH cycle with an accompanied dimensional response. Mecklenburg also asserts that moisture adsorption or desorption depends very much on temperature⁵. Lower temperatures will slow down uptake (or release) of moisture significantly. This might be the reason why in unheated spaces such as Skokloster Castle, Stockholm, Sweden many objects in the collection are in a relatively good condition.

The mechanisms of adsorption and desorption of moisture in wood are not fully understood. The hydrophilic nature of cellulose and hemicellulose is due to the hydroxyl groups on the molecules providing hydrogen bonding sites for water molecules. The lignin cementing the cells together in the secondary walls is hydrophobic and can limit the uptake of water (Wiedenhoeft 2010), however this does not appear to mask the primary effect of the cellulosic material. Sorption of moisture by wood is a surface phenomena whereby the hydroxyl groups in the

⁴ Ray Marchant, personal observation.

⁵ Personal communication with Bart Ankersmit.

cellulosic material attract moisture to form layers of water molecules on the wood surface in an exothermic reaction. Inagaki et al (2010) have suggested a model for a 3-stage water adsorption mechanism based on free water molecules, those with one OH group engaged in hydrogen bonding, and those with two OH groups engaged. This was used with experimental results from Near-infrared (NIR) spectroscopy to look at the behaviour of water in wood. [see section on Ageing of Wood.\[page 31\]](#)

The EMC obtained at any set RH in any given timber is different depending on whether the water is being adsorbed or desorbed. As previously stated, timber reaches equilibrium at a lower percentage moisture content when it is taking up moisture than when it is releasing moisture. Attempts have been made to explain this hysteresis effect both physically and chemically (Dinwoodie 2000) however it does not appear to be wholly understood. Bratasz et al (2008) observed a hysteresis effect during their measurements of sorption and desorption of moisture of historically important wood species, however, they were unable to state if this were due to the increase of the internal surface with more adsorption sites made available, or by a delayed removal of water trapped in the smallest capillaries and channels in wood on desorption. It is unclear how large the impact of hysteresis is within the oscillating fluctuations of RH in any environment. It may be relevant in understanding the many cycles of dimensional change and resultant permanent deformations of panel paintings.

Moisture Gradients

Moisture transfer with the surrounding air begins at the exposed surfaces of the wood, slowly penetrating through the cellular structure by ways of the anatomic features mentioned previously. The rate of transfer is increased with an increase in temperature. The slow penetration causes a moisture gradient to be set up through the thickness of the timber from the time that the RH levels change until a uniform EMC is established. The presence of a moisture gradient within a board of wood will induce a non-uniform dimensional change across the structure, leading to localised internal mechanical (Eigen) stresses. This situation is further exacerbated in many panel paintings by the asymmetrical structure where a panel may be painted (coated) on only one side. In most panel paintings therefore the reverse surface is the main transfer surface, and the painted surface is a partial moisture barrier. Allegretti et al (2008) made experimental measurements of diffuse water vapour flux through samples of spruce with 16 different coating combinations replicating different paint films finding that the barrier effect of tempera on gesso is small when compared to oil paint, gilding and varnish. Dionisi Vici et al (2006) studied the mechanical response of wooden boards subjected to realistic step changes in RH (35%, 50% and 65%) comparing symmetrical (uncoated) and asym-

metrical (one surface waterproofed) and restrained and unrestrained panels. A monitoring cross beam, screwed into the panel, was used to measure cupping and strain. Hygrometric response times were very fast, however approximately 3 (symmetrical panel) to 6 (asymmetrical panel) months were required to reach a steady EMC. The symmetrical boards produced slow deformations in response to changes in RH, determined by their individual wood structure characteristics, the asymmetric panels produced a strong transient reaction, reaching a peak of deformation after about 2 weeks, then fading out after approximately 3 months. This was interpreted as a consequence of a moisture gradient across the thickness of the wood, producing a strong tendency to deform, increasing or decreasing cupping, then fading out as the gradient decreases. Both the size of the deformation and the strength of the forces were greater in the asymmetric panels.

Common methods used to measure the MC of wood (resistance meters, capacitance meters or power-loss meters) either require holes to be made in the timber, or give readings only from the surface of the wood (Dinwoodie 2000) and therefore cannot provide a moisture gradient throughout the thickness of the wood. To obtain true data about the moisture gradients in panel paintings using these methods, sacrificial objects would need to be used, or the use of destructive testing would have to be accepted, however less invasive methods are now being developed. Bratasz et al (2005) have extrapolated data by modelling, projecting strain information from a polychromed altarpiece onto experimental gradients measured in same species wood. More recently, Fragiaco et al (2011) investigated the moisture induced stresses perpendicular to wood grain, using finite element modelling based on a Fickian moisture diffusion analysis and a mechanical model for time dependant behaviour of wood. Larger stresses were found for larger RH fluctuations. The hysteresis effect was ignored which was assumed to be likely to lower the stress values calculated, however new moisture transfer models are being developed to also include plasticity in compression and cracking in tension. Dvinskikh et al (2011) have published experimental work into the distribution and dynamics of water movement using nuclear magnetic resonance (NMR) imaging, a non-destructive technique. Experimental data was successfully compared to multi-Fickian models taking into account water vapour diffusion in cell lumens and bound water diffusion in cell walls. The equation was prepared for building structures, however does bear relevance. The experimental study showed moisture uptake to be faster in the longitudinal direction, producing a much smaller moisture gradient. Tangentially, the largest gradient was observed, with the average MC changing much more slowly. In the radial direction a significant moisture gradient was also observed, along with a rate of change in MC comparable to the tangential direction.

Weathering of the Reverse

Changes to the surface properties of wood used outside are well studied, particularly due to large temperature fluctuations and surface water (as opposed to water vapour). Other factors to consider are photochemical degradation caused by ultraviolet and visible light. Tolvaj et al (2010) have shown that although extreme effects of photochemical degradation causing degradation of lignin require sunlight, some thermal degradation of the carbonyl groups can happen in shadow, causing more degradation to the earlywood than the latewood. Pollutants may also lead to changes in the wood surface. The significance of this in panel paintings is difficult to judge. The reverse of a panel is unlikely to be subjected to any of the extremes of condition encountered in wood outdoors, however, it is well known that a freshly cut piece of wood reacts differently to one which has a ‘weathered’ surface. The mechanisms leading to this ‘weathering’ do not appear to be studied.

Ageing of Wood

In general literature it does not appear that the simple ageing of wood within a panel painting has any great effect on its structural or mechanical characteristics (Klein et al 1990), although what may have an effect are external influences over time such as past conservation treatments, biological deterioration factors or climatic influences. Erhardt et al (1996) produced isotherms and investigated the stress-strain relationship and stiffness of 17th century timber and new wood cut from the same species (*Pinus sylvestris* L) and same location. They found no appreciable differences between the old and the new wood. However, more recent work shows that chemical changes to the components of wood do occur over time, the content of carbon, hydrogen and mineral salts increase, whilst the content of oxygen and nitrogen decrease. Inagaki et al (2010) showed that ageing leads to a decrease in adsorption sites on hemicellulose and amorphous cellulose molecules along with a decrease in EMC. This is confirmed by Kawai et al (2010) who link these changes to a slow thermo-oxidative process caused by oxygen in the air. Also observed is an increase in strength and stiffness and a decrease in toughness upon ageing. This observation can be explained by a reduction in hemicellulose and cellulose content, whilst leaving behind lignin to provide compressive strength, but little strength in tension either parallel or perpendicular to the grain, leading to increased brittle behaviour in these planes. Grabner et al (2010) also note that ageing affects the chemical structure which may affect density, but not the physical or anatomical structure unless biodeteriorated.

2.c Damage Observed in Wooden Panels

Although the support is a valuable aspect of the history and the physicality of an object, the worth of a panel painting is placed on its painted surface. The durability of the support leads to the long-term preservation of the paint, therefore conservators work on the support to conserve the decorated surface. This is not true of all painted or decorated surfaces, where the support is regarded as an integral part of the object, such as in polychromed objects and many furniture items. Unfortunately, the drive to preserve the paint film with a misguided understanding of the wooden support has led in the past to drastic treatments, causing long-term damage to the decorative surface as well as the support. Almost without exception, any fixed cross-grain restraint is likely to cause damage. As mentioned previously, a panel painting might have a variety of support structures, however as the location and function of many of these objects has changed over time (altarpieces were removed from their original settings and physically separated or dismembered into several pieces to fit new chapels or to be sold on the open market as several paintings) so too have the support structures of many changed (Gordon et al 2012). Polyptychs may have had constituent panels separated or single panels may have been sawn into several pieces to separate different compositional elements. Double sided panels may have been sawn through their centre to separate two images (Schiessl 1998). Whilst many objects were not affected by such interventions, sadly fragments of paintings are very common throughout collections worldwide. Inevitably, these types of intervention create changes in the types of support / restraint mechanisms, many of which, along with the inexorable change in climate conditions as they were altered, transported and re-housed, were unsuitable to the individual panels, and have led to a consequential cycle of treatments and re-treatments since.

Whilst damage to the wood structure of a panel painting may be caused by its conservation and acquisition history, a variety of other factors such as the quality of the wood chosen, biological infestations and inappropriate housing in bad environmental conditions also play a part in the deterioration of wooden structures. Timber not fully seasoned before use may produce deformations, and climatic fluctuations induce constant expansion and contraction movements within the support leading to distortion and fracture, particularly where support devices cause restraint.

Wood Damage by Biological Attack

The wooden support of a panel painting is often susceptible to biodeterioration such as insect or fungal attack, depending on the conditions in which it is housed.

Types of fungal growth and species of wood-attacking insect along with the types of damage caused are well documented (Blanchette 1998). Multi analytical work carried out by Popescu et al (2005) assesses the selective degradation of the chemical components of wood caused by fungal and bacterial attack. Sandu et al (2003) carried out a thermogravimetric study on the ageing of limewood supports using a variety of samples of different objects from between 26-200 years of age and at different stages of insect damage. Findings included the increase in adsorption of water by insect damaged wood, increasing the likelihood of bacterial attack. This increase is likely to be due to the opened structure of the wood and the presence of wood flour which is far more adsorbing of water. What is not clear is how an increase in insect damage will change the mechanical properties of the support, at what level it can result in total failure of the support and how this might be assessed. Ultrasound technology is currently being developed for such use.

Seasoning Shrinkage

As previously noted, panels are complex composite objects with the ability to display a number of deformations relating to different elements of their construction. It is widely known that tangentially cut boards often develop a cupping deformation in a direction contrary to the growth rings due to the anisotropic shrinkage of the cellular structure of the wood. Single boards may also exhibit planar deformations such as crooking, cupping, twisting or bowing, due also to intrinsic structural anomalies such as atypical slope of grain and juvenile or reaction wood (Uzielli 2006). However, although these types of 'shrinkage' deformation are linked to the seasoning from 'green' wood, they may be observed in some panel paintings, perhaps linked to the MC of the panel at the time it was prepared and painted. [See fig 3,4 \[next page\]](#)

The anisotropy of wood in its different grain directions causes shrinkage to be minimal in the longitudinal direction, but quite significant in the transverse grain direction, being greater in the tangential direction than the radial direction. The microfibrillar angle appears to influence the differing degree of shrinkage of normal wood, particularly as it has been experimentally shown that compression wood, with a much higher than usual microfibrillar angle, exhibits much higher relative longitudinal shrinkage and lower relative transverse shrinkage. The difference in shrinkage between the radial and tangential planes have been explained as follows; the restricting effect of the rays in the radial direction, the increased thickness of the middle lamella in the tangential plane, the difference in lignification between the two planes, the small difference in microfibrillar angles between the two walls and finally the alternation of the earlywood and latewood in the radial plane which because of the greater shrinkage of latewood, causes the

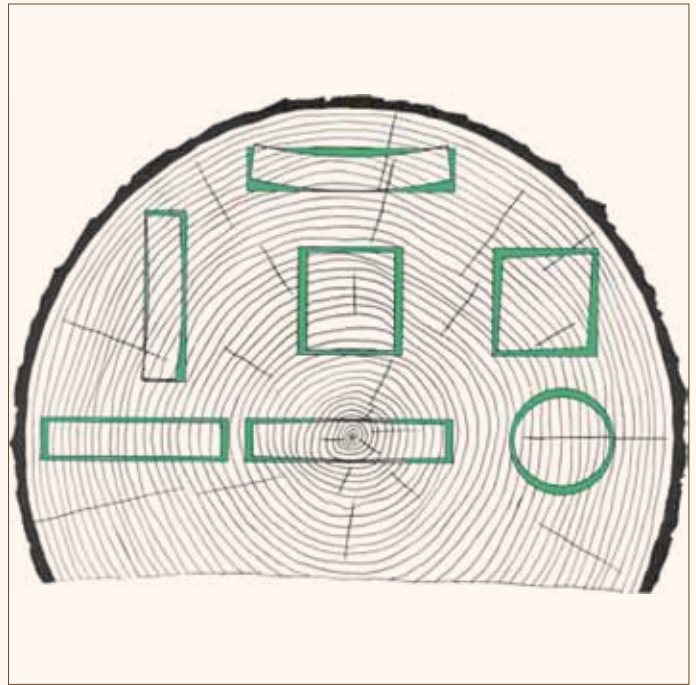


Figure 3 Seasoning distortions (Wolfgang Gard)

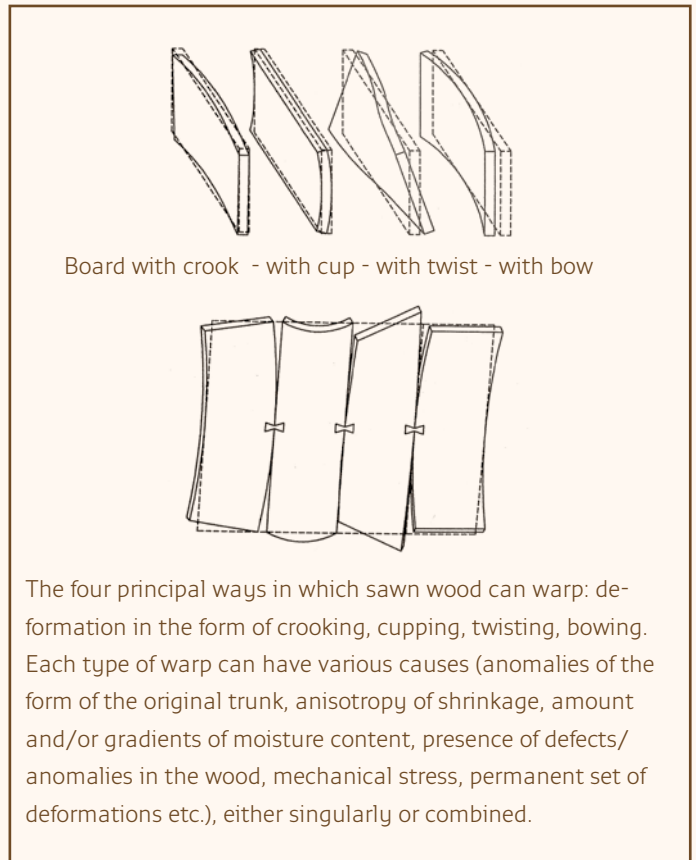


Figure 4 Planar board deformations
(L. Bevilacqua and L. Uzielli, OPD)

weaker earlywood to shrink more in the tangential direction than it would if it was isolated. In an attempt to avoid shrinkage after timber has been dried for use, Dinwoodie (2000) therefore recommends that timber is seasoned to the expected equilibrium moisture conditions in which the object will be situated; 12% for an environment with regular intermittent heating, and 10% in a building with central heating.

Pellerano (2003) studied the wood grain of the Madonna of Itria, identifying the species and region of the trunk from which the panel was cut, however did not identify any anomalies in the cellular structure of the wood or link them to deformations in the panel. The 2004 study of the Mona Lisa (Mohen et al 2006) is an excellent example of detailed examination of a wooden support, there is no other publication known to this author that has included an examination of the support at this level, linked it to observed deformations and predicted future behaviour, however although the wood grain and cut are examined, the wood quality, density and possibility of cellular anomaly are not discussed.

Creep

When a load is placed upon a piece of wood, an initial instantaneous deformation will occur, as with any elastic material. However, if the load is maintained for a period of time, the deformation will continue, albeit at a reduced rate. This increase in deformation or displacement, occurring at a molecular level, is termed creep. Creep behaviour can be partially reversible, but is also partially permanent resulting from plastic or viscous flow. [See figure 5 \[next page\]](#)

When dealing with a panel painting undergoing cyclic changes in RH, a physical load may be replaced by internal stresses resulting from moisture gradients and structural restraint devices. Many studies are based on longitudinal grain creep due to the relevance to load bearing structural timber, however transverse grain creep is more relevant to historic objects. Kusunoki et al (2005) in experimentation over a time period of 4 years found the cross-grain bending creep in structural timbers of Japanese Cypress to be 2.5 times greater than the initial deflection of load, whilst the compressive creep was as large as 5 times greater. During this time period, cyclic changes in amount of deformation due to seasonal changes in climate were also observed. Madsen (1992) and Gnanaharan et al (1979) also find that creep perpendicular to grain is considerably (at least 3 times) greater than creep parallel to grain. Madsen also confirms that creep behaviour under varying climate conditions could be multiple times higher than under constant climate load because of its mechano-sorptive behaviour. Colmars et al (2010) performed 3 point bend tests in radially cut poplar under constant load for 10 hours and found the creep compliance increased as the MC increased. This observation is borne out by Brewer et al (1997).

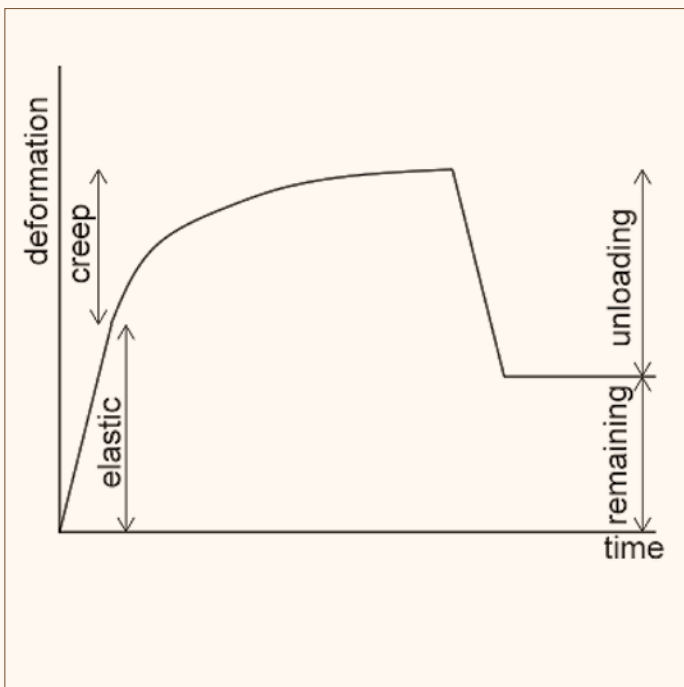


Figure 5 Rheological behaviour of wood (evolution of deformation under long-duration loading and successive unloading), André Jorissen.

Wood Movement & Compression Set

It is the uptake and loss of moisture within the cell structure of timber that the fundamental mechanical properties of panel paintings are based upon, as Hoadley (1978) stated “wood-moisture relationships underlie most problems with wood facing conservators”, “everyone knows that woods shrinks and swells, no one understands every complication of the mechanisms involved”.

Dimensional changes under the heading of ‘wood movement’ relate to those cyclic dimensional expansions and contractions caused by changes to the RH in which the object is housed. These occur both on a seasonal basis and also on a daily basis. Dinwoodie (2000, p73) suggests that these changes are likely to be small, inducing only slight changes in the MC and as a considerable delay occurs in the diffusion of water vapour into and out of the centre of a piece of timber, he believes that dimensional changes in seasoned timber are considerably smaller than those due to seasoning shrinkage. However, observation by conservators has shown that the dimensional changes in relation to changes in RH in objects such as panel paintings, particularly those that are very thin can be both swift (a matter of minutes) and significant (Brewer 1994), (Dionisi Vici et al 2006). Wadum (1998) confirms that dimensional change in hardwoods is greater than that in softwoods, thin pieces of wood respond more quickly than thick ones, and small pieces respond more quickly than large pieces of equal thickness. As with the initial seasoning shrinkage, the wood movement is least significant in the longitudinal direction, and most significant in the tangential direction, as demonstrated by Bratasz et al (2010) who have now provided sorption and desorption isotherms along with the expected dimensional change in radial and tangential (but not longitudinal) directions for 21 species used in historic objects. Rijdsdijk (1994) also contains values for longitudinal shrinkage and swelling in many timbers.

Apparent from the observation of panel paintings, is that ‘shrinkage’ does not seem to be limited to the initial seasoning of wood. Compression Set (or Compression Set Shrinkage) can be defined as plastic deformation as a result of the combined effect of moisture changes and restrained support condition. Examination of paintings executed within an engaged frame often reveals a large discrepancy between the sight edge of the frame and the painted surface with its raised barbe of paint and ground at the original junction of the frame and support (Brewer 2000). This phenomenon can also be observed by the discrepancy between the length of cross-grain applied members of auxiliary supports such as cradles and the (smaller) width of the panel support (Rothe 1998). Another example of ongoing compression / shrinkage is demonstrated in some painted panels in the Great Chamber at Chastleton House, England. These panels have painted roundels, marked out by

compass incision and measurements show that the roundels are now slightly elliptical, having shrunk slightly more across the grain⁶. This mechanism of progressive cross-grain shrinkage or compression set⁷ as observed by conservators and considered due to long-term fluctuations in MC in association with movement most easily discerned across the grain, is not fully understood, nor is its association with the degree of restraint placed upon a panel.

The relevance of longitudinal compression is often dismissed; Mecklenburg et al (1998) “in the direction parallel to the grain of a wood substrate, applied materials are considered to be nearly fully restrained because woods longitudinal dimension remains essentially unchanged by fluctuations in relative humidity”. However, observations have been made by conservators of panels cupping in the longitudinal direction. This type of deformation was described in the work conducted by Brewer (2000) who detected a pattern of longitudinal warp using digital photogrammetry and moiré fringe analysis in looking at the reaction of unrestrained panels to changes in RH. In these experiments, a cumulative saddle shaped warp deformation was observed, rather than a cylindrical warp that would relate to only transverse grain shrinkage. Observation of longitudinal deformation when subjected to a longitudinal restraint such as a cradle has also been noted during panel treatments (New et al 2011). This concave warp parallel to the grain may be a result of the lamination of different timber types, e.g. mahogany and oak, where only a very slight difference in response to environmental effects can become exaggerated in the same way that a bi-metallic strip responds to temperature change⁸.

6 The ‘Sibyls and Prophets frieze’ in Chastleton’s Great Chamber consists of 24 panels framed by the room’s wooden panelling. Three of these panels are modern reconstructions, however, the rest are original paintings from the first half of the 17th century. Each painting depicts the head and shoulders of a sibyl or prophet within a roundel. The panels appear to have been cut and prepared as a group from local oak. Each is radially cut with bevelled edges and approximately 35cm square. Observations from microscopy, raking light and x-radiography suggest that a compass was used to mark the roundels in the ground; a small hole is evident in the centre of each panel.

7 This type of deformation occurs at a cellular level, rather than at the molecular level of creep.

8 Correspondence with Ray Marchant.

Another type of warp, displayed as an overall convex curvature across the grain in an unrestrained panel, and often as a washboard deformation in a panel with a cross-grain restraining auxiliary support with fixed localised attachments is an ongoing phenomenon found in seasoned and aged panels regardless of the cut of wood or positioning of boards. This manifestation of ‘compression set’ has long been identified in conservation literature (Stout 1955; Buck 1972). Within conservation, this is understood as an effect of the asymmetrical nature of a panel painted on one side. The paint and ground film have a dual effect of mechanical restraint and vapour ‘barrier’. The asymmetric moisture sorption and desorption lead to a differential moisture gradient resulting in constrained ‘wood movement’ on the reverse of the panel leading to plastic compression damage to the outermost cell walls during cycles of high RH, followed in turn by shrinkage during cycles of low RH. Due to the plastic crushing deformation, the cell walls make an incomplete recovery to their original dimensions, leading to a convex deformation across the grain, the direction in which the wood structure is most dense. This type of slow, cumulative and permanent deformation can be observed in action by the cyclical change in curvature of a panel undergoing changes in RH. Brewer et al (1997) note that as the RH increases, the MC increases in a gradient from the unpainted side through the thickness of the wood. They reason that this gradient produces rolling shear stresses between the wood fibres and tensile stresses perpendicular to the grain in the wood and the coatings on the front, which are not yet swollen. These act as a restraint on the swelling wood which is in compression. The resultant out-of-plane deformation or warp relieves both the shear and compression stresses by allowing more swelling at the reverse, although this is partially resisted by the remaining unswollen thickness (therefore thin panels warp more easily). As the MC become uniform there is some reversal of the warp, restrained by the coatings on the front surface. Over time, the visco-elastic behaviour is overcome by creep, at a higher MC creep is increased and therefore at the reverse of the panel, the compressive stresses cause the wood fibres to become progressively crushed, leading to a long term relaxation of the warp, inducing a permanent warp when the RH is decreased. The complex process described here, consisting of creep, compression set and relaxation is not fully understood, nor easy to effectively describe. Scientific investigation and practical proof of this behaviour is intrinsic to understanding and safeguarding painted wood panels.

The relationships between the vapour barrier effect and the mechanical restraint of the paint film within compression set is not fully understood, and does require clarification in order to inform treatments, particularly where a coating might be applied to the reverse of a panel as a moisture barrier, as moisture uptake could also be controlled by buffering the local environment (Monfardini 2011).

Modification of Wood Movement

Dimensional stabilisation has been found to improve by heating timber to very high temperatures for a short period, inducing the degradation of the hemicellulose with considerable loss of strength and toughness (Dinwoodie 2000) although Colmars et al (2010) found the decrease in strength to be lessened if the duration of the treatment (at 150°C) was decreased. Wirth (2004) studied the thermal behaviour of wood, stemming from research into a burnt cabinet and found that thermal degradation can take place at much lower temperatures if held for a long period of time. Thermal stabilisation is clearly not a practical solution for a historic object such as a panel painting⁹, having said this, there may be some evidence for panel makers attempting to reduce wood movement in boards prior to constructing the panel. Recent (unpublished) expert examinations of Van Eyck's Ghent Altarpiece, Belgium and Rogier Van der Weyden's Descent from the Cross at the Prado Museum, Madrid showed local burn marks on the individual oak boards which did not cross board joints. This charring could have been a deliberate attempt to increase the dimensional stability of the panels, which indeed remain in very good condition despite a chequered conservation and environmental history¹⁰. This would be an interesting area to investigate further. Other methods attempting to reduce hygroscopicity of timber are the chemical substitution of the active hydroxyl group by less polar molecules, crosslinking of the hydroxyl molecules or bulking of the cell wall to hold it in a swollen state using substances such as polyethylene glycol (PEG) or phenol formaldehyde. PEG has been used previously in conservation for the treatment of waterlogged wood, a discussion of the use of this substance in the treatment of the shipwrecked Swedish warship Vasa provides insight into its use today (Hocker et al 2012).

Moisture barriers and coatings for the reverse of panel paintings have been previously looked into as a method of stabilising wood movement, by imitating the level of moisture permeability of the paint and ground films thereby reducing the speed of moisture transfer, and removing the asymmetrical nature of the structure (Buck 1972), (Richard 1978), (Brewer 1991). Several coatings were tested and proposed by Buck and Brewer, wax or wax / resin coatings, for example, have seen significant favour in the past in some Northern European countries, shellac and various varnishes likewise, however, no wide-scale coating treatments are currently adopted by the conservation community. Instead, methods of stabilisation

⁹ Of note to mention is the thermal treatment currently used for many wooden objects 'Thermo Lignum' for removing insect and rot infestations. Objects are warmed up to around 55°C, within a constant RH for around a 24hr cycle.

¹⁰ Observations by George Bisacca. Ray Marchant also proposed that these marks may have been the result of pre-warming the boards to increase the working time of the hide glue used in the joints in the panels.

have turned to control of the environment, both of whole buildings and of localised climate vitrines. More recently panel supports have been designed utilising inset wooden strips to act as an RH buffer between the reverse of the panel and the surrounding climate (Castelli 1998), (Monfardini 2011). Further information about coating materials can be found in Chapter 4, Adhesives, Consolidants, Coatings.

Effect of Restraint

The relationship between load and resultant deformation in timber is extremely complex, timber does not behave in an entirely elastic manner – its behaviour is time dependant and the magnitude of the strain is influenced by factors such as density, wood quality (angle of the microfibrils within the cell wall), angle of the grain in relation to the load and RH. Although panel paintings are not necessarily designed to withstand load as structural timbers might be, they are often relatively fragile boards held under heavy restraint in terms of their support or framing system. Intrinsically linked to compression set, is the reaction of the wooden support to climate induced swelling and shrinkage whilst under restraint. Where a restrained, but un-fixed panel has the ability to shrink after climate induced swelling, a panel fixed across the grain will build up enough stress to fracture, (Hoadley 1978). [See fig 6](#)

Hoadley observed fractures often propagate from the end-grain surmising that these surfaces react most quickly in response to changes in moisture. Due to the anisotropic behaviour of wood, the moisture diffusion coefficient in longitudinal and cross-sectional directions are considerably different, therefore this could lead to distortions and cracks at the ends of the boards, however this was not confirmed in the experiments carried out by Brewer (2000), nor is this borne out by other structural conservation professionals¹¹. Regardless of the cause, once intercellular cleavage has occurred, propagation parallel to the grain, within the lignin along the middle lamella and primary wall can occur, exacerbated by ‘wood movement’ (Jeronimidis 1978).

Types of Restraint

Numerous conservation papers supply details of individual structural treatments and reinforcements. Proceedings from the 1995 symposium The Structural Conservation Panel Paintings organized by the Getty details much of the history of structural conservation, listing different practitioners and their methods (Rothe, Schiessl, McClure, Bret et al, Bergeon et al, Horns et al 1998). Invariably it is cross-

¹¹ Conversations with Ray Marchant and Al Brewer. It is often cited that greater moisture losses occur from the end-grain, this is more relevant during seasoning, but might give rise to micro-fracturing at that time, which will later then easily propagate under stress. Conventional framing frequently places points of high resistance on these edges. However, exposed cell structure is the obvious place for any fracturing to originate.

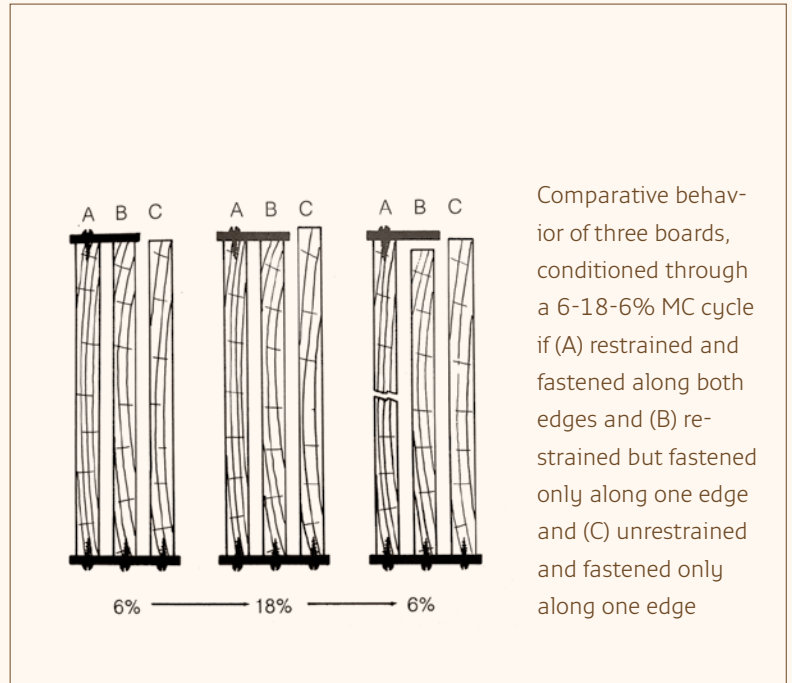


Figure 6 Restrained shrinkage (Bruce Hoadley)

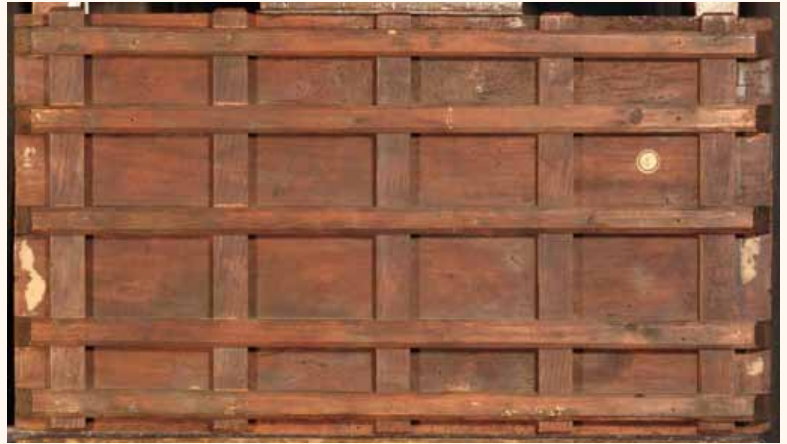


Figure 7 Cradle structure (Ray Marchant)



Figure 8 Inappropriate framing causing fracture in panel (Ray Marchant)



Figure 9A Anonymous, The Deposition. French school, 1575-1625. Oil on wooden panel, 99.5 x 70.8 cm. Example of 'washboarding' deformations due to cradle restraint of the original support in a panel painting (Fitzwilliam Museum, ©Hamilton Kerr Institute)



Figure 9B Anonymous, The Deposition. French school, 1575-1625. Oil on wooden panel, 99.5 x 70.8 cm. After conservation. ©Fitzwilliam Museum.

grain restraint, linked to the suppression of out-of-plane movement that causes the greatest damage to the structure of a panel painting. In Northern European and Northern American collections, the greatest single cause of harm to the support tends to be the previous (18th or 19th century) thinning of the support and application of a cradle in order to flatten the natural curvature of the panel. [See fig 7 \[previous page\]](#)

Brewer et al (1997) carried out moire fringe analysis of cradled and unrestrained panels aiming to investigate the relationship between wood movement and compression set, washboarding and flaking paint. This study has an excellent discussion of the types of climate induced deformation in both types of panels with an explanation of the type of wood failure experienced with cradle restraints. It was noted that compression stress on the reverse is increased when a panel is re-restrained due to the further compression caused by restraint from bending along with restraint from swelling. Other types of historic intervention included the complete transfer of the paint film to a new support because of worm-damage, flaking paint or warpage, different types of cross batten structures held either within the structure of the panel or between glued 'cleats', cross-grain join or split repair inserts and overall glued solid reinforcements. The framing devise is another form of restraint that should be mentioned. Although a panel might be structurally sound in itself, if framed inappropriately without allowance made for the climatic environment in which it is housed, dimensional change can be restricted and stresses can build up causing the panel to fracture. [See fig 8,9 \[previous page\]](#)

2.d The Role of Climatic Conditions

It is clear that the dimensional changes damaging to decorated wooden panels are due to changes in the atmospheric RH within which the panel is housed, leading to dimensional expansion and contraction of the wooden object. Mastering an understanding of the response of panels to differing RH has long been a goal of the structural conservator in an attempt to provide each object with a safe and reliable reinforcement, support structure or framing device that can allow it to remain within the environment in which it is housed without damage. One of the problematic aspects of this principle is that although many paintings are housed within a climate-controlled environment such as a museum, many are not. An artwork might also be situated within a historic house or a church with no climate control, or a private home with the more damaging possibility of human comfort control requiring heating in the winter and air conditioning in the summer without regard for levels of RH required to preserve artworks.

Currently in many museums housing paintings, air conditioning is strictly programmed to provide a constant temperature and relative humidity within certain boundaries, depending on the external regional climate of the museum¹². Altering these conditions to allow for seasonal fluctuations can reduce energy consumption and cost, however many conservation professionals are yet to be convinced that this is the best course of action for the preservation of artworks. Following research, suggestions have been made for museums to change climate conditions. Erhardt et al (1996) during their study of old versus new wood, put forward recommendations of ‘safe’ relative humidity fluctuations of $\pm 10\%$, for wooden objects such as furniture kept within a moderate relative humidity (of 50% RH). This was based on an average dimensional response of 0.4%, which they believe to be within the elastic limit of wood – i.e. before creep reaction. However, the softwood tested would not give representative values for the range of hardwood species used in most cultural objects due to the difference in density, denser wood is likely to have a greater dimensional response, and therefore could produce more damaging movements. The samples were also uncoated, and would also not be representative of a panel painting structure. Attention is often paid to the magnitude of variation of percentage RH. More consideration must be given to rates of change, as rapid changes of a lower magnitude may be more damaging. Bratasz et al (2007a) in their study in the Santa Maria Maddalena were able to show by monitoring movements of cracks within polychrome sculpture that large short-term (daily) fluctuations are far more damaging than similar long-term (seasonal) fluctuations, due to the lower moisture gradients set up by a slower rate of change. They also concluded that larger, thicker pieces of wood were slower to react, but much greater stresses were induced due to the moisture gradients, along with constant flux in dimension of the outer layers of wood. Work done by Olstad et al (2007) and Bratasz et al (2007b) presented at the 2007 Copenhagen conference Museum Microclimates, outline problems experienced due to short-term congregational heating in churches, investigate the target microclimates and propose future research. A multi-disciplinary project conducted jointly by Eindhoven University of Technology, the Rijksmuseum Amsterdam, the Cultural Heritage Agency of the Netherlands and Delft University of Technology to begin late 2012 entitled Climate-4Wood aims to identify the allowable fluctuations that wooden panels can safely sustain and develop rational guidelines for climate specifications in museums. Investigations into heating in churches without damage to artworks is ongoing. During the 2004 evaluation of the Mona Lisa (Dureissex et al 2006) a mechanical model calculated from experimental measurements was devised to predict future behaviour, and was used to evaluate the likelihood of split propagation of the

¹² Relative humidity at the National Gallery, London is 55%, thereby allowing anything between 50% and 60%. The Metropolitan Museum, and MOMA, New York allow an RH of 48%, $\pm 5\%$.

fracture in the panel. The results of the model predicted a lower energy release rate than a value that would be critical to wood and the split was therefore predicted to be stable under current climate conditions, however, the model was based on 2D analysis and requires confirmation with 3D analysis. This type of analysis is likely to be important in the discussions surrounding the establishment of new appropriate climate conditions, allowing for differences between, for example, national museums and churches. The conference *Climate for Collections: Standards and Uncertainties*, Munich, Germany, 7-9 November 2012, held after this paper was prepared, addresses many of the questions posed by conservation professionals.

2.e Current Conservation Practise

There are several different schools of thought in terms of the best structural conservation treatment technique for panels. These relate to the history of conservation in different countries, different types of problems encountered in different places by different types of objects, and perceived ethical considerations. As each panel, and each problem is by its nature unique, practitioners might have a general method and a tendency to use certain materials, but adjust the fine details for each different case. Without a good understanding of the nature of each technique and the reasoning behind the choices made in each separate circumstance, it can be quite dangerous to simply work to 'template'. The extended training scheme that the Getty Panel Paintings Initiative is currently facilitating works towards ensuring that the understanding of these methods is passed on to younger generations, however, a systematic appraisal of the different types of method has not been carried out since the work done by Brewer (1998) in his unpublished PhD *Effects of Reinforcements on the Preservation of Paintings on Wood Panel*. Scientific methods in non-destructive testing have evolved considerably in recent years and harnessing these tools could provide an invaluable insight into the current methods of working. The 2004 examination of the *Mona Lisa* is one example of the possibilities of collaboration between conservation and science (Mohen et al 2006). Work specifically directed towards the possibilities of scientific examination of panel paintings has been published in the proceedings of conferences held by COST action IE0601 *Wood Science for the Conservation of Cultural Heritage*¹³ in 2007, 2008, and 2009 and are detailed in Chapter 5, *Acquisition of Information*.

Many structural problems encountered in panel paintings are a result of earlier treatments, such as thinning and cradling. Current conservation practise is generally aimed at making allowance for the ongoing shrinkage and warp deformations common in panel paintings. A degree of warpage is now considered accept-

able. In recent years it is also possible to detect a trend for allowing greater flexibility in the type of auxiliary support or framing devise chosen by conservators in Western Europe and North America. Fatigue has been investigated by way of the crack propagation in gesso films (Kozlowski et al 2011), however fatigue has not been measured within the wood structure, nor has an allowable limit of restraint been scientifically calculated or modelled. Although we can measure strain in terms of dimensional change, we are not currently able to measure stress within a panel, we must calculate stress as a result of applied load and surface area, or deformation and MOE. The balance between restraint and flexibility is judged empirically by the conservator, relying on the experience and understanding of the many variables.

Although this paper cannot contain an exhaustive survey of the different methods of restraint or support in current usage, some of the more common generic techniques familiar to the authors can be outlined. These are used selectively by different conservators when facing different problems due to size, thickness, fragility of an insect damaged structure, poor original construction and previous conservation treatments. Conservation treatments to panels which retain their original thickness are usually restricted to re-glueing of loose joints or cracks. Not all cradles need replacing, in many cases they have survived well or only need easing of sliding-members. Many of these minimal treatments are not represented in the literature because they are well understood within the profession, and have not been considered necessary to publish. Of importance to mention is the likelihood of certain display limitations, for example size and depth of frame, which must be adhered to during the development of a support, along with the time constraint often placed upon treatments due to loan or display requirements.

Laminated Structures

The most drastic panel treatment is that of complete transfer. This is very rarely carried out nowadays, but was previously seen as a solution to continually flaking panels where the ground had severely degraded or in cases where the wood was severely worm-eaten and had lost structural strength. Some of the panels damaged in the 1966 flood in Florence, Italy required transfer due to the ground layer being washed away along with the very high level of shrinkage of the support no longer providing enough surface area to lay the remaining paint. In this type of treatment, the paint film is usually detached from the ground and support and adhered to a new / stable support, usually with a textile interleaf (Rostain 1981). The obvious problems with such treatments are the very high risk of damage to the paint film, along with the loss of the structure, history and mechanical characteristics of the painting including superimposing new crackle or deformations relating to

other types of support. Current treatments of remaining flood damaged paintings at the OPD now involve painstaking consolidation and facing treatments, followed by panel repair using inserts between boards to modify the surface area.¹⁴

Many laminate panel supports were developed not only as support structures for damaged panels, but also as a flattening treatment for paintings exhibiting warp deformations. Richard Buck developed the balsa backing from the 1950s in the USA as a treatment suitable for the full support of thin panels (Horns 1998). The treatment is similar to a marouflage, in which a thinned panel is flattened and adhered to a solid, flat timber board. The balsa back support may consist of one or more layers of balsa blocks or strips, cut in various grain orientations, traditionally using a wax-resin adhesive. The panel may be subjected to a moisture treatment to flatten it and the backing is intended to act as a mechanical restraint as the panel dries out, thereby holding the reverse of the panel in tension to relieve the plastic deformation without inducing compression on the front. The longer the panel is held under tension in this way, the greater the effect of stress relaxation, in effect, creep is being induced to flatten the panel. The backing is also intended to act as a future moisture barrier. The basic principles of the method remain the same, but the application techniques have been developed over the years (Spurlock 1978), (Beardsley 1978), (Von Imhoff 1978), (Glatigny 1998), (Reeve 1998), (Lebas 1998). However, problems have been encountered with balsa backings including concave and twisting deformations. Partial delaminations may also arise in regions of high strain caused by the excessive restraint that the panel is held under. This in turn leads to points of high stress loading and possible failure of the support. Work carried out by Al Brewer indicates that wax and wax-resins, whether containing EVA or natural wax, shrink significantly when they cool. This is believed to have contributed to warps in wax-resin / canvas / balsa / wax-resin backings. The application of the hot wax-resin is likely to drive out moisture from the wood support, possibly causing a reversal of the usual moisture gradient, which may lead to the often encountered concave curvature. The panel is locked in deformation as the adhesive solidifies, then shrinks causing further in-plane stresses. However, few alternatives present themselves, and balsa backings and hybrid laminated supports are still carried out by experienced practitioners, particularly where a panel is judged to be too thin to be self-supporting or to utilise a fixed-point local attachment support method. Experimentation with types and placement of blocks, adhesives both stiff and flexible and same species wood continues in order to find a suitable laminate support for very thin panels that will not suffer from the same problems as the traditional balsa backings¹⁵. New et al (2011) presented a case study where the boards of a thinned oak panel (between 1-2mm in thickness) were attached to strips

¹⁴ Authors experience at the OPD Florence as a participant of the PPI training scheme.

¹⁵ Conversations with Elisabeth Grail regarding single layer balsa blocking with codfish glue.

of parallel grain balsa using a stable carvable epoxy adhesive. The work was carried out with conditioned timber at a raised RH to induce temporary flattening during the necessary clamping process. The boards were then rejoined and a diamond pattern cut into the balsa to limit any influence due to wood movement within the balsa. This panel took up a 'normal' curvature, consistent with the curvature of the individual boards before treatment and appears to be stable within the conditions in which it is housed. The continuous adhesive coating on the reverse may block some expansion and contraction, however a stiff adhesive was chosen to help reduce the many local deformations in the original support by inducing relaxation over time. Recent work carried out at the Metropolitan Museum, New York¹⁶ includes a laminated backing consisting of 2cm strips of same species timber adhered with a flexible silicone adhesive used with the aim of allowing the panel and the backing strips to vary slightly in terms of reaction to environmental conditions, whilst still maintaining support. These strips were positioned and lightly clamped one at a time to ensure that the natural curvature of the panel was maintained, with no further stress imparted onto the panel. This treatment was inspired by the experience of several 17th century Dutch panel paintings in the collection which had been thinned and marouflaged with same species timber (high quality oak) parallel to the grain direction in the 19th century, which are still relatively stable, for example, Rubens' Family portrait.

Another recent lamination technique performed at the University for Applied Sciences and Arts at Hildesheim / Holzminde / Gottingen uses somewhat different materials and techniques (Hamann 2005). In this case a badly worm damaged panel was consolidated, then adhered to a phenol-coated polyamide honeycomb structure with acrylic resin. The topography of the reverse of the panel was mapped, and the honeycomb sheet was laser shaped to fit the panel. The adhesive was applied by roller, keeping the voids of the honeycomb clear, thereby ensuring that the elastic properties of the honeycomb could function in response to dimensional changes in the panel. Paper and nylon honeycomb supports have been used in the past within support structures (Lennon 1978; Brewer 1998) but acidic degradation of the paper has been known to cause failure within the structure. Hamann's method uses an elastic synthetic material, coated to increase the mechanical stability and hygroscopy, which should allow both in and out-of-plane movement. Further investigation of this technique would be interesting.

Local Fixed-Point Attachment Supports

The cradle is the typical example of a local fixed point attachment system, the washboarding and fracture deformations due to in-plane and out-of-plane

¹⁶ Conversations with George Bisacca regarding same species wood strip laminates and flexible silicone adhesives.

restraint are well known. Seized cradle systems may be made functional by withdrawing and reducing the thickness of the sliding members before replacing, this not only allows in plane movement, but also can allow a significant release of tension in the out-of-plane direction. Alterations may also be made to improve the deformations without actually removing and replacing the cradle with a different type of support. Bauermeister et al (2011) have published the treatment of some medieval panel paintings at the Stadtmuseum, Muenster where cradles were fully or partially removed, gaps between remaining fixed cradle members were filled with balsa strips to balance moisture transfer on the reverse of the panels, the frames were built up to allow for a central spring framing devise at each end, holding the panels in place with a card backing. Adjustment of the traditional cradle is also carried out in Moscow¹⁷, cutting the sliding cross-battens diagonally and so reducing their in-plane span whilst also incorporating gaps for shrinkage, this type of mechanism is also developed as a stand-alone system of partial cross-batten, however it does appear that support of the structure is combined with a restraint of out-of-plane movement.

The perimeter frame spring system, one of the earliest systems to attempt to overcome the types of damage encountered with cradling systems, was first developed at the Istituto Centrale per il Restauro (ICR) in Rome in the 1970's. These systems provided initial adjustment of depth by spring tension against the perimeter frame, but did not take into account deflection movement. By the 1980s, deflection movement was also incorporated into the system (Basile et al 1993). In the mid 1980s the OPD developed a mechanism that also allowed spring tension to be continually adjusted (Castelli 1987), and these types of mechanisms are still in use today. This system was evaluated by Marcon et al (2010) who produced and compared a finite element model with experimental displacement sensors on a mock-up panel painting. This is the first model known to the author to be developed specifically to evaluate an auxiliary support for a panel painting. Recently a new type of spring system has been developed at the Metropolitan Museum, New York incorporating a spring tensioner with a linear compression spring. A wire cable attaches the spring to the panel by slotting into a brass button adhered to the panel surface. This system allows adjustment of tension and movement in all directions (Miller et al 2011; Bisacca et al 2011). [See fig 10](#)

The perimeter frames, which may also include cross members depending on the size of the panel, have also been developed in recent years, and now tend to be

¹⁷ Correspondence between Anne van Grevenstein and Alexander Petrov.

constructed from laminated strips of hardwood, formed to fit the curvature of the panel at an RH judged to be at the centre of any likely fluctuations. The springs are positioned regularly in bands across the grain of the panel within the perimeter frame and tensioned empirically by the conservator, so providing the panel with adjustable support and restraint.

Another system, also developed in the 1980s, in the UK by Ray Marchant and Simon Bobak of Ebury St Studio, London, is based more closely on the lattice structure of a cradle with very minimal points of attachment. This system consists of a series of supporting tapered battens held against the surface of the panel with a number of flexible longitudinal battens held in place by a series of small slotted retaining blocks adhered to the panel. The tapered battens provide a progressively reduced level of restraint towards the outer edges of the panel, where the deflection will be the greatest, this shape also allows the batten to conform to a curve against the panel, rather than contacting the panel only at the centre and the edges. The number and depth of the tapered battens (within limitations of machining and construction) are calculated based upon the weight and size of the panel and the distance of deflection at particular RH. The number and positioning of the longitudinal battens and retaining blocks are judged empirically, where possible avoiding potential areas of weakness, unlike traditional cradling, which places the fixed elements on fractures and board joins to reinforce them. A recent development of this flexible attached support system is to use laminated battens with a preformed curve to accommodate dramatic curvature. This system provides a flexible support both in and out-of-plane and will not suffer the out-of-plane locking of the lattice system encountered by cradles. It is designed to reinforce weak structures, reduce existing curvature and restrain further increase, within safe limits. The framing of the panel is integral to the success of this system, using a system of backsprings holding the panel against the frame rebate with a central framing bar (Marchant 1998). [See fig 11](#)

To the authors' knowledge, both of these systems have provided numerous panels with effective support and restraint systems; neither have resulted in detrimental deformation¹⁸ or damage to a panel. The symmetry and preload placed upon both structures also means that highly irregular warp deformations are unlikely to occur. Whilst following the same general principle, both systems are able to be adapted for each panel. The spring system continues to evolve, the perimeter

¹⁸ They may provide a restraint which could be classed as a strictly mechanical deformation.



Figure 10 Bisacca's Spring Tensioned Perimeter Frame (George Bisacca)



Figure 11 Marchant's Flexible support (Ray Marchant)

frames are becoming more flexible across the grain¹⁹ although there is no flexibility in the longitudinal direction and the spring mechanisms are continually reassessed to allow for different sizes of panels. The framing of this system is not often mentioned, but it must also be of a flexible nature to ensure that the movement of the panel is not blocked between the rebate and the perimeter frame. The flexible support system provides a sympathetic support which can be easily machined and provides a greater contact area with the panel and allowance of movement within the framing. The spring systems tend to have contact points positioned in lines across the grain, reminiscent of cross-batten supports, while the flexible supports tend to have a greater number of attachments, therefore are more likely to distribute the points of stress to a greater degree across the whole surface, however, they are less adjustable and more time-consuming to prepare. Although unlikely provided one remains within the elastic limit, the use of wood as the construction material for the flexible backing may be problematic due to the possible creep factor over time. However as the panel itself is made from the same type of material, it is difficult to judge if this is really a problematic factor (many plastics degrade, creep and off-gas and metals suffer degradation and from thermally induced problems including condensation). Furthermore, any creep within the flexible support could be considered failsafe as it would result in a lower degree of restraint. Further scientific evaluation of these systems could be valuable, particularly in terms of the levels of allowable restraint.

Further systems from Europe and North America are mentioned and tested in the thesis of Al Brewer (1998). An international survey of structural conservation materials and techniques in the field of panel paintings would be welcomed.

Cross-Grain Batten Supports

Whilst the systems above have been developed primarily for the support of thinned panel paintings, many large panels retaining their original thickness, but damaged by excessive warp find a more sympathetic solution in the application or adjustment of cross-battens. It has long been a tradition in Italy to apply sliding wooden or metal battens across the grain within cleats glued to the panel surface (Rothe 1998), these have not always been successful because of the restraint of out-of-plane movement. Thinner flexible sliding battens have performed somewhat more successfully (Rothe et al 1998), and more recently spring attachments have been used to allow even greater flexibility in the placement of cross battens within original dovetail tracks. Current work at both the OPD and the Metropolitan Museum includes the use of curved cross-battens reflecting the curvature of the panel (where possible the original battens are altered in a lamination technique, (Bisacca et al 2011) inserted within the original dovetail track (Castelli et al 2006).

¹⁹ Conversation with George Bisacca regarding the use of silicone adhesive in saw kerfs to improve cross-grain flexibility particularly at the outer extremities, along with reduction of the depth of the timber perimeter frame, again to increase flexibility.



Figure 12 Glatigny's Aluminium 'T' Section cross battens
(Jean-Albert Glatigny)

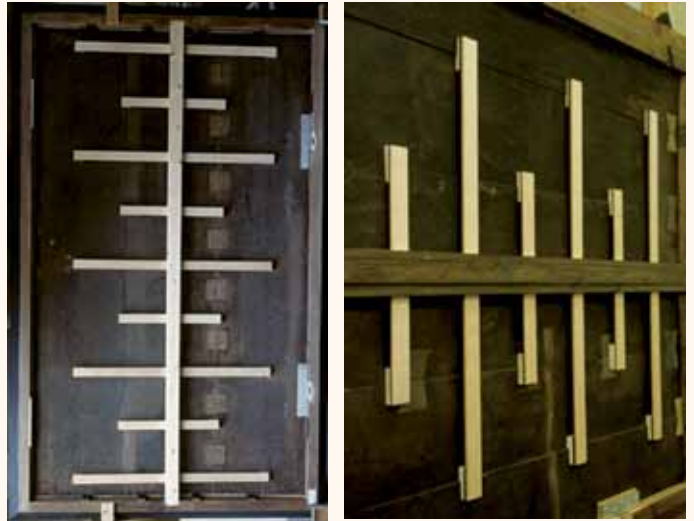


Figure 13 Flexible framing system held by central bar
(Ray Marchant)

These systems relate to earlier work carried out in the conservation studios of the Vatican Museum (Carita 1956). Maintaining the historic integrity of the object by returning original components to functionality is very satisfying, however it is not known whether the compression set curvature has reached stability, or if it is likely to progressively increase, putting increasing stress on the panel over time where the battens restrain it. This is an aspect of progressive compression set requiring investigation.

Current work in Belgium utilises 'T' sections of aluminium of differing flexibility held between wooden cleats, Roeders (2009) describes an example of this work at the Frans Hals Museum, Haarlem supervised by Jean-Albert Glatigny. [See fig 12](#)

In Portugal, Garcia (2011) also utilises a cross-batten support of flat aluminium bars sliding over wooden 'bridge' blocks, held in place by thin aluminium brackets. Brewer (1999) discusses several different types of non-original cross-batten of differing flexibility, discussing the effect these have on the panel. The restraint that a crossbar should put upon a panel has always been difficult to judge or predict, excessive restraints block movement and facilitate split formation, whilst too little restraint can allow too high a level of deformation.

Unattached Supports

Several unattached support systems are in use, generally for smaller thinned panels that can make use of the relatively small perimeter to surface area ratio. The National Gallery in London has made use of a foam cushioned tray for some years as a support mechanism for display and handling of fragile paintings (Brough 1984). The panel is held against a profiled foam rebate using a series of shaped foam buttons within an inert tray. This system is a good example of minimal intervention successful within a museum environment. However within an uncontrolled environment the restraint exercised by the foam pads as the panel deforms can be easily misjudged and block out of plane movement. The flexible unattached support developed at Ebury St Studio, London within a similar tray structure performs along similar lines to the flexible attached support and is likely to be more successful in uncontrolled environments (Bobak 1998), however the technique is far more involved and time-consuming. Work carried out at the Kunsthistorisches Museum, Vienna is devised along similar lines to the spring support mechanisms. Initially points of attachment were made with Velcro and Beva 371 film, but the technique was developed to allow unattached support pads. In this case both conical and leaf springs were used to support the panel within a tray structure, allowing in and out-of-plane movement, and some measurement of movement with integrated strain-gauges (Hopfner 2011). The idea of monitoring

the panel movement within the support structure, if allowable within the display limitations is useful in tracking the reinforcement, although imaging techniques have now developed to such an extent that they might be a more straightforward full-field solution.

Framing Supports / Restraints

Most panels were originally fitted into a rebate in their frame, secured by some thin nails allowing the panels to move. Many panels have later been fixed within their frames using rigid attachments all around the perimeter of the panel, this along with spacers blocking the panel movement are particularly damaging to panel paintings. Most framing is now carried out with framing clips holding the panel in position within the rebate only in the central portion of the panel, located across the end-grain, thereby allowing the outer edges of the panel less restricted movement. Many practitioners use rigid clips with foam spacers or sprung steel clips, however, these all rely on attachment only at the end grain edges, concentrating resistance to movement at localised points where crack propagation is most likely. An alternative framing system has been developed to provide more central, distributed support whilst still allowing large dimensional changes. The design is very simply constructed consisting of a number of flexible battens with pads at either end contacting the panel, held in position by a central beam recessed into the frame running parallel to the grain of the panel (Marchant 2011). Also considered are methods to reduce frictional resistance to movement on the bottom edge of the panel, particularly in horizontal grain paintings, either by lining the rebate with low friction tape, or by fabrication of a ball-bearing support.

See fig 13

A hybrid of the flexible batten system was carried out at the Mauritshuis in the framing of the Baptism of the Chamberlain of the Queen of Candace by Hendrick van Balen and Jan Brueghel the Younger. The painting is executed upon a large, heavy oak panel consisting of six horizontally orientated boards. In this case a series of flexible battens were attached to a central beam recessed into the frame. Using nylon screw threads, the central beam was then attached to blocks adhered across the central join in the panel. This attachment allowed the panel to 'hang' within the frame, against a cushioned profiled slip, ensuring that there would be no restriction of movement, particularly along the bottom edge (Pottasch et al 2012). This notion of 'hanging' the painting from a central spine attached to blocks on the panel is also presented by Griesbach (2011) with several other case studies using hybrid methods taken from experience with different structural conservation practises.

Other Conservation Practises

In order to evaluate the best support or restraint mechanisms for panel paintings, repairs and pre-treatments should also be considered. Worm damaged or fungally attacked wood presents a particular problem for successful split repair or board rejoining. The materials and methods of successful consolidation, and the structural stability of the remaining support can be problematic factors. Many of the supports require regions of a thinned panel to be covered, whilst other regions are exposed to the surrounding environment. It is not know exactly what effect this might have on future deformations relating to moisture transfer. Ethical considerations as well as practical sensibilities lead to a difference in methods of rejoining. Some practitioners prefer the use of mechanical tools to clean out old repairs and damages and provide a fresh surface for adhesion with the use of wedge shaped inserts, whilst others favour the removal of such contaminants by hand or poultice followed by repairs often incorporating gap-filling adhesives. Differences of opinion exist regarding same-species use of wood for repairing losses in the support. Likewise, the use of single or multiple piece inserts, or the use of a stiff adhesive forming a localised difference in mechanical behaviour. These types of considerations have not been systematically investigated and should be addressed when considering the mechanical characteristics of panel paintings.

2.f. Conclusions

This section provides an overview and review of current literature and practise within the field of structural panel painting conservation, along with more recent work in the field of Wood Science, specifically addressing the problems encountered in the field of Cultural Heritage. However, it is clear that although the fundamentals of wood structure are well researched, there are still many areas in which further applied research would be helpful. Complete surveys of original construction materials and techniques along with current conservation treatments and theories would be both interesting and helpful, especially if this information is easily accessible. Little is known about the ageing or indoor weathering of wood. Hysteresis and the mechanisms of adsorption and desorption are not fully understood. The effects of moisture gradients and the impact of local heating and thermal treatments, too often dismissed, require further work. Although individuals provide reasoning to explain the phenomena of compression set and progressive shrinkage, these processes are complex combinations of mechanisms that are neither fully understood, nor easy to describe across different professions. Nor do we fully understand the process of longitudinal wood movements. Clarifying these types of behaviour is essential to the progression of the structural conservation of

panel paintings and requires multi-disciplinary cooperation of paintings, structural and furniture conservators, wood scientists and structural engineers. Conservators do not generally have tools to assess wood quality and fragility of insect damage. The allowable levels of restraint imposed upon a panel are currently judged by experience, vital to the treatment, but without scientific endorsement. Similarly, the level of restraint a paint film, coating or adhesive might impose upon a wood panel is unknown, and highly variable. Work is beginning on assessing the levels required for suitable, sustainable climates in which to house panel paintings, however much is still to be looked into.



Figure left and right: Willem Bartsius, A captain. The Netherlands, 1600-1625. Oak, 38.5 x 29.5 x 1.1 cm. The support consists of one vertical oak board which is slightly less wide at the top. The reverse of the panel shows regularly spaced saw marks and seems untreated.

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2.g. Research questions

Properties of wood in panels

What are the Hygro-mechanical Properties; can we understand and control these?

- Surface and bulk
- Weathering
- Hysteresis
- Moisture gradients
- Longitudinal movement
- Abnormal wood (e.g. reaction wood, non uniform wood)
- Thermal treatments

Can we understand the Ageing of Wood?

- Effects on mechanical, hygro-mechanical and chemical properties
- Compression set
- Insect Damage
- Fungal Damage

Panel structure

What are the Interlaminar Stresses and fracture mechanics of polymeric surfaces?

- Varnish-paint / decorative layers / paint-paint / paint-ground / ground-canvas-wood / ground-wood / coatings.

Can we reliably use crack patterns as indicators of particular mechanical failures within the panel structure?

Original Supports – what are the effects on the hygro-mechanical response of the Panel?

Structural Treatments – what are the effects on the hygro-mechanical response of the Panel?

Consolidation (layer and wood) – what change to the physical properties and environment response are caused by the introduction of each type of consolidant?

Preventive Treatments – what are the effects on the hygro-mechanical response of the Panel?

Moisture Barriers – what are the effects on the hygro-mechanical response of the Panel?

Framing – what are the effects on the hygro-mechanical Response of the Panel?

What is the epidemiology for existing panels?

– [Original construction](#) / [current condition](#) / [treatment](#)

How does the profession agree a format or procedure for reporting the condition?

How does the information become consolidated and used?

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Figure A+B Jan van Mekerem, Door of a cabinet with floral marquetry. The Netherlands, 1690-1700. Oak, veneered with ebony, kingwood, olive, holly and other indigenous and tropical wood species, 110 x 80 x 3.5 cm. Before (left) and after (right) conservation treatment in 1995. By dismantling and regluing the three vertical boards onto which the marquetry is applied, it was possible to close the two large cracks which disfigured the composition. © Rijksmuseum.



3. The painted surface and interface



CHAPTER 3

The painted surface and interface

Christina Young

The conservation of panel paintings and related objects

Research agenda 2014-2020

3. The painted surface and interface

3. The Painted Surface and Interface

This section considers the state-of-the-art, in knowledge, research and treatments, with regard to the physical aspects of the painted surface and the interface between various layers from which a panel painting is constructed. In this context the “painted surface and interface” includes the surface of the wooden support, preparation layers and subsequent layers of paint, gilding and varnish. The “interface” is defined as the point between any two layers which are in contact, so that there is physical interaction between them.

There is a wealth of research into the structure of panel paintings, related workshop practice, stylistic influences, the alteration to the appearance over time and the final image we perceive today. (Bomford et al 1989; Uzielli 1995; OPD 1995-2011; Dorge and Howlett 1998; Ciatti et al 2006; Nadolny et al 2006; Laaser et al 2009; Ciatti et al 2010). Therefore, there is a good understanding of the possible underlying layers from which a panel can be made. There are a variety of layer structures which have been employed to form the preparation layers prior to the painted surface. Some of these techniques can be traced to practices for related polychromy (Serck-Dewaide 1998; Perez-Martin et al 2009) and ancient ethnographic objects (Wrapson 2006). The evidence for the construction of the structures comes from the examination of extant paintings and written sources. Generally, canvas or parchment was adhered with a glue (adhesive) to the whole/ or part of surface of the wood before the application of a gesso layer. The gesso layer or layers comprised of chalk or gypsum bound in animal glue. It has been assumed that the inclusion of the canvas/parchment was to mitigate the inevitable difference in mechanical properties between the relatively thick gesso and the wood in response to moisture changes, which leads to delamination at that interface and loss of the image. Other materials, including leather have been encountered as well as direct application of the gesso onto the wood (e.g. sixth to ninth century icons (Karydis 2006). It also served to cover over irregularities in the wood and joins between boards. Five main variations of this method have been characterised, these include layers of canvas/parchment between two layers of gesso and partial layers which only cover joins and inclusions e.g. knots in the wood. Additionally, loose fibres (animal or vegetable origin) instead of continuous materials were also used directly adhered to the wood or between layers of gesso (Skaug 2008 & 2011). Within these

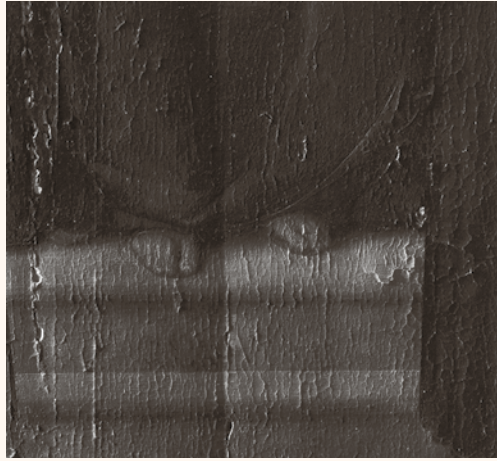


Figure 1a Raking light images of Virgin and Child with Saints Lawrence, John the Baptist, Monica and Augustine by Gerino da Pistoia, dated 1510. (Courtauld Institute of Art) Shows vertical tenting and an area of bid cleavage of the right.



Figure 1b Raking light images of Virgin and Child with Saints Lawrence, John the Baptist, Monica and Augustine by Gerino da Pistoia, dated 1510. (Courtauld Institute of Art) Shows cracks in the paint and gesso associated with splits in the wooden support.



Figure 2 Condition of bottom edge of the Gerino da Pistoia panel, showing the interface and areas of delamination. (Courtauld Institute of Art)



Figure 3 A detail of the Gerino da Pistoia panel from the reverse showing extensive wood worm damage. (Courtauld Institute of Art)

types are variations both chronologically and regionally, which broadly relate to wood species and quality, thickness of the gesso, workshop practice and stylistic technique. Thus, the variation in possible interfaces is considerable if one also takes into account not only material differences but compositional differences in adhesives and gesso formulations.

3.a. **Types of damage**

Cracks at or near the paint surface, and delamination of layers which incorporate the image are the most common forms of visible damage to the painting. “Tenting” and “cupping” are a combination of both cracks and partial delamination. Delamination at a subsurface interface without loss is known as “blind cleavage” and will alter the surface topography and image. However, it is possible for cracks to be present in any of the subsurface layers, these are only evident when a crack propagates to the upper paint surface or along an interface resulting in delamination. See [Figure 1a and 1b](#) The worm holes left by the Lyctus, death watch beetle and common furniture beetle can be present close or directly underneath the canvas/ gesso preparation layers. In this case there is no solid as support and voids exist which make the layers extremely vulnerable to delamination especially if the layers have cracks running into the gesso. Damage caused by woodworm results in loss of the bulk material. Thus, the underlying wood structure cannot provide a sufficiently strong layer for the gesso. However, the presence of canvas to some extent mitigates this problem as it provides resistance to crack propagating (fracture toughness) through the structure.

3.b. **The interaction of layers and adhesion**

Typically, delamination has been observed at the gesso/wood interface, gesso/ canvas interface and gesso/paint interface. See [Figure 2](#) These can be divided into delamination due to lack of adhesion caused by an inadequate or deteriorated layer which contains the adhesive component (including the gesso layer), or delamination caused by interlaminar crack growth. In the case of the former, there can be either “cohesive” failure within the layer or “adhesive” failure along the adjoining layer surfaces. Tenting in panels is usually directional, following the grain of the wood and is generally accepted to be a result of hygroscopic deformation of the wood (Michalski 1991). Tented paint is just one example when the bulk properties of the wood also need to be considered in the understanding of the mechanisms. The uptake of moisture leading to rehydration of aqueous adhesive or gesso layers can result in either cohesive or adhesive failure as the layer softens with the uptake of water.

Structural damage which relates to the painted surface and interface results from strain induced in the layers which lead to fractures within a layer or between layers (interlaminar) (Pandya and Williams 2000). Fractures may occur below the surface and therefore, will not necessarily be visible as cracks or layer delamination. The mechanical properties of these layers that need to be considered are the tensile, compressive, bending and shear stresses, along with the external forces which alter the stresses (Kim and Nairn 2000). This cannot be separated from the surface chemistry of the interface, and the associated diffusion processes that determined how adhesives, water and solvents move through the layers.

Factors affecting the loss of adhesion and the delamination of the paint layers

This area falls under fracture mechanics of polymeric surfaces. This is an established field within engineering but only fairly recently being applied to conservation. The simple deformable solid linear elastic models that were initially applied to structural understanding of canvas and panels now need to enter a difference phase to deal with the complexity of the interfaces and viscoelastic behaviour.

Consolidation

Consolidation is a generic description of the addition of an adhesive at an interface to prevent delamination. The expression is also more loosely used to describe the various methods of coating the surfaces or filling of voids of woodworm holes within the bulk of the wood. [See Figure 3](#)

Vapour Barriers

The use of vapour barriers directly applied to panel paintings has become less prevalent in the move away from impregnating the original support and replacing it with preventive methods including back boards, vitrines and tighter climate control. Typical vapour barriers have included wax (heated or unheated), polymeric synthetic coatings and foils. These have been used to slow down or stop the moisture exchange between the atmosphere and the wooden support (Brewer 1991).

3.c. Review of Research

Visible and subsurface damage

A few studies have attempted to relate chemical and physical changes in paintings with the visible evidence on the painting surface (Aloha 1993; Boguslaw and Ewa 2009; Jarmilko 2000). A study of the selective darkening of the ground and paint

layers in a case study of four 17th century panel paintings, found that it corresponded with the ground filled channels of early oak wood from which the panels were made. There was also a lead soap formation in the paint. It was postulated that this led to an expansion of the paint and contributed to the delamination associated with the darkening (Noble et al 2008).

Crack patterns visible in the upper paint layers “craquelure” of panel paintings have been classified to ascertain if they can be used as indicators of provenance, technique and period (Bucklow 1999). It has been reasonably assumed that these patterns relate to the materials, technique and stress/strain history which the painting has undergone (Mecklenburg et al 1995; Mecklenburg et al 1998). Modelling using Finite Element Analysis (FEA) has shown that some of the patterns may be ascribed to particular deformations. More recently a combination of analytical and experimental testing has been used to ascertain the mass transfer coefficient of representative panel painting layer structures. This data was then used in an FEA model to simulate the warp of panels with different coatings (Allegretti and Raffaelli 2008). This research work has provided a good methodology and foundation for developing predictive model and has provided data of physical properties without which realistic predictive simulations are ineffective. An alternative approach to predicting failure in panel paintings has been to investigate the fatigue (and hence, cracking) in a gesso layer due to hygroscopic wood movement combined measurement of surface/ near subsurface cracks with Digital Speckle Pattern Interferometry (DSPI) with analytical model for the moisture diffusion process. This has then formed the basis of a FEA model of the moisture movement and strain in the wood with the aim of relating changing environmental conditions to cracks initiated by fatigue (Rachwal 2011). Fatigue as possible contributing factor in damage of works of art has been highlighted by several authors (Michalski 1991 & 2010; Kozłowski 2011; Young 2011). Although, a developed research area in engineering for over 100 years, theoretical fatigue models have only been applied to cultural heritage in the last five years. Thus, the models as yet do not represent the complexity or variety encountered in panel paintings. Experimental fracture mechanics has recently been applied to understanding the failure mechanisms of multilayer decorative systems (Schellmann and Taylor 2011). This research is formed on a sound experimental basis (Levers and Marenco 2005; Kinloch et al 1994) and in-depth understanding of the fracture process which specifically addresses the mechanisms occurring at the interface. This research is particularly relevant because the research objective was to evaluate the effect of consolidants on the mechanical failure behaviour of gesso-type foundations. Related research into the prediction of delamination in multilayer artist paint systems caused by changing

environmental conditions has combined experimental fatigue testing with a viscoelastic FEA model. This takes into account the properties of the polymeric materials found in paintings. (Tantideeravit et al 2011 & 2012). This method has yet to be applied to the constituent materials and multilayer structures of panel paintings. All of the above research which combines experimental data with more sophisticated, predictive analytical and FEA models, is at a relatively early stage within the field of conservation. However, with a good dialogue between scientists and conservators this area can be developed to more accurately analyse, understand and predict the mechanical properties and response of paint layers and the interface for real panel paintings.

Air-coupled ultra sound has been used to detect various defects in panel paintings including splits, checks, delaminations and worm holes. It was found that further development was needed to reliably distinguish between natural anomalies in the wood and defects associated with deterioration (Murray et al 1994). Flash thermography has also been used to detect worm damage in wood. However, because of the thermal insulating properties of the wood it is only able to detect worm holes directly under the gesso and not in the bulk of the wood (Blessley et al 2010). These techniques complement the established technical examination techniques of X-radiography and infrared reflectography for interpreting subsurface damage, but as yet there are no reliable techniques which map the extent of worm channels through the thickness of a panel. At present, a method of providing adequate and accurate data to evaluate subsurface structural treatments on model or real panel paintings does not exist. Using cross sections with scanning electron microscopy with or without radioactive doping or fluorescence markers has produced some of the most useful experimental data to date (Pellizzi et al 2011).

Vapour barriers

To obtain a better understanding of the permeability, moisture transport and the related movement of the layers and wood, more recent research has readdressed the effect of coatings (gesso/paint/gilding and barriers) in general (Hagan et al 2005; Allegretti and Raffaelli 2008; Rachwal et al 2011). The measurement of properties such as the diffusion and surface emission coefficients provide the much needed data required for modelling the response of panels. In the future, this approach should also provide a sound experimental methodology on which to assess various treatment options. Relevant research is also being carried out by the timber industry into vapour barriers and paint adhesion (Bardage and Bjurman 1998). Studies of the effects of acidic pollutants on the adhesion of acrylic and alkyd paint on Cedar wood used fracture toughness testing to measure the adhesion at

the interface (Knaebe and Williams 1996). Again this fracture mechanics approach to assessing the properties of the paint layer and interface can provide data for understanding the factors effecting adhesion, for modelling and for assessing the effectiveness of treatments.

Consolidation

Woodworm consolidation

Research into the bulk of the wood has been more widely studied in the field of objects, furniture and archeological conservation. Schiewind reviewed the relevant literature with reference to panels (Schiewind 1995). Recent research has focused on assessing the changes to the dimensional changes resulting in immersion in a consolidant (Gratan and Baker 2011). Studies have continued to measure the transport of the adhesive using cross sections. Fluorescent markers and SEM imaging has provided us with a better understanding of the how the consolidant coats the damaged wood. Some testing on the compression strength of the treated wood has also been undertaken (Gindl 2007). Other modes of wood failure in the content of panel paintings have yet to be explored. Alternatives to conventional adhesives have also been explored for paper and foam artefacts which may be relevant in the long term for wood (Pellizzi et al 2011).

Paint consolidation

There is a reasonable amount of research on many of the adhesives used as consolidants and their properties including ageing behaviour (see section on Consolidants). The physical properties of the paint layer are mostly covered by the research into paint on canvas paintings (Michalski 1991; Erlebacher et al 1992; Carr 2003; Hagan et al 2009). However, there has been very little research about the effects on the mechanical and optical properties of the paints and ground for panel painting especially where the medium is egg. One could assume this is no difference from canvas unless the cause is directly related to the wood. Wood chemistry e.g. hydrogen bonding at the cellulose/lignin level will have some effect on the diffusion process, penetration and adhesion achieved between interfaces. Recent research has focused on measuring (Buzzegoli et al 2008) or modelling the transport of adhesives through a material (Michalski 2008). This approach complimented with the experimental fracture mechanics discussed above and developing non-invasive techniques of mapping the distribution of consolidants in multilayer structures is required to develop our understanding and practice.

Effectiveness of present treatments

There are many publications detailing practical treatments of the paint surface which usually relate to consolidation (Weeks and Look 1982; Ciatti et al 2010;

Nadolny et al 2006; Kargère and Marincola 2011). However, the long term effectiveness and best methods to assess their effectiveness has yet to be investigated in a consistent way. Any study of this nature will be complicated by the diversity of the original structures, subsequent treatments and varying histories of these works. However, they may provide a useful data set.

3.d. **Research questions**

The variation in possible interfaces is considerable if one also takes into account not only material differences but compositional differences in adhesives and gesso formulations and subsequent paint layers. We have yet to establish from experimental data rather than empirical observations the correlation between the variations in the original preparation layers and the resulting different crack patterns or delamination at particular interfaces.

We do not have sufficient data to reliably use crack patterns as indicators of particular mechanical failures within the panel structure.

There is insufficient data on moisture barriers related to moisture uptake and release in fluctuating conditions. Research is also needed to relate this to the data related to internal pollutants and volatile materials.

There are various methods of coating the surfaces or filling of voids of woodworm holes within the bulk of the wood. Worm channelling along glue joins and under gesso is a particular challenge. There is insufficient systematic experimental data for panel paintings establishing what is occurring within the wood at either the bulk or molecular level. Both conservators and scientists have yet to establish a consensus on what wood worm consolidation processes should achieve mechanically. The effectiveness of the consolidation process requires full evaluation using established testing methodology and theoretical framework. Particular emphasis is required in establishing the stress at the adhesion interface both in terms of a theoretical framework and experimentally. To that end a network should be established among experimental researchers to develop testing protocols and to discuss the validity of using ASTM/ISO/BSI standard tests compared to modifying them or devising new tests.

Specific research questions

- What is it that we think we are trying to achieve by woodworm consolidation?
For both paint/gesso and wood worm consolidation - what change to the physical properties and environment response are caused by the introduction of each type of consolidant?
- How effective are the various methods of consolidation used at present?
- What type and degree of movement results in interlaminar stresses resulting in paint fracture and delamination?
- How does this relate to current environmental control strategies and proposals to change environmental guidelines?
- What are the effects of restraint versus free movement on the layer interfaces?
- What are the effects of restraint versus free movement on the warping of the wood?
- What are the stresses induced in the panel structure by the more recent designs in, restrained and flexible, auxiliary supports?



Left top and bottom: Hendrik Meerman, Antonius Antonides van der Linden, physician in Amsterdam. The Netherlands, 1633. Oak, 88 x 63 cm. The support consists of three vertical boards. The joints have been reinforced with strips of veneer. Part of the back has a lighter color due to scraping or planing. © Rijksmuseum.

Rigth top and bottom: Hendrik Meerman, Sara Sweerts de Weert, second wife of Antonius Antonides van der Linden. The Netherlands, 1636. Oak, 88 x 63 cm. The support consists of three vertical boards. The joints have been reinforced with dovetailed inserts as well as strips of veneer. © Rijksmuseum.

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**4. Adhesives,
consolidants,
coatings**

4. Adhesives, consolidants, coatings

4. Adhesives, consolidants, coatings

4.a. The hows and whys of adhesion

A useable adhesive bond occurs when an adhesive covers a surface, bonds with the surface, then can withstand the applied forces which tend to pull the bond apart. How a bond fails is a good indication of how these various factors contributed to the original bond (Horie 2010).

The adhesive bond in wood results from a combination of contributing forces and processes.

The first stage is for a liquid adhesive to cover the surface¹. The liquid must both be able to wet and to flow over the surface.

Wetting results from the interaction between the chemicals at surfaces of the liquid and the substrate, and may be little affected by the underlying bulk properties. The ease with which a liquid can wet a surface can be measured by the contact angle between the liquid and the solid. When the angle is $>90^\circ$, the liquid balls up like water on wax. As the angle becomes less, the liquid will have less resistance to spreading out until, at 0° , the liquid will flow over the surface spontaneously. The contact angle is dependent on the relative surface tensions of the liquid and substrate, which are the result of the surface molecular forces. If the surface tension of the liquid is less than that of the substrate, the liquid will flow over the surface. If it is higher, there is less attraction with the surface than with itself, so requires energy to make it spread. Wood surfaces are nominally composed of cellulose and lignin. Although cellulose has a high polarity, lignin has a much lower one, so wood surface may present a mixed polar and non-polar surface to an advancing liquid. More important is the rapid contamination of the polar surface by low polarity oils rising from within the wood or contamination from oily atmospheric pollutants. These non-polar surfaces may prevent a water based adhesive from wetting the surface. Different measures are available to enable wetting by a liquid adhesive, for instance by choosing a lower surface tension liquid or by pre-wetting the surface with a compatible low surface tension liquid.

see figure 1

¹ Though not important for wood panel adhesion, some adhesives are applied as vapours and condense onto the adhered surface. Another type not further discussed here is the pressure sensitive adhesive, a specialised liquid that flows sufficiently but with sufficient cohesive strength to withstand the applied forces.

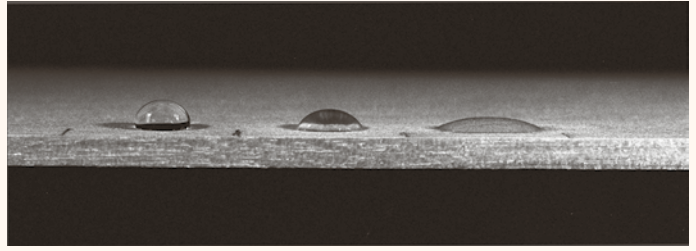


Figure 1 Spreading of a drop of water on an exposed wood surface. On the left is an untreated surface. In the middle the surface was treated by 2 strokes of sandpaper. On the right by 4 strokes of sandpaper. (Frihart and Hunt 2010)

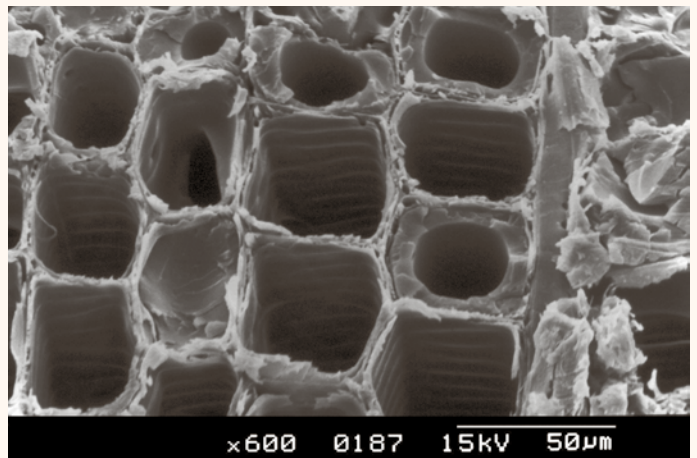


Figure 2 Shows plugs of Paraloid B-72 (applied as a 20% solution in toluene) partly or completely filling the wood vessels next to vessels with no sign of even a thin film deposited. SEM images courtesy of Peter Y. Eastman, Senior Scientist, Rohm and Haas Company, obtained while studying at University of California

Viscosity is defined as the resistance to flow. Flow can therefore be increased by reducing the viscosity of the liquid. Flow takes time. The more surface the liquid has to cover, the longer it takes. Many wood surfaces are rough and have a much larger microscopic surface than the macroscopic measurements suggest. If the liquid does not spontaneously wet the wood, force will need to be applied to make the liquid flow over the complex surface. Another resistance to flow not usually met with in wood is air trapped by liquid in pores in the surface after the liquid adhesive has been forced over the top. The flow of a liquid adhesive into wood can be modelled (Mendoza et al 2012).

The viscosity of a liquid adhesive increases as it transforms into a solid adhesive. This increase of viscosity will reduce flow into pores etc. This effect can be used deliberately to restrict penetration into the structure of the wood or may be undesirable. All liquid adhesives for wood reduce in volume as they transform into solids. Shrinkage occurs in two stages, first while the adhesive is still able to flow then after it has gelled. Most dispersion adhesives remain in a plastic state (i.e. above their glass transition temperature) even when set. In contrast, glue sets to a solid gel then becomes rigid and shrinks when the water evaporates, becoming stronger than the wood itself. This shrinkage can set up damaging tensions between the adhesive and substrate. The process of setting of solvent deposited materials, especially consolidants, creates very uneven distribution, for reasons that are not well understood. Although the initial polymer solution appears to have been evenly distributed, during evaporation the polymer is redistributed. Figure 2 shows the distribution of polymer consolidant in wood vessels deposited from consolidating solution applied to 3x3x50mm specimens of degraded Douglas fir, seen on SEM pictures of fracture sections (Schniewind and Eastman 1994).

[See figure 2](#)

There are a number of mechanisms that contribute to the strength of the bond between the solid adhesive and substrate (Frihart 2005). With wood especially the contaminated surfaces of old panels, the greatest contribution is probably mechanical interlocking created as the liquid adhesive flows into the cells. The adhesive bond itself is developed by the secondary chemical bonds, dipolar and hydrogen bonds. It is possible that formal chemical bonds are created between reactive groups in the adhesive and wood. For instance it is known that PVAL becomes firmly attached to cellulose on drying. [See figure 3](#)

The bond adjusts to stresses by movement in both the adhesive and the wood. If the set adhesive can flow, i.e. it is a thermoplastic above its glass transition temperature, stress placed on the bond will cause the adhesive to creep in order to reduce

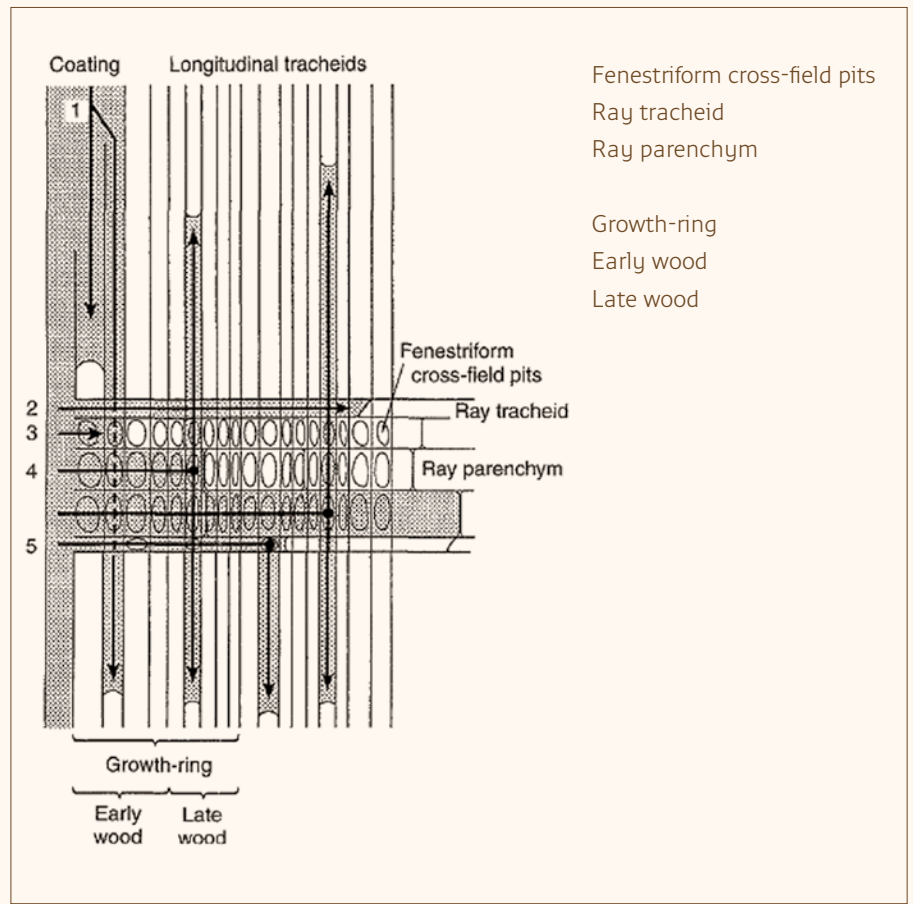


Figure 3 Showing how a liquid coating flows into a wood surface (de Meijer, Thurich and Militz 1998):

Schematic presentation of the different ways of possible coating penetration in softwoods seen from a radial cross-section (1) flow into open end of longitudinal tracheid; (2) flow into ray tracheid; (3) flow into ray parenchyma; (4) flow from ray parenchyma into longitudinal latewood tracheid; (5) flow from ray tracheid into longitudinal tracheid

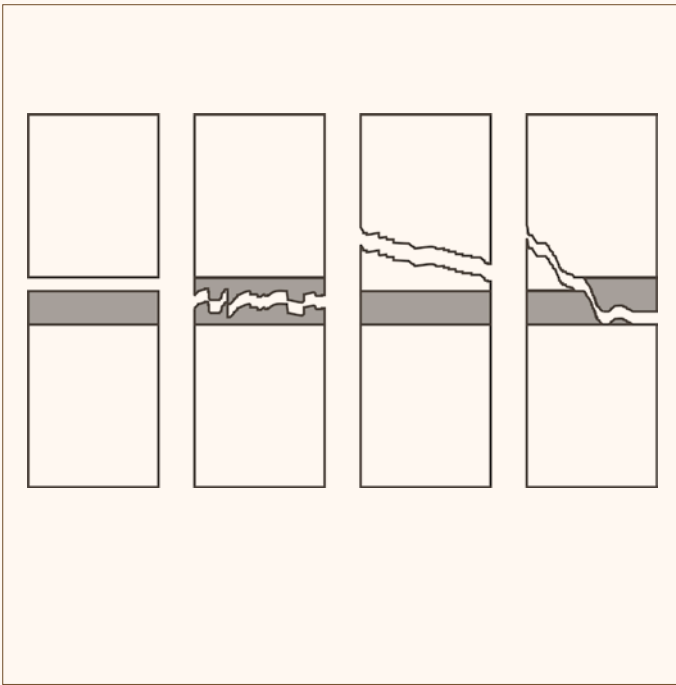


Figure 4 Failure modes, from left to right, (a) adhesive (interface), (b) cohesive failure in the adhesive, (c) cohesive failure in the substrate, (d) all three modes simultaneously (Horie 2010)



Figure 5 A fragment of degraded wood of St Cuthbert's coffin adhered with PVAC slumped over 30 years, due to the low T_g of the polymer. (Cronyn and Horie 1985)

the stress. If the adhesive cannot flow, the wood can also adjust by breaking and remaking new secondary bonds within the structure, also a form of creep. Industrial requirement for adhesion “The standard for excellent bonds is that the wood breaks away from the adhesive joint” (Frihart and Hunt 2010) is very different from that required for conservation. The desired properties of both the adhesive and the bond must be specified for conservation, using industrial research and technologies with caution. Bonds can fail in three basic ways, or a combination of these, *see figure 4*. Ideally for conservation, mode (a) where the adhesive peels cleanly off the wood is the desired outcome. In practice, this is never achieved even for the cleanest separation – even where a clean separation appears to have occurred. Separation occurs in a very thin transition layer adjacent to the wood surface, leaving a small amount of adhesive firmly attached to the substrate at the microscopic or chemical structural scale.

Next best is mode (b). Failure in the adhesive occurs when it is weaker, in the long or short term, than the adherend. Two situations are seen. If one chooses an adhesive that easily breaks, such as starch or poly(ethylene glycol), stress applied to the bond will break the adhesive. However, some adhesives are strong under short term stress, but suffer long term creep or flow, *see figure 5*. This can also prove a problem with low Tg coatings which permanently absorb dirt by flowing around the pollution.

The most damaging mode of failure is (c). Many of the panels are fragile in unknown ways and places – a crack once initiated at a weak point can propagate deep into its structure. Failure is likely to occur where stress on the overall bond is transmitted through small areas of the wood because of uneven distribution or adhesion of the adhesive. Much commercial bonding therefore uses pressure to force the liquid adhesive into the wood pores to ensure that the stress is transmitted through the wood surface into the structure of the wood.

To achieve reversibility of a bond without causing damage to the object, the solid adhesive must be removable from the wood. Because of the porosity of wood, dissolving the adhesive frequently results in redistributing the polymer through the adjacent wood. Mechanical methods are usually used to reduce this need. The adhesive must therefore be weak enough, or weakened during the removal process, to be disrupted without damaging the object.

4.b. The nature of wood as an adherend

The interaction of a piece of wood as an adherend needs to be considered at various levels of structure, macro (visible), microscopic (cellular) and molecular (chemical) (Frihart and Hunt 2010). All these structures affect the interaction with added adhesive, liquid or set. There are systematic differences in the structural organisation of wood between the hard- and soft-wood categories. Within these categories, there is a wide range of properties (e.g. density, extractives, pore size) across different species. So specific are these properties, that conclusions drawn from one species frequently cannot be extrapolated to another.

These structures vary considerably within a single piece of wood. Wood is anisotropic, with different properties when considered in the longitudinal, radial and tangential directions. Wood displays structural and chemical variations due to tree growth and reaction to its environment, such as knots, heart- and sap-wood, and resin canals. Wood then alters considerably during conversion into timber, in use, surface weathering, subsurface biological and chemical deterioration, and by materials added during use and conservation treatments.

The structures that particularly affect how wood forms adhesive bonds are: the surface roughness; the available porosity; the chemicals on the available surfaces.

Industrially, it has been shown that increased surface roughness on new piece of wood reduces the quality of an adhesive joint. The best bonds are formed when the wood surface has been created by an extremely sharp knife producing a macroscopically smooth, flat, surface with easy access to the cellular pores. The adhesive can then flow evenly over the surface and into the pores with few impediments. Sanding will normally deform the cell walls and reduce the penetration of the liquid adhesive, see [figure 6](#).

There is a contrasting effect of a sanded surface increasing the adhesion where cellular penetration does not provide the mechanical interlocking but the raised cellular fibres do, as long as the adhesive is able to flow around fibres which are firmly attached to the rest of the wood structure.

As wood degrades by chemical or biological mechanisms, wood substance (cellulose 45% dry weight, hemicellulose 30%, lignin 25%) is lost, decreasing its strength and increasing its porosity. Loss of substance and strength has been extensively studied for the conservation of waterlogged wood, whose porosity has been measured in terms of the relative amount of water filling the remaining degraded

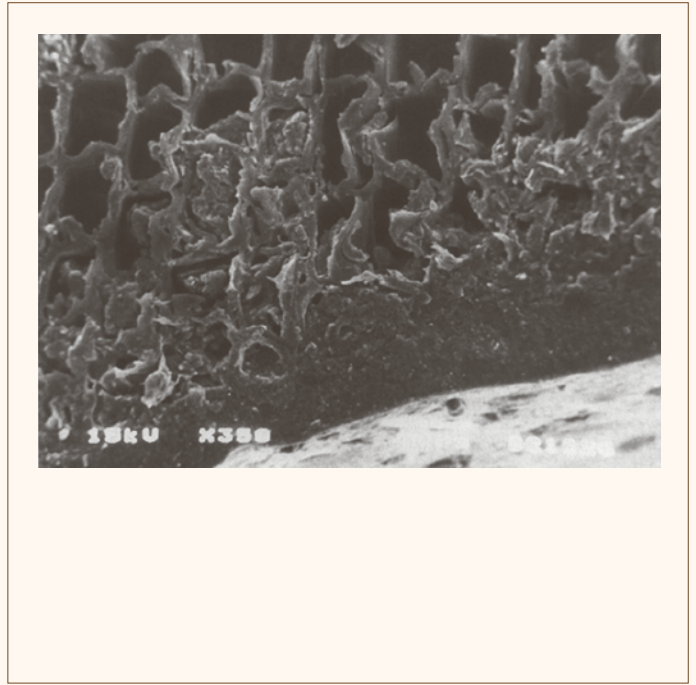


Figure 6 Effect of sanding on a wood surface (de Meijer, Thurich and Militz 1998): SEM-microphotograph (350x) showing the WAD300 coating on spruce planed and sanded with fine (180) sand paper. Note that the outer cell walls are deformed by the sanding process

wood structure (Jensen and Gregory 2006). However, these methods give little indication of the spatial or size distribution of the pores. Methods for consolidation of degraded wood should be informed by these distributions and the variation of strength improvement required. Fungi attacking wood can destroy the components cellulose, hemicellulose or lignin preferentially. For instance, soft rot and brown rot fungi dissolve cellulose leaving the brown lignin, and white rot fungi dissolve lignin leaving white cellulose (Deacon 2005). When cellulose is lost, the liquid adhesive sees an increasing surface of the less polar lignin. This will restrict wetting and flow of water based adhesives or consolidants. It will however make the wood structure less sensitive to added water (Rawat et al 1998).

The interaction of the wood components with the components of the liquid adhesive depend considerably on their solubility parameters (Loskutov and Aniskina 2008). Organic solvents and water swell the wood, with non-polar solvents having relatively little effect and polar solvents much more. This interaction is reflected in increased resulting adhesion when the liquid adhesive is applied in polar solvents, with water based adhesive resulting in higher strengths (Sakuno and Schniewind 1990). However, this swelling can cause changes and damage to the wood in and around the adhesive bond (Frihart 2009).

Swelling of the wood structure enables increased penetration of monomers of industrial cross-linking adhesives into the cells and cell walls. However, molecules with a molecular weight $>3,000$, ca 5 nm diameter (Lin et al 1987), are not able to diffuse into the cell walls (Tarkow, Feist, and Southerland 1965) and are therefore able to move only through open vessels and pores. Except for very low molecular weight materials such as dammar, Laropal A-81 and PEGs, most polymers applied in solution have much greater molecular weights and will flow only into the cell lumens, 0.01-0.4 mm in diameter. For example, Paraloid B-72 as a MW of 45,000, with a diameter in solution of ca 0.015 μm . The greater size of dispersion particles, 0.03-3 μm in diameter, restrict their flow into the cellular structures, especially as a large particle can block a pore.

Wooden panels of paintings have undergone considerable change. Rarely does the conservator come across a clean wood surface. Even if it has not been treated in the past, the wood will have degraded chemically and acquired a layer of pollution. This pollution will also have penetrated into the wood structure. Many panels have been dismantled and re-adhered, had a coating applied, been consolidated or been stuck to another support, pesticides added, or even all of these. Each of these additional materials will alter the characteristics important for adhesion, surface texture, porosity, surface chemistry etc. The current state and properties of the altered

wood should be understood before applying a further material. An increasing number of techniques are becoming available to assess the state of degraded wood and its mechanical properties (Sfarra et al 2012; Zhang et al 2011). How these macro properties of strength etc relate to their microscopic equivalents for ensuring adequate adhesion and consolidation is yet to be determined. See (Bader et al 2011) for a study of archaeological wood.

4.c. Conservation reports

Historic materials

Traditional materials have been reviewed (Unger et al 2001; Dardes and Rothe 1998). Adhesives for joining panels were casein and glue. The joints have frequently been reinforced on the painted side with cloth adhered with glue either alone or made up as gesso. Imperfections in the panels, such as knots or damaged areas, were also filled and covered with glue or gesso. These materials continued in use for repair and restoration until the 20th century.

Glue is likely to deteriorate, by biodeterioration, by hydrolysis / oxidation and by movement in the glue and substrate creating cracks. This loss of structural integrity and adhesion will cause the bond to weaken and fail. The glue will remain soluble and relatively easy to remove.

Casein, assuming that it is cross-linked with lime, is much more resistant to degradation and its bonds are less likely to fail. And the bond will be much more difficult to separate and clean up.

Restoration materials

Restoration materials have been reviewed (Unger et al 2001; Horie 2010; Dardes and Rothe 1998; Phenix and Chui 2011).

Adhesives and gap fillers for repair of joins and breaks in panels

Glue is widely used to re-make joins between planks of panels. Both mammal glue solutions (which gel at room temperature) and fish based glue solutions (which remain fluid) are used. In order to achieve a good join, the solution will have to wet the surface and penetrate into the cell structure. This usually requires that the adherend surfaces are cleaned, usually by removing the thin of aged, contaminated wood. There is a widespread practice of applying gelatine based glues in water (frequently fish derived) to “reactivate” remaining solid glue in joins. There seem to be no reports that this is an accurate description of the process and result. Unless

the original glue is highly degraded becoming soluble at room temperature, it is likely that the original glue particles will merely swell when exposed to the applied water and be encapsulated in the new drying glue. Since glue shrinks considerably after setting as the water evaporates, joints have to be tight in order to reduce the overall shrinkage. Glues cannot provide the gap filling necessary for distorted matted surfaces on deteriorated panels. Glue has been shown to form joints that can be disassembled using simple techniques, though the water required for softening the glue will have effects on the wood and other materials of the painting.

Urea resins and epoxy resins have been used for making joints in broken planks or for applying spot attachments for support frameworks. When tested (Young et al 2002), these (and hide glue) proved stronger than the wood, causing damage to the wood when the joint fails.

PVAC dispersions are widely reported as adhesives though the trade name of the product used is frequently not specified, and of course there will be no reliable details about its composition. Each manufacturer makes its own range of dispersions to fulfil considerably different industrial requirements, as demonstrated by the contrast between Evo-Stik Resin W, Mowilith DMC427, and Jade 403N, all PVAC dispersions (Young, New, and Marchant 2011). Because the particle size of the dispersion is much larger than those of either solutions or pre-polymers, penetration into the pore structure of the wood is likely to be less. This in turn will mean that the adhesive bond will rely on the roughness of the surface and the wetting by the liquid adhesive. As the polymer film will be sitting on the surface, it will be more easily removed than penetrating types. However, the polymers in commercial dispersions have a very high molecular weight and will be dissolved with considerable difficulty, so in practice requiring mechanical methods for removal. The ease with which dispersions can be adapted to specific requirements should encourage and enable the production of dispersions meeting conservation requirements, as has been achieved with epoxy resins for glass, wood and leather, and with ketone resin picture varnishes.

There has been an increasing use of separation layers between adhesive and wood substrate, to enable an intractable adhesive to be removed mechanically and the separating layer removed using less damaging methods. Paraloid B-72 is commonly used for this purpose because it is claimed to be a reversible treatment, but without evidence for this claim. It seems unlikely that significant amounts of a soluble varnish can be removed using solvents from a porous wood surface. The stability of this acrylic resin will probably reduce the likelihood of long term ill effects, except if driven through the structure of the wood into painting layers.

If glue is used as a separation layer, this is less likely to be removable from the wood structure and may affect subsequent treatments more. However, wax separating layers (Williams 2011) are unlikely to be removable, creating future adhesion problems. The addition of another layer into the adhesive joint increases the number of locations for failure of the joint, whether designed into the reversal strategy or as a result of excessive strain. Ideally perhaps, the addition failure location could be within the separation layer or between this layer and the adhesive.

The relative strength of the adhesive, the wood and the bond has been investigated (Young et al 2002; Young, New, and Marchant 2011). These experiments using recent wood showed that even this sample material has weak areas that fail at low stress before the adhesive. In choosing a strategy for joining planks, one must estimate the range of strengths of the aged wood. Support for the joints can be supplied by a combination of the strength of the adhesive and any applied cradle, choosing where the location of failure of the joint will be.

Wax resin adhesive for balsa backing has been applied widely. Both these components have low molecular weights and should remain easily soluble. After mechanically scrapping off the backing and adhesive, removal would normally be by dissolution. A poultice using low polarity solvents may extract part of the resin and some of the wax from the wood pores. Any remaining in the pores would probably interfere with subsequent adhesion.

Consolidation of degraded wood

Many materials have been used to strengthen wood: wax, wax / resin mixtures, solutions of shellac, Paraloid B-72 and other resins, dispersions such as Plexigum P28, glue with alum, and cross-linking polyester resins.

It has been shown that soluble consolidants can be removed by intensive extraction with solvents leaving ca 0.5-1% of the polymer in the wood structure: PVB (Butvar B98) – methanol, PVAC (AYAT) – acetone, acrylic resin (Paraloid B-72) – toluene and acetone (Schniewind 1988); PEG – toluene (Jeremic and Cooper 2009).

Much of the best conservation directed research on wood consolidation and its interaction with added strengthening materials was carried out by (Schniewind 1998), firmly based in knowledge of the wood and its properties. His research on consolidants and adhesives, although small scale and short term, increased understanding but revealed considerable holes in that understanding. There is now somewhat increased knowledge about how both solvent and dispersion borne polymers interact with wood, but recent publications on consolidation (Horie 2010; Michalski 2008) show that these holes have not yet been filled. The research

needs to be extended from modern wood to understand the change in properties that are achieved by treating degraded wood.

Coatings

Backs of panels have been coated during construction of the panel and thereafter. The reasons for coating will have varied e.g., aesthetic appearance, deterring pests, reducing moisture sensitivity. The coatings have been gesso, unspecified paints, solutions of shellac, cellulose acetate and nitrate. The low moisture transmission poly(vinylidene chloride) polymers have been applied to wood in order to reduce movement in wood. Most coatings crack when the underlying substrate moves, so drastically reducing their moisture resisting properties.

Fillers for defects include gesso, wax / resin mixtures, solvent based PVAC fillers and epoxy resins.

The outcomes of past treatments have been widely described in narrative form. It would be easier to contrast and compare these treatments if the materials, methods and outcomes were gathered and tabulated.

4.d. Insights required for designing conservation applications

Desired outcomes

In recent decades, preservation of the support as part of a whole object has become more important, historically, aesthetically and for its conservation. The extent to which the state and changes in the support are allowed to determine the appearance of the painted surface will limit the options available for treating the support and the surrounding environmental control measures. In addition, it must be expected that these objects will be repeatedly retreated. In the past, many treatments with their added materials have been carried out to forestall damage caused by environmental changes. As in many other fields of conservation, this has rarely been effective in the long term, often resulting in greater problems, just delayed until the conservator has retired. In designing a treatment, the complete treatment cycle of application, setting, ageing, reversal and retreatment must be explicitly specified:

- Anticipated uses of the objects, acceptable changes to the wood support, acceptable changes to the painted surface resulting from the support, reversibility of treatment, effect of treatment on information contained within the materials of the panel, ethical criteria, cultural criteria, alternatives to treatment.

Knowledge of the wood

Although there is a large past and current research base on commercial sound wood, the nature and properties of old and degraded wood have received far less attention. The properties important to conservation are:

- Density, porosity, surface properties, strength, EMC, response to RH changes.

Knowledge of the panel

It is as a support to the painted surface that determines the importance of the panel. Most of the past judgements of the required mechanical properties have been made by experience, with little use of explicit modelling of the influences, forces and responses involved, short and long term:

- Strength requirements, dimensional requirements, adhesion to the paint layer, prediction of changes in these properties over time and in different environments.

Treatment methods and materials

In order of decreasing interaction, consolidants, adhesives and coatings are used on the panels. For each of these, it is necessary to know how the material interacts with the object at all stages of the treatment cycle:

- Application – as a liquid, viscosity, surface tension, flow, penetration, migration, adsorption, swelling of wood, extraction of solubles
- Setting – gelling, mass deposited, distribution of deposition, solvent loss, shrinkage
- Ageing – creep, cracking, chemical reactions with wood, degradation / cross-linking / oxidation, migration of components into and out of the wood
- Properties required of added material – molecular weight, solubility characteristics, stiffness, strength, creep, Tg, colour, adhesion, chemical stability
- Changes in wood / composite physical properties across the cycle – stiffness, strength, porosity, response to RH changes, scale of changes (macro to molecular)
- Reversal – mechanical methods, solvent swelling, dissolution, extraction, effect on object, extent of removal, changes in object resulting from treatment cycle
- Retreatment – restrictions on further treatments

4.e. Conclusions

Consolidation

Common to many areas of conservation is a lack of understanding of consolidation. This is demonstrated by the numerous experiments which are not based on any theoretical model, but merely trying out a range of tests. The best attempts so far are those of (Jensen 1997; Michalski 2008). This will require a campaign to explore the theoretical models, comparing these initially with experimental models and then with real objects.

Real adhesives

Also common to other areas of conservation is a lack of knowledge of what happens to real adhesives etc applied to objects over time. The striking findings by (Hansen 1995) that the properties of real thermoplastic films on objects were very different from the starting materials and the properties recorded in the literature show that our assumptions about polymer properties are misplaced. This has not been followed up. Although Hansen's work was on synthetic resins, we have similar ignorance about glues and casein.

Adhesives for conservation

A programme of developing adhesives designed for conservation requirements is becoming more urgent as previously well understood commercial materials are discontinued. The re-design of an adhesive system requires reconsideration (and modification if necessary) of all the factors involved: the nature of the adherends, application method, setting method, forces applied, environmental influences, method of reversing the join etc. Once the specifications for adhesive system have been clarified, the adhesive itself can be designed. This will require collaboration with polymer system designers, commissioning of small scale production and quality control evaluation of the product. (McGlinchey and Yuan 2004) is good example of the processes involved.

Technology transfer

Studies of industrial adhesives on wood are demonstrating that the bonds formed are highly dependent on three factors: the materials applied; methods used for application; and the relevant structures of wood. Industrially, each of these factors can be, and are, adjusted to achieve the desired bond. The type and strength of the bond has considerable implications for its stability and reversibility. Lessons from conservation practice and industrial research could be combined to improve the tuning of techniques for specific applications.

NDT calibration

More fundamentally, we do not have understanding of the degraded wood of the panels that come for conservation. This understanding is necessary to tune the treatment, and is currently rarely informed by instrumental examination. Non-destructive testing machines have been developed, but their application to conservation depends on creating data sets that calibrate the NDT measurements using destructive measurements on real objects, from the molecular to macroscopic scales.

Learning from collective experience

The outcomes of past treatments have been widely described in narrative form. It would be easier to contrast and compare these treatments if the materials, methods and outcomes were gathered and tabulated. An expert group would then have a rich resource to draw further conclusions and insights.

4.f. Research questions

Consolidation

- The most common degradation of wood panels is the result of insect damage. How much increase in strength is required to achieve stability of the paint layer, and where should the consolidant be placed?

Real adhesives

- What are the properties of the adhesives, consolidants and coatings actually measured on wooden panels, and what are the interactions with the substrate?

Adhesives for conservation

- What factors need to be integrated to design adhesive systems for the different tasks in conserving panels?

NDT calibration

- Can NDT techniques be adapted to assess the state of wood before practical conservation is undertaken?

Learning from collective experience

- Can a metadata structure be agreed that can be used to gather comparable data for comparison between history and outcomes of panel paintings?



Figure A,B,C Johannes Cornelisz Verspronck, Maria Strijp (1627-1707), wife of Eduard Wallis. Haarlem, 1652. Oak, 97 x 75 x 0,8 cm. The support consists of three butt-joined boards. The reverse of the panel shows regularly spaced saw marks and a St. Andrew's cross (see detail). © Rijksmuseum.

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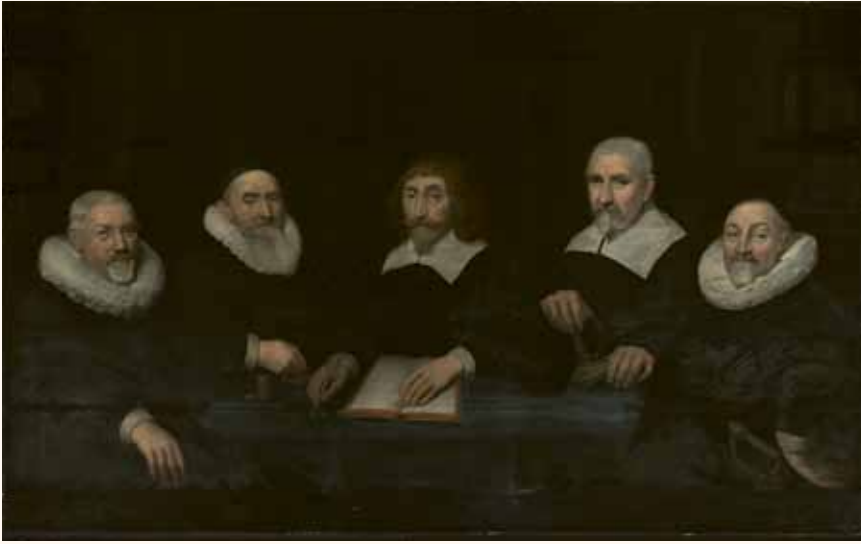
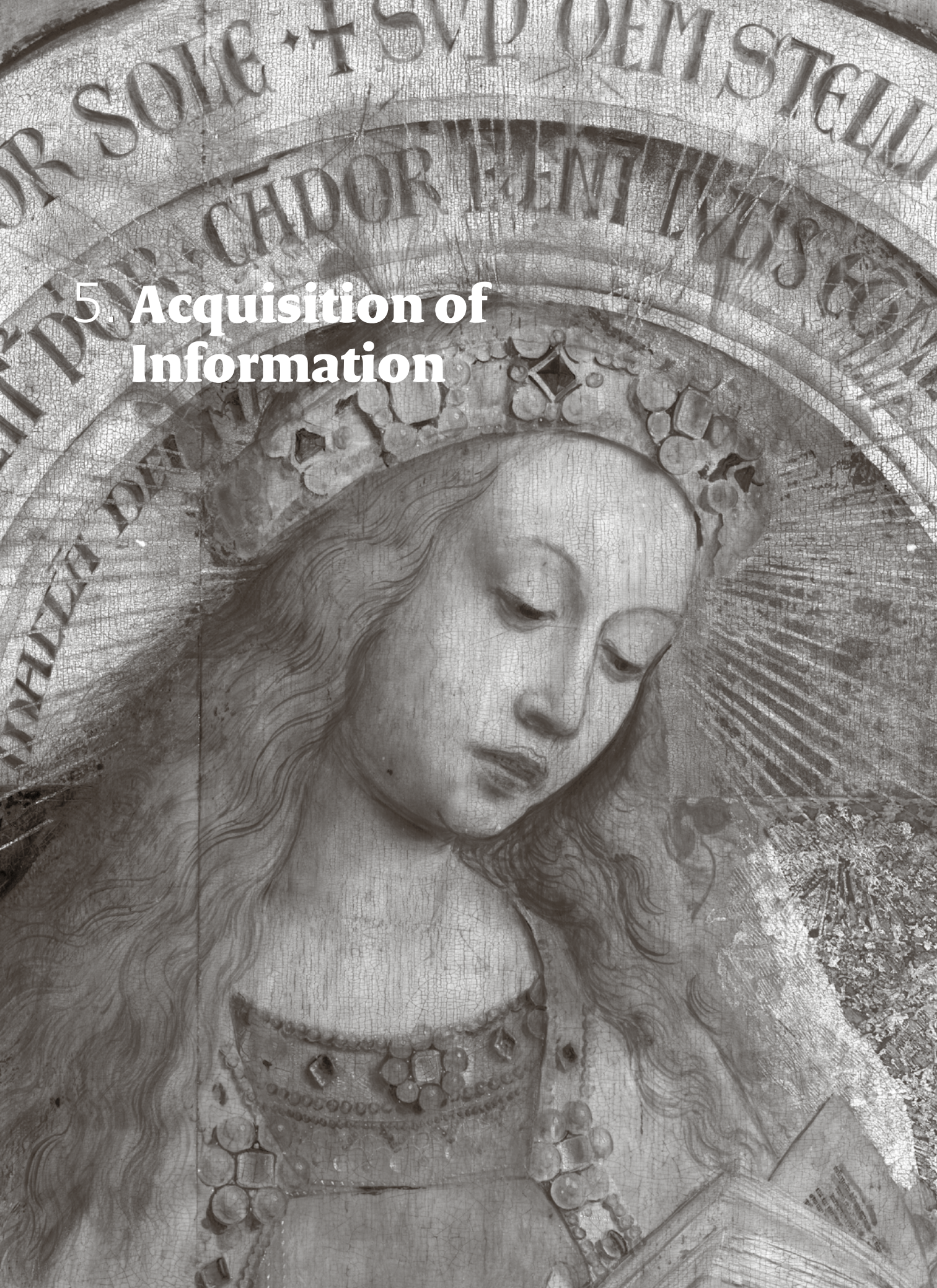


Figure A+B Allaert van Loeninga, *The Regents of the House of Correction in Middelburg, the Netherlands, 1643*. Oak, 147 x 220 x 1.8 cm. The support consists of seven horizontal oak boards. The bottom board is a later addition. The joints were previously reinforced with dovetailed inserts as well as battens, which were later removed. © Rijksmuseum.



5. Acquisition of Information



2. Acquisition of Information

5. Acquisition of Information

This section addresses techniques and methods for the acquisition of information to assist the structural conservation of wooden panel paintings. It is a relatively diverse topic as it includes population studies performed by conservators, modelling of wood performed by wood scientists and numerical modelling experts, techniques and methods performed by measurement and instrumentation specialists, and finally processing the data by image and 3D data processing experts.

Population studies are addressed in the first section, as this topic defines the scope and methods for the later parts. Then the requirements of the analytical and numerical models are presented along with state-of-the art in the scientific aspects of this modelling. A wide range of sensors and instruments have been used for the structural diagnostics of wooden panel paintings with some new techniques becoming available as electrical components and computing power increases. Operating software is becoming more user friendly; however in many cases instrument costs remain high. Rapidly developing with the increase in computing power, including on portable devices, are signal and image processing methods, including 3D and 4D dataset processing. Also improving are interfaces to display data to the end user, for example, virtual reality displays.

5.a. Population Studies

The topic of population studies in conservation is introduced by Caple (2000). The aim is to obtain knowledge of the behaviour of objects by looking at relatively large amounts of objects. It is a procedure for selecting items from the collection for more detailed research. Once a broad research topic, e.g. panel paintings, has been defined, the collection is initially assessed from either database records or a walk around the gallery and storerooms to identify objects that fall within the broad scope. This data is analysed and the scope is narrowed iteratively, for example first to objects showing significant damage, then to objects displaying a specific type of cracking, until a manageable small number of objects are selected for detailed study, within the project constraints of budget and manpower. High value objects

are commonly selected because of their importance to the collection, although this is in contradiction with obtaining knowledge of general behaviour. This is because of the opportunity to gain specialist knowledge in studying these valuable and unusual objects.

Population studies can be applied across different areas of conservation and as such no specific style for designing a population study exists for wooden panel paintings. Very limited examples of population studies for wooden objects are published in the literature, e.g. van Duin (2011). In a wider sense population studies are conducted on mock-up to gain information of general behaviour. Brewer (1991) made a detailed study of the moisture sorption for a range of coatings in combination with a range of wood types. This article describes how the wood and coating types were selected and the statistical techniques used to analyse the results. Alternatively a single object may be studied in detail, for example, Lasyk, Łukomski et al (2012) describe a condition survey of a wooden altarpiece is used to guide subsequent assessment using digital speckle pattern interferometry (DSPI), a structural assessment technique described in more detail in the section 5.c. *Methods & Imaging*. The need to look at the behaviour of larger numbers of museum objects rather than individual objects was expressed by the participants of the expert meeting in January 2011 in Amsterdam and will be an important aspect of the Climate4Wood research programme.

Further work is required to define the procedures specific to panel paintings and to collate existing, including unpublished, population studies.

5.b. **Modelling**

Modelling and simulation are used to answer specific questions about a wooden object, for example how does it respond to moisture changes? An early paper by Mukudai and Yata (1986) described the modelling and simulation of wood undergoing viscoelastic behaviour due to moisture change. The model was constructed by considering how the interaction between layers in the cell wall (microscale) could interact with the macroscale mechanical properties. This model was extended to the modelling of bending deflection in a follow-up paper by the same authors Mukudai and Yata (1987). The structural response of painted wooden surfaces was considered in a paper by Mecklenburg, Tumosa et al (1998). This paper determined many physical relationships (humidity-moisture; humidity-strain; stress-strain, etc.) for a variety of coatings, including hide glue, gesso and paint, that can be used to develop mechanical models.

Sandu, Brebu et al (2003) studied the aging of limewood supports of old paintings. Experimental studies and the modelling of the aging of wood and its influence on the structural properties of wood is a topic that has received limited attention. Ellis and Heginbotham (2004) measured the mechanical properties of barrier coatings to assess solvent evaporation and the shear strength of adhesives. They concluded by determining the following failure modes (i) wood failure, (ii) barrier-coating to wood interface failure, (iii) barrier coating to epoxy interface failure, and (iv) epoxy failure. The group of Luca Uzielli (Dionisi Vici, Mazzanti et al 2006) studied the mechanical response of wooden boards subjected to step variations in humidity and related experimental and mechanical models. One of their conclusions was that about the cupping deformations and through-thickness moisture gradients when waterproofing was applied to one side of a board.

The relationship between museum climate and mechanical properties was explored in a paper by Michalski (2007) on risk models. The theme of the paper was to relate the allowable museum climate to the actual mechanical behaviour of the object, including fracture models, fatigue and stress. The topic was also investigated by Bratasz, Jakiela et al (2005) who established thresholds for the magnitude and rate of humidity fluctuations. Issifou-Samarou, Wittmann et al (2007) considered the relationship between the drying of wood and crack formation. They considered these properties for European spruce, as well as for West-African woods (Iroko, Mahogany and Teak). The microclimate of a display case was modelled by Steeman, Belleghem et al (2009) using commercial computational fluid dynamics software. The model considered the coupling of heat and moisture transport. Residual stresses were modelled by Dureisseix, Colmarsy et al (2011) using a combined finite element modelling and experimental approach. By incorporating the experimental 3D deformation data, the model was able to predict residual stresses in the panel before and after restoration.

Models have some limitations. They are time consuming to construct and by necessity they represent a simplification of the object. They need to be validated by measurement techniques, such as those described in the next section. Modellers and experimentalists need to work closely together to come to a successful outcome.

Challenges for the modelling and simulation are to representatively reproduce the wooden artwork in a way that useful results can be obtained for conservators. Further the aging of wood has a significant influence on the structural properties, but has received little attention in the modelling. Open source modelling can potentially allow a faster exchange of information between researchers on optimum modelling techniques and for closer networking.

5.c. Methods & Imaging

A large number of structural diagnostic techniques have been investigated for wooden panel paintings, however few are in subsequent routine usage in conservation laboratories. Recent review papers have covered the range of non-destructive testing (NDT) techniques available. (Maev, Gavrilov et al 2008; Elias, Masa et al 2011; Sfarra, Theodorakeas et al 2011). These papers discuss a range of techniques for both chemical and structural analysis, including acoustic imaging, multispectral illumination and imaging, optical coherence tomography, spectroscopy, thermography and ultrasonic techniques. Other measurement techniques for wooden panel paintings mentioned in the literature include holography and speckle interferometry techniques, reviewed by (Ambrosini and Paoletti 2004); x-ray and terahertz techniques (Krug, Porra et al 2007) and (Jackson, Bowen et al 2011) respectively; and NMR (Senni, Casieri et al 2009). The main groups of techniques will be elaborated in the following paragraphs.

Wood identification and dating are the starting points for the assessment of a wooden object, not only from the structural point of view, but also from an historical perspective. (Zhang 1997) assessed the variations in ring width and density in European oak. Later, (Bernabei, Quarta et al 2007) applied dendrochronological and radiocarbon dating analysis to the assessment of a wooden panel painting attributed to Cesare da Sesto. The same authors applied similar analyses in (Bernabei, Bontadi et al 2010) and (Bernabei and Bontadi 2011) to the study of stringed instruments from the Cherubini Conservatory in Florence, Italy.

3D measurement techniques can accurately measure the shape of an artwork. Taylor, Beraldin et al (2003) applied a laser-based triangulation scanning system to the measurement of museum objects. Three laser wavelengths (red, green and blue) together project a 'white' spot of 50 to 100 μm diameter on the object via an auto-synchronised scanning configuration. A tilted charge coupled device (CCD) array allows a large field of view and reduces shadow effects. An accuracy of 50 μm (spatial resolution) and 10 μm (depth resolution) was achieved. Optical scanning was also performed by Guidi, Atzeni et al (2004) to document visible defects in 'Adoration of the Magi' by Leonardo da Vinci, achieving a maximum spatial resolution of 90 μm . Robson, Bucklow et al (2004) used a photogrammetric system to measure the Westminster Retable, which is the oldest surviving easel painting in Britain. It is made up of six oak planks and survives from the second half of the thirteenth century. Its size is 3.4 m long by 1 m high by 0.1 m thick. The photogrammetric technique described uses a grid based method and achieves a maximum spatial resolution of 20 μm . Allowable thresholds for dynamic changes in wooden

cultural objects are determined by Bratasz, Jakiela et al (2005) who apply triangulation laser sensors for continuous in-situ monitoring of the dimensional changes of a polychrome wooden altar in the church of Rocca Pietore, Italy. [see Table 1](#) Long term monitoring over a period of more than 2 years was performed. Together with parallel monitoring of humidity, temperature and strain a detailed dataset of the response of wooden panels in-situ was obtained. A 3D full-field profile of the front and back faces of the Mona Lisa was recorded by (Brémand, Doumalin et al 2008) using fringe projection profilometry (FPP). The average uncertainty is a 12.5 µm. These results were used by Gril, Ravaut et al (2006) to validate a hygromechanical simulation.

Current challenges in 3D measurement techniques are to improve accessibility to the conservation community and to improve measurement speed, allowing closer to real-time reporting of data.

Strain and deformation in wooden panels can be measured using a range of techniques for strain and deformation measurement, e.g. as reviewed by Dulieu-Barton, Dokos et al (2005). They reviewed measurement techniques that will be discussed below, including optical fibre sensors, holography and image correlation. A more detailed review of holographic and speckle techniques for the investigation of panel paintings was published by Ambrosini and Paoletti (2004). Historically classical holography techniques were the more important. In 1990, Paoletti, Schirripa Spagnolo et al (1990) presented a technique based on sandwich holography for various objects, including the identification of defects in a panel painting model. Digital recording became more important with the improvements in CCD camera technology in the 1980's and 1990's and the displacement measurement technique of electronic speckle pattern interferometry (ESPI) developed rapidly. This technique acquired several names, including electro-optic holography, tv-holography, digital speckle pattern interferometry (DSPI) and digital holographic speckle pattern interferometry (DHSPI) and can measure displacements in the tens of nm to µm range. Spagnolo, Ambrosini et al (1997) describe an electro-optic holography instrument for the in situ analysis of microclimate variation of artworks. Displacements were correlated with temperature and relative humidity variations. Later Schirripa Spagnolo, Ambrosini et al (1997) used an adapted ESPI instrument to assess wooden artefacts in situ using image decorrelation. This configuration is described as simpler to operate than ESPI; however the results are less detailed. Antique Italian panel paintings were studied by (Albrecht, Franchi et al 2000) using portable ESPI instrumentation. A region of the painting 400 by 300 mm was assessed to determine the conservation state of the painting by location of irregularities in the surface deformation. Ambrosini, Paoletti et al (2008) reviewed

Table 1 Summary of shape measurement techniques

| Technique | Depth resolution | Spatial Resolution | Measurement Speed |
|--------------------------------|--------------------|--------------------|-------------------|
| Triangulation | 10 μm | 50 μm | Slow |
| Photogrammetry | 20 μm | Not known | Medium |
| Fringe projection profilometry | 12.5 μm | Not known | Slow |

digital speckle based techniques, including the previously mentioned ESPI and speckle decorrelation, together with shearography and speckle (pattern) photography (SPP). At the same conference Tornari, Bernikola et al (2007) described a multifunctional encoding system for the assessment of movable cultural heritage. This multifunctional encoding system combined holography, DSPI and shearography techniques. The effect of climate change on wooden panels was studied by Bernikola, Nevin et al (2009) using DHSPI. A climate control box was used to vary the relative humidity and temperature of the sample painting during measurement. Previously Young and Debashis (2005) had used a similar technique to study canvas paintings. Current research by Lasyk, Łukowski et al (2012) is to use DSPI for in situ condition surveys in a church in Hedalen, Norway. Shearography is a technique related to ESPI that is sensitive to the displacement gradient. It was reviewed recently by Francis, Tatam et al (2010). It has been applied to the structural diagnostics and monitoring at intervals of wooden panel paintings by Groves, Osten et al (2008), with an emphasis on the detection of signature features using an Impact Assessment Procedure and in a combined study with terahertz imaging Groves, Pradarutti et al (2009) to investigate defects both at the surface and in the bulk of the wooden panel. A recent publication by Tornari, Tsiranidou et al (2011) studied further the processing of fringe patterns from the above mentioned holographic and interferometric techniques including algorithms for the automatic detection of defects.

An alternative for the measurement of strain and deformation is to use image processing based techniques for detecting the displacement of fringe patterns. Triangulation laser displacement sensors (Bratasz and Kozłowski 2005) for continuous in situ monitoring of wooden objects. (Olstad and Haugen 2007) assessed a grid method for measuring the displacement of wooden panels in churches. The reference grid may be made by ‘hole drilling’ or by the addition of a white dot (grid) pattern. (Brewer and Forno 1997) used Moiré fringe projection to assess displacements in cradled wooden panel paintings due to relative humidity changes. A diffractive optical element (DOE) was used as an innovative fringe generator Giuseppe Schirripa Spagnolo (2003) in the analysis of ancient paintings by digital Moiré. Other applications for Moiré include 3D shape measurement by shadow Moiré (Brémand, Doumalin et al 2008), mentioned previously. A sufficiently accurate shape measurement allows deformations to be determined by subtracting shape profiles. Fringe projection, in conjunction with finite-element modelling, was described by Dureisseix, Colmarsy et al (2011) for the calculation of residual stresses in panels. Digital image correlation (DIC) uses algorithms to correlate patterns present on the surface of an object undergoing deformation. These patterns may be *natural* patterns (i.e. from the grain of the wood or painted surface)

Table 2 Summary of displacement measurement techniques

| Technique | Displacement resolution | Spatial Resolution | Measurement Speed |
|----------------------|---|---------------------|-----------------------------|
| Classical holography | 50 nm | < 100 μm | Slow |
| Digital holography | 50 nm | < 1mm | Fast |
| ESPI | 50 nm | < 1mm | Fast |
| Shearography | 20 $\mu\text{H}\eta$ (displacement gradient) | < 1mm | Fast |
| Grid Method | Variable | Variable | Fast |
| Moiré | 10 μm | < 1mm | Fast |
| DIC | 200 $\mu\text{H}\eta$ (displacement gradient) | < 1 mm | Medium |
| Deformation Kit | Not known | Single point | Fast, continuous monitoring |

or applied patterns as is more usual for engineering objects to increase the sensitivity of the technique. The technique is described in more detail by Dulieu-Barton, Dokos et al (2005). Several displacement measurement techniques do not fall within the above categories. The Fraunhofer Institut IRB describe an apparatus for measuring the 3D surface deformation of a painting (Vigi 2001). Measuring a wooden panel painting from Bartholomeus Spranger dating from 1580 is given as an example application. Dionisi-Vici, Bucciardini et al (2009) describe the *Deformation Kit*, developed for measuring microclimate variations of Wooden Cultural Heritage Objects (WCHOs). The Deformation Kit is based on low power displacement transducers and a data logging system. However it is required that the sensor is screwed to the back of the artwork. The researchers applied this kit to the monitoring of climate dependent variations of panel paintings in San Marco and other museums. A fibre Bragg grating is a strain sensor formed within an optical fibre. Fibre Bragg gratings have been used in Falciari, Trono et al (2003) for the continuous monitoring of wooden artworks.

In future these strain and deformation measurement techniques need to be portable to measure artwork in-situ and more easily accessible to the conservation community. Also further work on calibration is required to check the sensor performance on the variable surface textures and colours of artwork, especially for the more sensitive measurement techniques.

The bulk structure of the panel painting is also of interest and several techniques from terahertz imaging to x-rays to NMR have been used to study this. Terahertz imaging for cultural heritage conservation science was recently reviewed by Jackson, Bowen et al (2011). Terahertz radiation is electromagnetic radiation at a wavelength range between infra-red and microwaves. It is non-ionising and non-destructive, both for the object and the instrument operator. Several measurement configurations are possible, including those for time of flight, reflection, absorption and for spectral signatures. Groves, Pradarutti et al (2009) showed how terahertz imaging could be used for time delay and absorbance measurements of a wooden panel painting, identifying subsurface features, such as a knot within the wooden panel. Younus, Caumes et al (2011) describe a continuous millimetre-wave imaging scanner for art conservation science. Janssens, Dik et al (2010) review photon-based techniques for subsurface analysis of cultural heritage artefacts. The article contains a detailed study of different x-ray measurement configurations, including the full-field methods of macroscopic x-ray radiography (XRR), macroscopic and microscopic computed tomography (CT and MCT / μ -CT respectively), phase-contrast tomography and laminography. Microscopic scanning beam methods of XRF mapping (μ -XRF), XANES mapping (μ -XANES), XRD mapping (μ -XRD), confocal micro-XRF



Figure 1 Measuring a panel (presentation Christina Young)



Figure 2 Measuring deformation (presentation Uzielli)



Figure 3 Standard measurement protocol (presentation Groves)

(CXRF) and micro-XRF / XRD tomography are reviewed along with macroscopic scanning XRF (MA-XRF). Comparisons are made with infrared reflectography (IRR), optical coherence tomography (OCT) and terahertz time-domain spectroscopic imaging (THz-TDS). The x-ray techniques achieve spatial resolutions down to 100 nm and provide 2D or 3D datasets, depending on the configuration. Liang, Gomez Cid et al (2005) describe the OCT technique in more detail. OCT has a typical application in cultural heritage of assessing the paint and varnish layers, along with revealing underdrawings. High-resolution 3D imaging of flat objects by synchrotron-radiation computed laminography is performed by Helfen, Baumbach et al (2005). Laminography is a variation of x-ray imaging suitable for measuring flat objects. Krug, Porra et al (2007) applied computed tomography and laminography to the assessment of a wooden test panel. Morigi, Casali et al (2007) investigated two paintings on wooden tables by Gentile da Fabriano using computed tomography. Holes caused by woodworm and a layer of white lead were clearly identified. Nuclear magnetic resonance (NMR) can also be used for monitoring of the bulk moisture content of wooden panels, as shown by Senni, Casieri et al (2009). Infrared methods can also give information on the subsurface features Gavrillov, Ibarra-Castaneda et al (2008). Near infrared light (waveband 700 nm to 2.5 μm) penetrates the paint layers and gives information on the lower paint layers and underdrawings. Thermography operates at longer infrared wavelengths (3 to 14 μm) and gives information on the thermal properties of the painting, including thermal conduction. Pulsed phase or flash thermography Blessley, Young et al (2010) has been used to study these thermal properties as both the heating exposure is lower and the signal to noise ratio of the data is improved.

The challenges for bulk and volumetric measurement techniques are to identify new sources and detectors to improve measurement resolution, signal to noise ratio and to allow greater depth penetration and detectability by extending the operating wavelengths. Lack of portability is a limitation for many of these instruments. Large 3D and 4D datasets provide challenges for signal processing and visualisation of results.

Acoustic, including ultrasonic, methods have found limited application for the assessment of wooden panel paintings. Water-coupled ultrasound, as typically used for engineering samples, is unsuitable as water would be in direct contact with the artwork. Murray, Mecklenburg et al (1996) used air-coupled ultrasonic to detect splits, delaminations and voids. It was recommended to use both amplitude and phase scans as these configurations had different sensitivities to delaminations and splits. Maev et al (2006) reviewed state of the art acoustic imaging methods, including non-contact ultrasound, contact ultrasound and acoustic microscopy. Air-coupled ultrasound was also applied by Siddiolo, D'Acquisto et al (2007). They assessed through-transmission (TT) and single-sided (SS) ultrasound and concluded that TT ultrasound was more robust, but required access to both

Table 3 Summary of bulk measurement techniques

| Technique | Material types | Spatial Resolution | Measurement Speed |
|--------------|---------------------------------|---------------------------------|-------------------|
| Terahertz | Wood, paint, paper | 1 mm | Slow-medium |
| x-ray | Most | Variable, down to μm | Medium |
| OCT | Partially optically transparent | $< 10 \mu\text{m}$ | Slow-medium |
| NMR | Wood, paint, paper | Not known | Medium-fast |
| Thermography | Non-metals | 1 mm (but indirect measurement) | Fast |

sides of the panel. An alternative technique is acoustic emission (AE) where sound generated by the panel itself (during cracking, for example) is detected by sensitive piezoelectric sensors. Jakięła, Bratasz et al (2007) assessed acoustic emission with wavelet analysis of the signals for monitoring the evolution of damage in wooden objects, concluding the potential and cost-effectiveness of monitoring using AE.

As further acoustic and related techniques become available, they should be assessed for their suitability for artwork measurements.

Spectroscopic methods are commonly used for the identification and assessment of paints, but here the link to the structural properties is emphasised. Luckenbach (2002) assessed the quality of the restoration of *die Johannestafel in der Stadtkirche Bad Wimphen*, with multi-spectral imaging in the infra-red wavelength range (760 to 2400 nm). Fontana, Gambino et al (2003) discuss the challenges of integrating 2D data (infrared reflectography, IR & colour reflectography and UV digital fluorescence) with shape data provided by conoscopic micro-profilometry. As hardware integration is usually not possible, spatial referencing of data is performed using software data interpolation. Examples of measurements of ‘Storia di San Giuliano’ by Masolino, ‘Canaa weddings’ by Perugino and ‘Madonna with Child’ by an anonymous Florentine are presented. The FP7 Syddarta project (2011-2014) studies how structural information from panel paintings may be combined with infrared hyperspectral information. Sitnik, Krzesłowski et al (2012) combined shape information from structured light projection with visible wavelength multispectral imaging data.

Spectroscopic methods are widely used for the analysis of paint layers. They may potentially be used to assess the wood itself, for example in a study related to the aging of wood.

5.d. **Conclusions**

Many structural parameters of wooden panels can be measured using existing measurement techniques, including shape, displacement & strain, bulk absorbance at infrared, terahertz and x-ray waves, along with acoustic and thermal waves. Continuous long term monitoring is applied less frequently but can be performed using fibre optic, laser, electro-mechanical displacement and acoustic emission sensors. Alternatively re-measuring at intervals following by automatic correlation of the data can be performed, with data fusion and correlation also being an important part of multi-parameter sensors, such as those that measure spectral and shape data.

5.e. Research questions

This aim of this section is to bring together the most important research questions identified in the review of the state of the art for Acquisition of Information. These are summarised below:

- Are specific procedures required for population studies of wooden panel paintings? How will the complexity of the wood and its behaviour be addressed in the reporting?
- How can the published and unpublished studies of wooden panel paintings be brought together? How will the differences in data reporting be overcome?
- How are the models and simulations validated and made applicable to conservation treatments? What can conservators realistically expect from the models? How can we promote open source modelling?
- How can the accessibility of advanced measurement techniques to conservators be improved, including portability and small-scale support funding?
- How do we identify and develop the necessary validation and calibration procedures for panels?
- In some cases the size of panels is a limiting factor, making long measurement times necessary. Can the acquisition times of the measurement techniques and signal processing be improved to allow measurements on more realistic time-scales?
- What information do you need to visualise and in what timeframe?
- How will emerging measurement techniques be identified and validated for wooden panel painting conservation? Do these techniques need specific development for the application?

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6. Knowledge dissemination and education



Knowledge dissemination and education

6 Knowledge dissemination and education

This section addresses the ways in which information acquired during the current project can be disseminated via educating young professionals and sharing knowledge between experts in the research and conservation communities. The initial Expert Meeting, held in January 2011 in the Rijksmuseum, defined a research agenda in order to further understand the properties of panel paintings and related works of art so that the investigation of these artworks and the treatment of such can be refined. This Getty funded project aimed to deliver position papers on the mechanics of wood, the interactions of the laminate layers, adhesives used to treat wood, and ways of imaging or investigating these laminate structures. Results pertaining to a year long study have been outlined in the previous sections.

During this kick-off meeting, the participants were unanimous in their concern that the dissemination of existing and new knowledge between stakeholders be improved. It was also established that defining professional competencies and protocols are crucial for the education of a new generation of experts within this sector. These should be provided and communicated to all relevant parties. It was agreed that future close cooperation of conservators with conservation (scientists), combined with an examination of the current situation, would lead to further insight into the processes that occur in panel paintings and related works of art, thus leading to a broader understanding of the consequences of treatments applied both in the past and in the future. The link between the conservator, who carries out the complex treatments of such objects, and the scientist, who investigates the physical and chemical components and changes therein, would thus be strengthened. Furthermore, problems regarding the gathering of pertinent information and the subsequent dissemination of that knowledge were also debated. Discussions held during the meeting confirmed the breadth and complexity of the conservation field, which is multidisciplinary in nature and highly fragmented. Thus it was agreed that specific measures are needed to ensure the vital flow of information. This section aims to outline some of those specific measures.

The investigation and conservation of panel paintings as a research field is a highly complex and comprises multifaceted areas of interest. These areas for the most

part already exist, if fragmented, in an international context. In order to improve communication and knowledge dissemination, thus providing a common platform and further enhancing advances in this field, conservators and (conservation) scientists will need to develop a common language in order to bridge cultural and professional differences. In this manner stakeholders, who possess very different kinds of knowledge deriving from many different areas, can come together and share vital information necessary for the preservation and treatment of these important cultural heritage objects.

Meetings of professionals and other experts from different areas, such as that that occurred in January 2011, are essential. This allows experts, who often tend to remain within their own area of expertise, to collaborate with others from different fields, thus providing an incentive to look for new areas of research and to reach a basic understanding of topics that fall outside their own scope. In order to stimulate exchanges and interdisciplinary relations clear areas of expertise should be defined.

Other suggestions posed at the January meeting were to create a database in which existing research data is catalogued. This database should contain an inventory of existing apostate literature, relevant conservation reports and reviews of the effectiveness of past treatments. To create a database that is effective and user-friendly is a challenging project, which in itself is not the goal of this current project.

6.a. Knowledge and skills requirements

Professional competences

Professional competence is represented by a blend of theoretical knowledge and practical skills, including the ability to judge ethical and aesthetic issues in a systematic way (Larsen 2008). A number of key factors enable conservators to make informed decisions regarding treatment choices appropriate for a particular artwork or case. Firstly, a broad art historical and material knowledge of the object in hand is essential. Further, an understanding of the history and physical changes undergone by the object logically follows. Thirdly, comprehending the ethics and/or consequences of any action carried forms the third leg of this particular three-legged stool.¹ Moreover, the conservator should be aware of the latest state-of-the-

¹ George L. Stout used the phrase a “three-legged stool” to describe the interdisciplinary collaboration between science, art history, and practice within the conservation field. Source: Joyce Hill-Stoner.

art developments within a particular field of specialisation and standards of best practice. Thus, the domains of competence that a conservator should possess include material knowledge, communication skills, and problem solving capacities in addition to practical skills. Thus, it is essential that any theoretical knowledge be underpinned with practical examples and real life scenarios; that conservators are stimulated to discuss these experiences; and that new developments are exchanged on an international level between researchers and conservators (Seymour 2011).

These competences are adequately described and represented in the European Confederation of Conservator-Restorers' Organisations (ECCO) framework of competences for access to the profession of conservation-restoration, which is updated on a regular basis, outlining the knowledge and skills required by a conservator at the entry level to the profession (ECCO 2010). Each competency can be judged within a hierarchy of skill (see Table 1), allowing the conservator to move upward in competence as each new skill level is achieved.²

These competencies can adequately be applied to those treating panel paintings and related works of arts. A number of experts currently exist in this field who are fully capable of carrying out complex treatments to a high level of standard. These experts have developed over the course of their careers an inbuilt affinity to the objects. They have an in depth understanding of the problems encountered and have instigated innovative techniques and methods for treatment. What's more, while the current survey has shown that there are few conservators possessing proficient levels of competency in this field, there are a number of young conservators that are developing an interested in this highly specialised field. It remains paramount that these intermediate level conservators are given the right information and knowledge so that their skills can develop up the hierarchy of skill ladder. Furthermore, the draw of new conservators into this field remains a key aspect.

² While this taxonomy is tailored to the profession, it is noteworthy that the dissemination of new knowledge, through oral presentation or publication, is not mentioned within this hierarchy, though it is cited within the framework flow diagram.

Table 1: The ECCO hierarchy of skill (ECCO 2010)

| | | |
|---|---------------------|---|
| 1 | Basic | The ability to carry out only basic tasks in a complex conservation/restoration process. Unlikely to possess an in-depth knowledge of any subject area required to carry out the task unsupervised. May not be aware of many of the ethical rules that apply and operate well within the boundaries that are laid down by the profession. |
| 2 | Intermediate | A higher level of skill both in terms of breadth and depth. Expected to possess basic skills across the whole field of expertise, able to place different concepts within that field, and be knowledgeable about the rules. Able to carry out basic conservation tasks unsupervised and work within a team on complex conservation problems. |
| 3 | Proficient | Possessing adequate skill to carry out conservation processes autonomously and understands the spirit of the rules that govern that field. Capable of carrying out conservation-restoration tasks and processes to a level that is acceptable within the profession, but may not work as effectively as someone with many years of experience and may not possess adequate skill to carry out the most difficult tasks. |
| 4 | Expert | A comprehensive ability to carry out tasks and undertake processes within their field of expertise. Able to also carry out tasks and undertake processes proficiently in associated fields and apply knowledge and understanding of processes in new and innovative ways. Able to adapt and create new methods within the field of conservation/restoration. |

Education

Hutchings mentions that: “A profession’s need for an education sector that supplies appropriately qualified graduates is unequivocal. Equally so is the need for an education establishment to demonstrate that it meets these requirements.”

(Hutchings 2011)

Acquiring appropriate knowledge and skills at the relevant time within any individual professional development trajectory is determined by the most part by the availability of said knowledge and skills, in addition to an individual’s ability to assimilate said knowledge and skills.

Knowledge transfer and skill acquisition often initiates in the student-conservator’s formative years within a formal academic setting and will evidently develop throughout their professional career. Access to the latest findings and new developments within the field tends to be more accessible early in a conservator’s career within such an academic setting, institutions which by definition foster knowledge propagation.

Universities and other tertiary education institutions provide a melting-pot of multidisciplinary specialists and researchers, easy access to a multitude of resources including analytical and archival facilities, and a forum for like-minded individuals to express and exchange ideas. Getty Foundation’s Panel Paintings Initiative [http://www.getty.edu/foundation/funding/conservation/current/panel_paintings.html] provides opportunities for the specialization of young conservators, mostly trained as paintings conservators, in the structural conservation of panel paintings, as this is not offered anywhere in the world by present education institutions. Though many training institutions do offer specialised courses within this area, there is rarely sufficient time within an educational programme for students, either at undergraduate, graduate, or post-graduate level, to become proficient in treating panel paintings and related art works.

This project has highlighted the need to have key information readily available to students, not only so that they are encouraged to take interest in this field, but also so that they are given the correct theoretical foundation necessary to take on future challenges, thus developing new and innovative methods for treatment or research. Time at more advanced training levels should be allocated to allow students to develop the relevant hand skills and methodology necessary to carry out treatments. Information and skill development should therefore be available in the form of seminal reference material, case studies reported in publications, available projects and contact with experts within the field.



Figure 1 Figure 1 Panel Paintings Initiative meeting Florence 2008, hosted by the Opificio delle Pietre Dure e Laboratori di Restauro (Copyright The J. Paul Getty Trust 2008. All rights reserved).'



Figure 2 Measuring Mona Lisa using optical methods developed in Institut PPrime, CNRS, University of Poitiers, France (presentation Luca Uzielli)

Learning Outcomes and Competency Levels

Studying educational development strategies for other hands-on professions³, it has become clear that active participation in higher performance learning experiences, providing ‘procedural knowledge’, produces better learning outcomes; though these experiences must be supported by more passive activities in which ‘declarative knowledge’ is given.⁴ Learning is at its most powerful when it is ‘authentic’, i.e. active (Miller 1990). Practical tasks allow the student/conservator to move through the pyramid of competence, from being given knowledge (the novice), to being asked to remember and comprehend it (the advanced beginner), to understanding and applying that information (the competent). The following step is to encourage the students’ ability to analyse and critically assess or reflect on results (the proficient), and ultimately develop the skills necessary to implement findings in real-life scenarios (the expert) (Bloom 1956; Dreyfus & Dreyfus 1980; Anderson 2001). At this stage the student/conservator should be able to disseminate any knowledge or skills acquired to further the state-of-the-art within the profession (Seymour 2011)

Thus finding appropriate projects for students to undertake throughout their training is an essential aspect of course development. The validity of this statement also rings true when considering the learning curve of those who have left the somewhat protective confines provided by the academic educational system. Providing the right project to ensure growth of both knowledge and skills is essential, if conservators move up the competency ladder.

Continual knowledge transfer from one generation to the next will ensure that the field of panel painting conservation and research does not remain stagnant. It should be noted that the field must not remain internalised. Competent practitioners in similar fields should be regularly consulted and included within new and existing research groups. Using didactic methods such as lateral thinking ensure that those entering the profession in junior positions are able to ‘think outside of the box’ or ‘think a problem through’.

³ Surgeons, dentists, nurses, etc

⁴ Declarative knowledge provides statements of fact, such as: Mowilith DMC2 is a dispersion of polymer in water. The polymer is made from the monomers ethylene and vinyl acetate. Procedural knowledge imparts the ‘knowing how’, such as: how to apply Mowilith DMC2 to achieve a good bond between two substrates.

6.b. Knowledge dissemination

Knowledge dissemination involves all functions and means that can enhance the transfer of facts, information and skills from the research and conservation sector for the benefit of society at large. As research results are generated all over the world, this is an international arena. The different stakeholders involved will each have their own particular skills, goals and responsibilities. Knowledge flows in a multitude of ways. It may be published in articles, in reports, journals, proceedings, or in books, or via web-based media and can be downloaded as PDF files hosted on web pages, forums or blogs. All knowledge dissemination or transfer relies heavily on a good network formation. Networks, both formal and informal are essential as channels to facilitate the exchange of information.

Mobility and education

Designing sets of competences that transcend geographical borders and encourage interdisciplinary collaboration at a training stage will encourage mobility within the field. Mobility of workforce is a key communication issue and thus promotes knowledge transfer. In Europe the European Qualification Framework (EQF) [see http://ec.europa.eu/education/lifelong-learning-policy/eqf_en.htm] has gone a long way to stimulate mobility of clearly defined workforces, amongst which are conservators (ECCO 2010). The EQF system aims to make qualifications from different countries easier to compare, thus allowing citizens from one country to attain training from another country or use existing qualifications, which is easily recognisable in all European member states. EQF Level 5 is classed as equivalent to a Bachelors education (3 year undergraduate degree), EQF Level 6 to a Masters degree and EQF Level 7 to a postgraduate PhD (Doctor of Philosophy).

Defining these key competences for each level is crucial for this system to work. In a European context, this task is well on its way and is being undertaken by E.C.C.O. (European Confederation of Conservator-Restorer Organisations) and ENCoRE (European Network for Conservation-Restoration Education). This transparency of competencies has already begun to support the exchange of ideas and information (i.e. promoting knowledge transfer) within the system as participants become aware of goals and levels achieved by international colleagues. However, it should be emphasised that competencies defined by these two European professional bodies are used to define board levels of proficiency rather than specific requirements for panel painting conservation. These competencies still have to be agreed upon by all interested stakeholders.

Furthermore, the European system encourages both students and staff within the educational system to move from one European educational institution to another, taking with them knowledge, understanding and expertise in areas unfamiliar or unexplored by their international colleagues. This wider view is encouraged by a variety of international exchange programmes, such as Erasmus Mundus, Leonardo da Vinci programme, and Europass (a standardised portfolio enabling people to describe their skills in a transparent manner) [see: <http://eacea.ec.europa.eu>]. As yet, to the author's knowledge, this system has not been put into effect within the field of panel painting conservation. These exchange programmes are geared towards increasing the mobility of staff between educational institutions. Finding funding to effectively hire freelance experts within this field remains difficult and thus impedes knowledge exchange at this level. Moreover, these exchange programmes are often only for short periods of time, which would be insufficient for providing sufficient guidance to develop practical skills which by definition necessitate improvement over longer periods of time. However, short exchanges are excellent for the dissemination of theoretical knowledge.

Additional transparent competency programmes exist within a variety of countries. Again within the European context, a National Qualification Framework (NQF) system has already been established in many countries [see for the UK context: <http://www.ofqual.gov.uk/qualifications-and-assessments/qualification-frameworks/>]. This system is aimed at defining the proficiency of people already practising within a defined sector of the workforce and has derived as a direct response to the EQF qualification system described above.

Qualification systems are a means which can be used to connect different elements of a country's educational system so that people can pursue a variety of different learning pathways. These pathways include gaining knowledge and expertise in a non-formal manner. Vocational training (or on-the-job) remains a key entry port to the field of conservation, especially in countries that do not have a formalised education system. Defining transparent competencies that equate to a formalised academic training for conservators is a necessity within the field of conservation in general and also in relation to the conservation of panel paintings and related artworks. Additionally, Life Long Learning (LLL) encourages the exchange of ideas and skill both at an individual level and within participating groups. Those pursuing this type of education are thus freer to move between institutions or countries and continue to practise their profession as their non-formal learning is recognised.

Once transparent competencies and learning outcomes have been established for the conservation of panel paintings and related artworks, qualifications can be given to those fulfilling the required levels. A formalised set of goals encourages participants to complete these modules whether in a formal academic setting or through vocational training. It is hoped that as supply increases so will demand to fulfil these modules, thus providing further interest in the field, as interest in the sector increases so will funding and recognition. While these schemes are well established for conservation in general, within this highly specialised field of panel painting there is a limited supply of funding and experts. The Getty Foundation's Panel Paintings Initiative has taken on a leading role in this sector. The initiative creates mobility and education by supplying funding for beginning and intermediate conservators to participate in important conservation projects in well-established conservation studios in various institutions.

Networks

A continuous expansion of competences should be encouraged through ease of information access. It needs to be taken into account that the field of conservation practice is rather diverse and conservators may work in relative isolation as freelancers or in small groups. Only a limited number of institutions and museums in the world have a combination of various disciplines as well as a research group. Conservators should thus form networks to establish an appropriate treatment approach for objects that consist of a complex variety of materials. Again here the Panel Painting Initiative has taken up the baton, providing focus groups for the discussion of conservation practise in a number of different countries and collating a database of literature relating to the subject of the structural treatment of panel paintings.

Continual professional development (CPD) courses can be seen as a further investment in the future for the conservation practice – and for the objects themselves, but are doubly costly for independent conservators as they do not earn while participating in the course. Funding should be made available for conservators of all levels to participate in workshops or summer schools, as has for instance been organised by the Panel Paintings Initiative, with a summer school in Krakow in 2011 for conservators and art historians and through various other meetings.

Establishing networks between experts from all sectors, whether this be practicing conservators, wood scientists, biologists, dendrochronologists, researchers, etc, is crucial. The exchange of information between interested parties leads to new lines of thought and innovations. Thus it is essential that those practicing within the sector make themselves aware of others with similar interests. The creation of a

database of these experts and interested participants would enhance the formation of networks between specialists.

Networks, funded by European financing, have been set up to enhance research opportunities by conservators, scientists and curators. One example is the Charisma project (an FP7 Capacities Specific Programme Research Infrastructures) [see: <http://www.charismaproject.eu/>], which provides an example for future collaboration on an international basis in a multidisciplinary context. The project aims are summarised in the objectives described on their website: “In a program that covers joint research, transnational access and networking, the planned challenging activities require a combined effort and commitment of an high-level partnership of twenty-one organizations to provide access to advanced facilities and develop research and applications on artwork materials finalised to the conservation of cultural heritage and favoring the opening of larger perspective to the heritage conservation activities in Europe.” [<http://www.charismaproject.eu/about-the-project.aspx>; accessed 14.12.12]. A similarly funded project centring on the conservation of panel paintings would be highly beneficial to the field.

Terminology

As mentioned, the conservation sector is international in nature and comprises many different fields. A common language and an established vocabulary is essential for members of this community to communicate easily between each other. While common terms exist for some areas, such as wood species, other terms are indeterminate, such as the names of specific wood joints. This leads to confusion and the misinterpretation of data provided in publications or elsewhere. The formation of a database of terminology, which could conceivably be made in a number of languages (e.g. English, French, German, Spanish, Italian, Polish) would be highly beneficial to the sector. Terms relating to the wood species, panel construction, tools, treatments carried out should be standardised and used when communicating with all stakeholders.

Publications (Scientific, Trade and Professional)

The dissemination of relevant knowledge to the conservation sector via publication at present tends to be aimed at a variety of target audiences, and is often not easily accessible by those outside those particular target groups. Scientific authors are prone to publish in peer reviewed scientific journals (e.g. SPIE, The International Society for Optics and Photonics) available only on subscription. Thus new findings discovered by researchers may take time to filter through to non-specialist stakeholders. Most conservation journals are as yet not peer-reviewed (with exceptions such as Studies in Conservation, ICOM-CC Triennial Preprints) and are

thus not attractive to the academic field. Open access resources are rapidly becoming more popular and may be one area for the cross-over between academia and the practising conservator.

It is key that information reach the practitioner or the researcher in order that they can work efficiently and implement state-of-the-art findings into their own research. The formation of a database of relevant articles to the field would be an invaluable resource to this sector.

Databases

Databases can be used to collect and share information, acting as a general resource guide. An information exchanging network would be useful for knowledge dissemination, taking the form of a structured web-based database that would have a low threshold in terms of accessibility and ease of use. This requires a uniform approach in the collection of data by means of a standard protocol and a common terminology.

Building a database does not automatically guarantee user-friendliness; too many databases have been made that are hardly ever visited. Being extensive, constructive and easy to use, is something that is not easily organised. A Wikipedia-like expert platform to facilitate interaction between conservators and scientists was suggested during the January 2011 expert meeting. This would require extensive funding and international cooperation. The NWO CATCH-programme (Continuous Access to Cultural Heritage), which similarly aims to make information on cultural heritage easily available by sharing information between specialists, might act as an example. The Panel Paintings Initiative produced a project bibliography of literature on the conservation of panel paintings and related objects. This is available on the Getty-website [see: <http://gcibibs.getty.edu/asp/>] and includes abstracts. More general databases are AATA Online [see: <http://www.aata.getty.edu/Home>] and the Bibliographic Database of the Conservation Information Network (BCIN) [see: http://www.bcin.ca/English/home_english.html]. These can be searched using key and relevant terms or by author, institution or publication keywords.

Websites hosting findings derived from specific projects, e.g. the Ghent Altarpiece Jan van Eyck project [see: <http://vaneck.kikirpa.be/>] are becoming common practice and are a paramount aid to future research by all key players. Similar initiatives should be encouraged.

In Europe a consortium of 14 national ministries and agencies jointly develop the NET-HERITAGE portal [see: <http://www.heritageportal.eu/>], which should also enable access to data and publications (Bratasz 2010, NET-Heritage 2010). Subscribing libraries can access publications through JSTOR [see: <http://www.jstor.org/>], though individuals require login details.

The German conservation journal, *Zeitschrift für Kunsttechnologie und Konservierung*, has maintained a database of (under)graduate thesis work for a number of years. Though lists of students dissertations and Master theses were published on a yearly basis, this information is not easily accessible. Due to lack of funds this task discontinued around 2000 but a recent effort to continue this has been proposed both by ENCorE and IIC.

It is hoped that a central database containing all pertinent material regarding the investigation and conservation of panel paintings and related artworks be set up. It is noted that any such attempt would need careful consideration and participation by key players from all stakeholders. Any resulting database should be maintained and be updated regularly.

Conferences, Symposia, Colloquia and Meetings

Exchange of ideas and expertise is a crucial aspect of knowledge transfer. Experts within the field can achieve this through disseminating their current research, innovations or findings through publication or in a more direct face-to-face manner by meeting like-minded experts. Conferences, symposia, colloquia and meetings, all at a variety of scales, are organised on a regular basis by professional bodies, educational institutions, major stakeholders within the field, musea etc. (e.g. Getty, IIC, ICOM-CC, AIC, ICON, VDR etc) on a national and international platform. Access to these meetings by those working in the field directly or indirectly is essential for the dissemination of knowledge. Moreover, these exchanges aid networking between participants which is logically extended to direct colleagues as those participants return to their own environments.

Conferences or meetings organised by national conservation associations or international bodies tend to be either general in theme or related to a specific topic. The majority of papers presented at these meetings are published either as pre- or post-prints. To date few have centred on the investigation and conservation of panel paintings and related artworks. These have included a number of symposia organised by the Getty:

- 1998: The Structural Conservation of Panel Paintings: Proceedings of a symposium at the J. Paul Getty Museum.
- 2002: Methodology for the Conservation of Polychromed Wooden Altarpieces: Proceedings of a workshop organised within the Conservation of Polychromed Wooden Altarpieces project (2000-2007).
- 2009: Facing the Challenges of Panel Paintings Conservation: Trends, Treatments and Training: Proceedings of a two day symposium at the Getty Centre within the Panel Paintings Initiative (Current Projects).

Future meetings dedicated to this theme should be encouraged. One such meeting will be organised by three ICOM-CC working groups hosted in collaboration with the National Museum and the Academy of Fine Arts in Warsaw - Heritage Wood: Research & Conservation In The 21st Century (28th to 30th October, 2013).

Smaller meetings of experts, such as that held at the beginning of this project, should also be promoted. Again the Panel Paintings Initiative is taking the forefront, arranging for a number of meetings and workshops for twelve selected young professionals over the forthcoming years (2013-2014) to gain knowledge from experts in the field.

Moreover, experts should be encouraged to visit training institutes as guest lecturers in order to foster interest in this field within the new generation of conservators. This system already exists in a number of training institutes, such as that organised at the University of Amsterdam (UvA)/Stichting Restauratie Atelier Limburg (SRAL). The training of young professionals as painting conservators with a basic knowledge and understanding of the problems facing panel paintings in the Netherlands has been supported by workshops given by experts such as Ray Marchant (Hamilton Kerr Institute/Ebury Street Studios), Al Brewer (The Royal Collection), Jean-Albert Glatigny (Freelance, KIK-IRPA), Britta New (The National Gallery, London), and Monica Griesbach (Freelance, USA/France). Here a week long workshop, organised on a yearly basis, is underpinned by project work by the students revolving around treating panel paintings. The students must complete a number of key theoretical models in wood science prior to commencing treatment projects in which the structural repair of panel paintings is paramount. While this situation is not exclusive to the Netherlands it could be used as a model elsewhere, though the author recognises that other training organisations do conduct similar courses. Those with expertise in this field should cultivate these initiatives which could lead to further advancements in terms of the study and treatment of panel paintings and related artworks.

The role of research councils

The challenge is to organise knowledge transfer between different disciplines and research areas. Besides supporting individual projects research councils stimulate this multidisciplinary interaction through targeted programmes. In the U.S.A. the National Science Foundation (NSF) has established in 2009 a programme Chemistry and Materials Research in Cultural Heritage Science (CHS, previously SciArt) [see: <http://www.nsf.gov/>], which aims to enhance opportunities for collaborative activities between conservation scientists, chemists and materials scientists (Madsen 2011). Similar, but broader programmes exist in the U.K., where the Engineering and Physical Sciences Research Council (EPSRC) and Arts and Humanities Research Council (AHRC) jointly set up the Science and Heritage Programme [see: <http://www.heritagescience.ac.uk/>], and in the Netherlands, where Netherlands Organisation for Scientific Research (NWO) funds Science4Arts, also in collaboration with the NSF [see: http://www.nwo.nl/nwohome.nsf/pages/NWOP_8BGG23_Eng].

Such programmes are valuable in bringing together different disciplines from both academic institutions, museums and research organisations. These programmes should be jointly developed under the auspices of a national research council in order that stakeholders needs and possibilities are understood, thus making the most of resources. Continuous collaboration in the execution of resulting projects enhances exchanges between institutions and disciplines. These projects also integrate research and education, thus contributing to the education of young professionals at various levels of training in a multidisciplinary environment, where practical skills and academic knowledge can be intertwined.

The European Joint Programming Initiative (EU JPI) aims at avoiding overlaps and repetition between programmes at an international level. An example is the Climate4Wood research project, funded by NWO Science4Arts, bringing together furniture and paintings conservators, conservation scientists and engineers in an international setting [see: http://www.nwo.nl/nwohome.nsf/pages/NWOP_8ASETA]

6.c. **Project Planning, Proprietary Materials, and Advanced Technology**

Several barriers complicate the free flow of information and must be addressed. The European regulations for obtaining conservation commissions, involves submitting treatment proposals “in competition” on the open market. The consequences of this procedure are often quite negative for reserving time for research and permanent education by freelance conservators, which are often seen as areas where costs can be cut both by the client and by the conservator. This problem needs to be addressed at the proper administrative and political level in order to foster research and innovation by those carrying actual treatment on panel paintings and related objects. Furthermore, exchanges between those implementing remedial work and those carrying out research should be championed.

Intellectual Property (IP) issues may also play a negative role in knowledge dissemination. One example of this phenomenon is the use of commercial products within the remedial treatment of panel paintings and related artworks. Commercial materials have been used extensively in the treatment of panel paintings and related artworks. These proprietary products are rarely developed for the conservation field as the market is too small to be a viable concern. Professional conservators are inventive and often use materials designed for other related, if only peripherally, fields such as the coating and adhesive industries. The miss use of such can lead to disastrous future consequences if these materials interact negatively with original material or do not remain stable chemically or physically. Moreover, the complete component list of such proprietary formulations is often unknown and kept secret by the registered manufacturer. This can inhibit the development of research strategies or the explicit testing of materials for particular purposes (e.g. adhesives for rejoining panels). While empirical data may be derived, scientific findings may be hindered by manufacturing companies that will not give insight into products commonly used within the conservation sector. Collaboration between industry stakeholders and conservation professionals should thus be encouraged. Furthermore, the formulation of proprietary products is subject to alteration as manufacturers adapt to changing requirements within their respective fields. This may lead to confusion as expected results from testing or usage by conservators differ from previous findings. One additional point on this theme should be made: proprietary products may also be discontinued (e.g. the polyvinyl acetate adhesive Mowilith DMC2 produced by Hoechst) and adequate replacements are often hard to find.

Another example relates to the analysis of materials found in panel paintings and related artworks. New advances within the conservation field often require highly advanced techniques or analytical machines to produce answers/results for standard or common questions posed by conservators. These machines are more often than not found only within specialist laboratories, are expensive to buy and demand constant specialist maintenance. Access to these techniques or machines are frequently limited to the academic world or industry. Researchers have limited time to spend on questions raised by the conservation field and the financial resources available tend to be limited. Research carried out tends to be related to ongoing projects, often at PhD or post-doctoral level, which may limit the dissemination of results until the end of the project, thus delaying new findings from reaching those professionals working in the field. This example of restrictions due to IP issues inhibits potential collaboration between the scientific and conservation worlds. Means to circumvent this problem should be investigated and implemented.

6.d. **Future desired outcomes**

Bringing people together

Actively bridge the gaps between the participating experts, by

- clearly defining areas of research;
- finding a common language;
- participating in research;
- facilitating communication.

Networks should be multidisciplinary whenever possible. This is a challenge with regard to scientists who are often expected to contribute in isolation, primarily to the research output within their specific discipline. Moreover, they, as mentioned, may be reluctant to share findings until the completion of their research or project. The publications they produce are important academic outputs, but may not necessarily be applicable to the day-to-day needs of the conservation practitioner. Techniques, products and materials derived from scientific research will – if not explored and generated within a clearly defined and interdisciplinary research network - often need further development and investigation before these can be applied in conservation practice.

The communication between the conservator and the scientist may be difficult to understand or liable to misinterpretation, if not written for direct application. Moreover, as each of the various scientific disciplines has their own vocabulary and

peculiarities, the input by these may be difficult to judge and prove overwhelming by many.

Scientists will quite often not be aware of the day-to-day problems that conservation experts encounter, while conservation experts are not fully aware of the possibilities or limits science can offer. Mutual exchange of staff, often part time, must be encouraged. Opening laboratories and conservation studios to interested parties may be a way to combat this issue. Direct contacts between researchers, conservation scientists and practicing conservators need to be encouraged so they can interact and learn to understand each other's vocabulary, views and 'culture'. This will enable all participants to gain a better insight in the needs of the conservation profession and the possible options and feasibility of initiating further research. Knowledge is created from both sides and ideally co-created together. A high level of interaction can be possible by encouraging double appointments, part time in a museum or conservation studio and part time at a university department, where relevant research is done. This will also increase capabilities to include research results from other academic institutions.

Granting programmes like SciArt and CHS of the NSF or Science4Arts stipulate interaction between both groups, scientists and practicing conservators, as a necessary condition. In Science4Arts the conservation field was involved in developing the programme and must participate in each research project. Joint projects have the advantage that the research can be tailored to the needs of the conservation profession during the whole process. Funding organisations can additionally stimulate useful developments by making available specific valorisation grants.

Two types of networking activities could be envisaged: Intra-networking and Outreach-networking. Intra-networking aims at establishing an optimum communication, information exchange and transfer of knowledge among research-participants across the network formed within a research project. Basic intra-networking instruments will be a) network meetings, b) network training workshops, and c) a research-website.

Interactive contacts between public and private sector will expand training opportunities, thus enabling young researchers to have access to high-tech facilities and exposure to the problem-solving orientation of a private company. This could catalyse the introduction of new instrumentation or upgrading of existing products. Furthermore, through such collaboration companies may have access to or generate new niche-markets for promoting high-tech analytical equipment for cultural heritage organisations.

Sharing resources

A general resource guide and information-sharing network could be developed by

- focusing on the development of a common terminology and methodology to prevent miscommunications;
- reviewing the existing literature to improve accessibility and determine its use for informed choices;
- assuring accessibility and ease of use.

A network of conservation institutes could fulfil a pivotal role in making available useful information from research. These institutes would also need to activate strong network links with other knowledge institutions, which may be working within another remit, but might have a better expertise to contribute to specific problems. Therefore, the author suggests that these institutions could take up a facilitating task to create a better access to the scientific literature relevant to the subject in question. This could be further stimulated by organising symposia/ workshops, where standard problems from practice can be presented and the scientific implications be discussed, possibly followed by a session to immediately develop an answer to the questions.

“In situ” meetings related to major conservation projects should also be encouraged. This “open doors” approach will enhance diagnostic awareness within decision-making processes, based on interdisciplinary analysis whilst providing interested parties with direct access to the actual object and its problems.

Connecting fundamental understanding and skills

The understanding of fundamental aging factors and development of skills should be increased by:

- providing conservation schools with recommendations on training;
- organising workshops to assure the transfer of manual skills to a new generation;
- teaching new methods developed through research;
- developing accessible publications to be used in training;
- continuing to stimulate future cooperation between scientists and conservators.

Case studies in conservation-related projects or issues should be made available and encouraged for interested students enrolled in other studies, chemistry, physics etc. This would foster multidisciplinary collaboration at a formative level encouraging links to be forged between future scientific researchers and conservation professionals.

The organisation of introduction courses in conservation is highly recommended. These would include aspects historical context, construction process, deterioration and degradation of related materials, case studies of pertinent projects, ethical and aesthetical dilemmas, etc. Interest should be nurtured at a very early stage in the training programme of physicists and chemists. Similar programmes geared to interest conservation students in the chemistry of materials and the analyses of these should also be endorsed.

Further collaboration can be instigated by:

- Setting up hub centres which will be able to provide not only the facilities but also the expertise (whether as permanent staff or as temporary guest lecturers/tutors) should be encouraged. A number of institutes are already partially set-up to accommodate these centres. These include the Opificio delle Pietre Dure (OPD) in Florence (<http://www.opificiodellepietredure.it/>), Stichting Restauratie Atelier Limburg (SRAL) in Maastricht (<http://www.sral.nl/>), the Royal Institute for Cultural Heritage in Brussels (KIK-IRPA) (<http://www.kikirpa.be/>), Hamilton Kerr Institute (HKI)/Ebury Street Studios in Cambridge/ London (<http://www-hki.fitzmuseum.cam.ac.uk/>), amongst others.
- PhD training for conservators, conservation scientists, curators, and related fields in collaboration with a multitude of academic institutions e.g. in The Netherlands, Denmark, Portugal, the United Kingdom, Germany, Italy and elsewhere in Europe.
- Workshops, mostly with an experimental component, in which advanced level students – at the discretion of the host institution - will give the opportunity to
 - a) obtain training in new techniques and instruments
 - b) improve participants communication skills, by presenting their work and
 - c) widen participants scientific knowledge by attending lectures from specialists in the field both within and outside the partnership.
 The Getty Panel Painting Initiative (PPI) has already instigated such workshops with an initial (of 4) gathering taking place in Krakow in 2011, and further meetings to be planned in 2013 and 2014.
- Autonomous research carried out in the framework of joint scientific projects, established among the different host institutes of the network in conjunction with associated partners.
- Master-classes arranged by the organising partners.
- Providing “simulation models” for their use in scientific departments (artificial ageing, response to fluctuating Relative Humidity).

Lastly, the scientific analysis of art objects is a challenging discipline. The materials used to create art in the past are seldom well-defined chemical compounds that lend themselves to simple scientific analysis. For instance, inorganic pigments

were, often, produced from raw minerals with different compositions and impurities, depending on their place of origin. Organic materials, used to make dyestuffs or binding media for paintings and coatings or varnishes, were obtained by processing natural materials originating in plants or insects, animal bones and skins. These materials were often highly complex mixtures of proteins, lipids or carbohydrates and were frequently combined in the creation of the art work, forming compounds that present a great number of analytical problems. Creating databases of analytical results of standards of artistic materials and those used for the treatment of such would be crucial in the advancement of this field.

6.e. Future Research questions

- How do we develop a common terminology?
- How do we disseminate existing unpublished research and knowledge?
- How do we provide further education, workshops and training?
- How do we promote collaboration between scientific laboratories and conservation studios?
- How do we develop new techniques, validate them and introduce them into everyday conservation practice?
- How do we promote collective experience?



Expert Meeting, 9-11 January 2011, Ateliergebouw, Amsterdam.

6.f. **Relevant Journals and References**

Relevant Journals

This list of Journals, Newsletters, Bulletins, and publishing possibilities is not intended to be absolute.

Professional Bodies

(membership required):

Flits & AuCourant (now defunct), Restauratoren Nederland, (<http://www.restauratoren.nl/over-ons/fl-its/item18>)

Journal of the American Institute of Conservation (JAIC), AIC (<http://cool.conservation-us.org/jaic/>)

Journal of the Institute of Conservation, ICON (<http://www.icon.org.uk>)

Tijdschrift van de Rijksdienst voor het Cultureel Erfgoed (RCE) (<http://www.cultureelerfgoed.nl/>)

SSCR (defunct, was UKIC, now ICON)

The Conservator (UKIC defunct now Journal of Conservation Institute)

The Paper Conservator (UKIC defunct now Journal of the Institute of Conservation)

The Picture Restorer, Journal of the British Association of Painting Conservator Restorers (BAPCR) (<http://www.bapcr.org.uk/>)

Reviews in Conservation (IIC defunct)

Studies in Conservation, IIC (www.iiconservation.org)

VDR-Newsletter, Verband der Restauratoren (VDR); (<http://www.restauratoren.de/>)

WAAC Newsletter, Western Association for Art Conservation (WAAC) (<http://cool.conservation-us.org/waac/wn/>)

Subscription:

CR, Dutch Journal for the Conservation and Restoration of Cultural Heritage (now defunct)

Journal of Cultural Heritage (<http://www.sciencedirect.com>)

Kermes (<http://www.italiarestauro.it/kermes2.php>)

kM: Material Technical Journal Vol 1-81,

Dutch journal for material/technical studies (<http://www.tijdschrift-km.eu/>)

Restaura (<http://www.restaura.de/>)

Zeitschrift für Kunsttechnologie und Konservierung (<http://www.siegl.de/Restaurierung/Zeitschriften/ZKK-Zeitschrift-fuer-Kunsttechnologie-und-Konservierung::754.html>)

Polymer, Elsevier (<http://store.elsevier.com/>)

The International Society for Optics and Photonics (SPIE) (<http://spie.org/>)

e-Publications:

Conservation, Exposition, Restauration d'Objects d'art (CEROART) (electronic journal: open online access: <http://ceroart.revues.org/>)

e-Magazine (<http://www.e-conservationline.com/>)

e-Preservation Science (<http://www.moranartd.com/e-preservation-science/>)

Museum and Institute Bulletins and Newsletters:

Hamilton Kerr Institute Bulletin Vols 1-3 (published articles, <http://www-hki.fitzmuseum.cam.ac.uk>)

KIK-IRPA Bulletin Vol 1-32, KIK-IRPA (published articles, <http://www.kikirpa.be/NL/115/0/Bulletin.htm>)

OPD-Restauro Vols 1-23 (published articles, <http://www.opificiodellepietredure.it/index.php?it/178/opd-restauro>)

National Gallery Technical Bulletin Vols 1-32 (<http://www.nationalgallery.org.uk/technical-bulletin/>)

Technical Research Bulletin (The British Museum online open access: <http://www.britishmuseum.org>)

Views Magazine, The National Trust (Internal distribution: <http://www.nationaltrust.org.uk>)

On Board, ICOM-CC (<http://www.icom-cc.org/>)

The Getty Conservation Institute (GCI) e-Bulletin (http://www.getty.edu/conservation/publications_resources/bulletin/index.html)

Tate Papers, Tate (<http://www.tate.org.uk/research/publications>)

V&A Conservation Journal, Victoria and Albert Museum (<http://www.vam.ac.uk>)

User Groups:

IRUG, Infrared Users Group (<http://www.irug.org/>)

MaSC, users group for Spectrography and Chromatography (<http://www.mascgroup.org/>)

Other:

Gerry Hedley Conferences 1-29 (1983-2012) (UK Student conference)

Publishers

Butterworth Heinemann (<http://store.elsevier.com/>)

ScienceDirect (<http://store.elsevier.com/>)

Earthscan / James and James (<http://www.routledge.com/sustainability/>)

Donhead (<http://www.donhead.com/>)

Archetype Books (<http://www.archetype.co.uk/>)

Elsevier (<http://store.elsevier.com/>)

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- Relevant Websites**
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- The Getty Foundation; http://www.getty.edu/foundation/funding/conservation/current/panel_paintings.html
- The Getty Conservation Institute; http://www.getty.edu/conservation/our_projects/education/panelpaintings/ (date accessed: 14.12.12)
- European Confederation of Conservator-Restorer Organisations (E.C.C.O.); <http://www.ecco-eu.org/> (date accessed 14.12.12)
- European Network for Conservation-Restoration Education (ENCoRE); <http://www.encore-edu.org/> (date accessed 14.12.12)
- Erasmus Mundus; http://eacea.ec.europa.eu/erasmus_mundus/index_en.php (date accessed 14.12.12)

- Leonardo da Vinci Programme; http://ec.europa.eu/education/lifelong-learning-programme/ldv_en.htm (date accessed 14.12.12)
- Europass; <http://europass.cedefop.europa.eu/en/home> (date accessed 14.12.12)
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7. Conclusions

7. Conclusions

CHAPTER 7

Conclusions

Nico Kos and Paul van Duin

The conservation of panel paintings and related objects

Research agenda 2014-2020

7. Conclusions

The previous chapters have described the current state of research in the field of panel paintings. It demonstrates that much work has been carried out and also that many questions still need to be resolved. Each chapter ends with a list of those questions. As the conservation profession is relatively young and has recently entered the academic world, conservators will be able to deepen their understanding of the artworks in their care when more systematic research is carried out into the material complexity and behavior of panel paintings. This research will be of great value in determining the best preservation and conservation strategies, including the prediction of the future behavior of panel paintings.

The research into the wide range of materials and techniques used in panel paintings requires the collaboration of specialists from many different disciplines, such as art historians, paintings conservators, wood conservators, materials researchers, conservation scientists, wood scientists, chemists, engineers, physicists, dendrochronologists, as well as computer scientists.

It became evident during the panel paintings expert meeting in January 2011 that specialists in different fields have to make an effort to collaborate as they need to formulate adequate research questions together as well as becoming acquainted with the expertise of the other field(-s). Conservators can provide a valuable and irreplaceable source of information and insight by closely observing the panel paintings and reporting their observations. In other words, they have to develop a common language. The need for multi-disciplinary research is acknowledged by the conservation field as well as by the research funding institutes. Examples of funding multidisciplinary research are the NWO Science4Arts programme in collaboration with the USA National Science Foundation and the UK Science and Heritage programme of the Arts and Humanities Research Council and the Engineering and Physical Science Research Council.

Also, the participants of the expert meeting were unanimous in recognizing the importance of knowledge dissemination. This includes tracing relevant research literature from other disciplines as well as making research outcomes easily

available to the conservation field. To make research outcomes an accepted part of the profession is an important issue, this is in itself an important research question.

While tremendous progress has been made in past decades, the field of panel paintings conservation could further advance through systematic research in the following areas:

Technical art history

To strengthen our understanding of manufacturing processes we need technical art history to help defining what materials, tools and methods were used by artists and craftsmen. Establishing who made the panels, what kind of wood was used and how this was processed, which glue, ground and paint layers were used, is essential information.

History of conservation

Long term effects of conservation treatments may provide essential data for making future choices in conservation. Research into the history of conservation is therefore important: what materials and methods were used; who decided on the treatment; what were the ethical and aesthetical considerations and how were conservators trained. Systematic evaluation based on these criteria would provide essential information and might improve conservation interventions.

Since conservation schools started in the 1970's, documentation has become an integral part of conservation treatments. This vast amount of information should become the subject of systematic research. Scientists participating in the expert meeting advocated easier accessibility to conservation reports.

Wood technology

Wood is a very complex material which is studied by scientists of many different disciplines. Recent collaboration between conservators and wood-scientists may be further developed to obtain a better understanding of stresses and strains within panels. Collaboration with engineers specialized in fracture mechanics, in wood construction as well as biologists who study properties of aged wood will undoubtedly lead to better insight in the behavior of panels.

Climate conditions

A stable climate is regarded by the conservation community as one of the most important preservation prerequisites and is a popular research theme. Research in the last two decades indicates that broader climate conditions, with considerable

lesser energy costs, are not harmful to panel paintings. During the Climate for Culture Conference in Munich (2012) with 350 participants it was apparent that conservators have recently started to research the behavior of ‘real’ panel paintings in their proper setting to counterbalance research based on experiments with mock-ups and/or modeling studies. Collaboration between conservators and scientists should be encouraged. To balance preservation of art, energy costs and effects on (historic) buildings and create sustainable conditions in the widest sense, this collaboration should include installation specialists and architects.

Climate boxes and moisture barriers

Climate boxes have been developed to provide a micro-climate suitable for panels. These sometimes have side-effects such as blanching. The so-called European Propaint project has investigated adverse side effects such as blanching. This project ended in 2010 and needs a follow-up to improve the systems. An older system is the application of a moisture barrier layer on the back of a panel. Previous research into this treatment could be advanced by collaborating with scientists as well as addressing ethical questions.

Support systems for thinned panels

A variety of systems is used by structural conservators of panel paintings to provide flexible supports to panels which have been thinned during previous treatments. Structural engineers and conservators may collaborate to test and compare these systems in order to assist conservators in choosing the best system for each particular panel.

Paint layers

The factors causing the fracture and/or delamination of paint layers are not well understood, such as stiffness, interlaminar stress, temperature and chemical degradation. Very little is known about the effect these factors have on the mechanical and optical properties of the paints and grounds. The interaction between support, ground- and paint layers is a complicated issue because there are many variations in materials and techniques. Research undertaken in paint layers on canvas seems to be applicable to paint layers on wooden supports, but this needs further investigation. Knowledge of the chemical and physical degradation processes of paint layers and their interface with the wooden substrate will help conservators understand the behaviour of the multi-layered system that forms a panel painting. This is essential for making conservation decisions.

Original glue

Glue plays an important role in joining the different wooden elements as well as in the adhesion between wooden support and ground- and paint layers. Identification of the composition of historic glues through analysis, archival sources and reconstructions is essential in understanding the properties of the glue. The study of degradation processes is essential in predicting the remaining strength of glue bonds and deciding on the necessity and nature of a consolidation treatment.

Consolidation

Consolidation is another technique performed in conservation treatments that needs further study. It mostly involves strengthening weakened wood and adhering lifting paint. Although there are numerous experiments testing their efficacy, they mostly rely on a range of tests are not based on any theoretical model. Theoretical models need to be explored, also using industrial knowledge, and subsequently consolidants should be tested first experimentally and finally on real objects. The aim is to develop treatment strategies for the different consolidation scenarios needed in conservation, also taking into account degradation processes of materials used in conservation.

Conservation adhesives

Choosing the proper adhesive depends on many factors, which are weighed against each other by a conservator. Traditional glues are favoured by some, others prefer industrial adhesives of which the properties may be changed by the manufacturer without informing the users. Collaboration with scientists specialized in adhesives might lead to better informed decision-making and possibly the development of new conservation adhesives.

Acquisition of information

Many structural parameters of wooden panels can be measured using existing measurement and imaging techniques. Continuous long term monitoring is applied less frequently but is also essential for tracing degradation mechanisms. Instruments are becoming easier to use and transport. Advanced techniques such as synchrotron radiation are now available to the conservation field. Population studies, where information on a large number of objects is being made available for research, is seen by the participants of the expert meeting as an important source of information for research. Innovative applications of ICT will be needed to manage and integrate all information.

Concluding remarks

The experts who participated in the meetings and who contributed to this publication have made a convincing argument that more research is needed to achieve a level of understanding that will enable conservators to choose conservation treatments from a broader menu of options than is currently available. This research can only be achieved through systematic, interdisciplinary and international collaboration. We hope that this publication will motivate researchers and conservators to actively establish multidisciplinary research networks. Institutions can act as knowledge centres, support established networks and stimulate knowledge exchange. In addition, and perhaps most importantly, institutions could stimulate coherence in research programmes, secure funding, and provide open access to research data.



Appendices

1. Glossary

The precise and consistent use of language aids communication. Indeed, the vocabulary one uses defines the concepts one is able to conceive then express. Most technical vocabularies grew out of common language, adapting words to specialised meanings. For instance in common English, “stress” and “strain” are used interchangeably for the effect of pulling. However in mechanics, stress is defined as the force applied to a material and strain is defined as the resultant extension in the material. One needs to be clear to oneself, then to any reader, what range of meaning is being applied. English tends to use the same word for all parts of an application. For instance, “coating” is used for the liquid applied to a surface, the solid material formed after setting and the process of applying the liquid. One can be led, and can lead others, into confusion by assuming that the single word “coating” describes a single underlying concept or physical attribute, when there are at least three.

Disciplines advance by distinguishing concepts in finer detail, defining them and giving them special names. In every subject, the definition and term (signifier) develop as understanding of the concept evolves. Frequently in each discipline, there are a number of competing standards of terminology and one must be clear which of these one is using. For instance, there are national variants of the IUPAC chemical naming conventions. It is good practice to state in a report what terminology standard one is using. This is especially important when using specialist terms or abbreviations which should be separately defined if there is potential for confusion.

Conservation is beginning to develop its own specialist vocabulary (Horie and Tzanne 2001) which needs to be agreed if it is to be useful for communication (EN 15898 2010). A useful general dictionary is (Lackie 2007). The following list is derived from a number of sources and is based on the glossary for the “Adhesives for Conservators” course developed by the Foundation of the American Institute for Conservation of Historic and Artistic Works (2005). It is provided to provide a common vocabulary when using this book. Although many of the definitions are based on industrial and scientific usage, some have been modified to reflect conservation practice where this has specific concept.

Terms and definitions were adapted in part from the following sources:

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- EN 15898 (2010). *Main general terms and definition concerning conservation of cultural property*. European Committee for Standardization(CEN)

ACOUSTIC IMAGING Spatially resolved acoustic measurements.

ADHERE Two surfaces adhere when they are held together by an adhesive. *Deprecated term: stick or glue.*

ADHEREND An adherend is a body which is held to another body by an adhesive. *Substrate is a broader term.*

ADHESION Adhesion is the state in which two surfaces are held together by interfacial forces. *Adhesion acts between a substrate and a coating, adhesive or consolidant.*

ADHESIVE An adhesive is a substance which holds two surfaces together by interfacial forces. *The term may be applied generically to a consolidant, adhesive or coating.*

ADHESIVE FAILURE Adhesive failure is the rupture of the adhesive bond, such that the separation appears to occur at the adhesive / adherend interface.

ADSORPTION The binding of molecules or particles to a surface.

AGEING Ageing is the total of the irreversible changes in the properties of a material which occur with the passage of time.

ANISOTROPY Differences in properties according to the direction of measurement .

ARTIFICIAL AGEING Artificial ageing is the exposure of a material to laboratory conditions in order to study the changes on ageing. *The environmental conditions are usually increased, in time or intensity, over that experienced by the material in normal use.*

ASSEMBLY TIME The assembly time is the interval between applying the adhesive to the substrate and the application of pressure and / or heat.

BATCH A batch of a product is the result of a single making of a formulation. *It is expected that there will be little variation between samples taken from the same batch, with significantly more batch to batch variation.*

BINDER The binder in a liquid coating is the non-volatile component of the medium.

BLOCKING Blocking is the unwanted adhesion of two surfaces.

BLOOMING Blooming is the unwanted deposit on the surface of a film.

BLUSHING Blushing occurs as a milky opalescence within a film of lacquer.

BOND To bond two adherends is to join them with an adhesive. *Deprecated term: glue.*

BOND LINE The bond line is the layer of adhesive that attaches the two adherends.

BOND STRENGTH The bond strength is the force needed to break an adhesive assembly with failure occurring near the plane of the bond line.

CASEIN ADHESIVE A casein adhesive is an aqueous dispersion of casein, compounded with other reactants especially alkalis.

CATALYST A catalyst is a substance that changes the rate of a chemical reaction but is not changed by the reaction.

CCD LINE ARRAY AND CCD CAMERA CCD is a charge-coupled device (an optical detector). They may be configured as a 1d array (or line) of optical detectors or as a 2d array in a camera.

CHAIN POLYMERISATION Chain polymerisation is the growth of a polymer by successive reaction of a monomer with a reactive site on the growing chain, with a reactive site being regenerated. *This results commonly from a free radical, but also an ionic reaction.*

CHAIN SCISSION Chain scission is a chemical reaction resulting in the breaking of the skeletal bonds.

CHALKING Chalking is the appearance of a loosely adherent powder on a film resulting from the degradation of the binder.

COATING A coating is a continuous layer formed after application of a coating material to a substrate. *Narrower terms: varnish, lacquer, paint.*

COATING MATERIAL A coating material is a product that, when applied to a substrate, forms a film with specific properties. *Most coating materials are liquids which form a liquid film. However, some materials are applied as vapours to form a solid film. Narrower terms: varnish, lacquer.*

COHESION Cohesion is the state in which the particles of a substance are held together by primary or secondary valence forces.

COHESIVE FAILURE Cohesive failure is the loss of cohesion within the body of a material. *Cohesive failure can take place in the adhesive, termed cohesive failure of the adhesive, or in the adherend, termed cohesive failure of the adherend.*

COLLAGEN Collagen is the major fibrous protein making up bone and skin. *Degraded collagen is the major component of glue and gelatin.*

COMPRESSION The deformation of a material in response to external stress.

COMPRESSION SET The permanent deformation remaining after release of a compressive stress. *Plastic deformation in wood results from the combined effect of moisture changes and restraining supports.*

CONSOLIDANT A consolidant is a solid material which changes properties of a porous object by filling the pores or joining the particles. *A consolidant is usually used for strengthening, but can also change the optical properties or the hydrophobicity.*

CONSOLIDANT MATERIAL A consolidant material infiltrates a porous substrate then sets to form a consolidant.

CONSOLIDATION Consolidation is a treatment designed to change a porous substrate by incorporating a consolidant.

CONTACT ADHESIVE A contact adhesive has the property of autoadhesion.

COPOLYMER A copolymer is composed of more than one type of monomer. *This term might be elaborated, like terpolymer (3 monomers). See polymer.*

CRADLE A commonly utilised rigid structure in lattice formation, devised in an attempt to restrain a panel from curvature.

CREEP Creep is the time-dependent strain in an adhesive or substrate resulting from a sustained stress.

CROSS-LINK A cross-link is a part of the polymer molecule where at least 3 chains emanate. *The cross-link is usually formed by covalent bonds, but may result from weaker chemical interactions, such as hydrogen bonds. The result of many cross-links is a three dimensional network.*

CURE When a liquid cures to form an adhesive, it sets as a result of a chemical reaction.

CURING Curing is the increase in molecular size of a binder by chemical reaction.

CURING AGENT A curing agent is an additive to a liquid material that promotes curing by taking part in the reaction.

CURING TEMPERATURE The curing temperature is the temperature to which the adhesive must be heated to cure the adhesive.

CURING TIME The curing time is the time necessary during which an assembly is subjected to heat to cure the adhesive. *The time will vary with the temperature of cure which should be stated, e.G. Room temperature, 40 °c etc.*

4D DATASET Typically a 3d dataset with additional time or spectrally resolved information.

DEFORMATION A material is deformed when its shape has been changed. *The change of shape can be reversible or irreversible.*

DEGRADATION Degradation occurs when a large molecule is broken into smaller molecules by chemical reactions.

DELAMINATION Delamination is the separation of layers in a laminate because of the failure of the adhesive, either in the adhesive itself or at the interface of the adhesive and adherend.

DEPOLYMERISATION Depolymerisation is the process of converting a polymer into a monomer. *Not to be confused with degradation.*

DIFFUSION A natural transport phenomenon, caused by the random movement of particles leading to mixing of the substances.

DIRT PICK UP Dirt pick up is the tendency of a dry film to attract soiling material to its surface.

DIRT RETENTION Dirt retention is the tendency of a dry film to attract and hold soiling material on or in its surface.

DESORPTION The removal of molecules or particles from a surface. *The opposite of adsorption.*

DISPERSION A dispersion is a two phase system in which one phase is particles suspended in another phase. *Both the dispersed and continuous phases can be solids, liquids or gases (except one cannot have a gas / gas dispersion). Smoke, beaten egg whites, and dispersion adhesives are all dispersions.*

DISTORTION A material suffers distortion when its shape has been changed more than it can recover elastically.

DIGITAL SPECKLE PATTERN INTERFEROMETRY (DSPI) Camera-based technique for displacement measurement. *Also known as ESPI.*

DRY When a liquid dries to form an adhesive, consolidant or coating, it sets as a result of loss of solvent.

DRYING TIME The drying time is the period of time during which a liquid material on a substrate is allowed to dry. *This is often assessed by the loss of tack to a finger (or thumb).*

ELASTICITY, MODULUS OF The modulus of elasticity is the ratio of stress to strain when a material is deformed elastically. *Young's modulus applies to tensile forces.*

ELASTOMER An elastomer is a polymer which returns rapidly to approximately its initial dimensions and shape after a substantial deformation by a weak stress and release of the stress at room temperature.

EMULSION An emulsion is a stable two phase system in which small droplets of one liquid (the internal phase) are dispersed in a second continuous liquid phase (the extended phase). *Deprecated: latex*

EQUILIBRIUM MOISTURE CONTENT (EMC) The moisture content at which the material is in equilibrium (neither gaining nor losing water) with the surrounding air. *For many materials, the EMC shows hysteresis.*

FAILURE The failure of a joint occurs when the adherends separate totally or in part. *Failure can occur in the adherend, in the adhesive or at the interface.*

FATIGUE Structural damage from repeated loading.

FIBRE SATURATION POINT The moisture content where there is no free water in the cell cavity but the cell walls are holding the maximum amount of bound water. *This is theoretical because currently the mechanisms are not fully understood and there is not a clear point where the water within the lumina is lost and only bound water remains.*

FICKIAN MODEL A fickian model uses fick's laws to estimate the diffusion of a substance into a substrate. *Fick's law relates the rate of diffusion to the concentration of the diffusant.*

FILL A fill is a replacement of a missing piece of an object.

FILLER A filler is a solid material used to modify the properties of an adhesive or gap-filler. *Fillers may be used to increase strength or weatherability, reduce weight etc.*

FILM A film is a layer of applied material. *A film could be the result of applying a liquid adhesive, a coating material or a liquid consolidant, from initial application to a final solid state.*

FINITE ELEMENT MODELLING A modelling method based on the discretization of continuous domains in subdomains (elements) in order to solve the mathematical equations for each domain.

FLASH POINT The flash point is the lowest temperature at which a product emits sufficient vapour to be ignited by a source of ignition. *A measured flash point depends on the condition of test.*

FLOW Flow is the movement of a liquid before it sets or gels.

FRACTURE MECHANICS The study of the propagation of cracks in materials.

GAP-FILLING ADHESIVE A gap-filling adhesive bridges the existing space between two adherends.

GEL A gel is a polymer highly swollen with a liquid.

GEL POINT The gel point is reached during the transition from liquid to solid when the film starts to exhibit elastic properties. *Gelation may occur because of cross-linking of the polymer or because the viscosity has risen so the film can no longer flow.*

GELATIN Gelatin is a protein adhesive made from degraded collagen extracted from parts of animals. *Glue is an impure form of gelatin.*

GLASS TRANSITION The glass transition is a reversible change on cooling in an amorphous polymer between a viscous rubbery condition and a hard brittle condition. *This property can be measured by a number of different properties such as elasticity or refractive index.*

GLASS TRANSITION TEMPERATURE The glass transition temperature is the approximate midpoint of the temperature range over which glass transition takes place. *The exact specification of the point chosen makes a considerable difference to the value quoted, so needs to be explicit, e.G. {Astm e1356-08, 2008 #6740}.*

GLOSS The gloss of a surface is its ability to reflect light specularly. *There is variation in glossiness, from matte through eggshell to mirror, whose value is determined by the method of test.*

GLUE Glue is a protein adhesive made from collagen broken down and extracted from parts of animals. *Gelatin is a purer form of glue.*

GUM A gum is a water soluble or dispersible adhesive (frequently composed of polysaccharides) obtained from plants.

HARDENER A hardener is one component of a multi-pack product that takes part in a chemical reaction to form a solid material.

HEAT ACTIVATED ADHESIVE A heat activated adhesive is a dry film that is made tacky by heat applied to the assembly. *Beva is heat activated above 68°C, waxes, b-72, etc. At differing temperatures.*

HEAT SETTING ADHESIVE A heat setting adhesive is one that sets on the application of heat.

HISTORIC Materials used traditionally for the original manufacture and repair of the objects

HOLOGRAPHY 3D optical technique based on reconstruction of waveforms.

HOMOPOLYMER A homopolymer is a polymer made up of only one type of monomer. *See polymer.*

HOT MELT ADHESIVE A hot melt adhesive is rendered fluid by heating and forms the bond on cooling.

HYDROMECHANICAL Combination of moisture and mechanical properties (for example in a simulation).

HYDROLYSIS Hydrolysis is a degradation reaction resulting from reaction with water.

HYGROSCOPIC A hygroscopic material is capable of absorbing from and releasing water to the environment.

HYSTERESIS The dependence of the state of an object not only on the present conditions but also on the past environment. *This leads to different adsorption and desorption curves as a function of the relative humidity in the air.*

INTERFACE The interface is the area of contact between the adherend and adhesive.

ISINGLASS Isinglass is a gelatin made from the swim bladders of fishes. *Sturgeon is the traditional source of isinglass.*

ISOTHERM A contour line (or surface) of constant temperature.

JOINT The joint is the location at which two adherends are held together by an adhesive.

LAMINATE A laminate is made by joining together two or more layers of material or materials.

LAMINATE To laminate is to make an assembly by bonding layers of materials together.

LEVELLING The levelling of a coating material is its ability to flow after application to minimise irregularities caused by the application process.

LIQUID ADHESIVE A liquid adhesive is one that when applied to a substrate sets to form an adhesive.

LUMINA Void within wood cell walls which when living was filled with sap.

MAROUFLAGE Adhering a panel to a flat solid timber board using an adhesive.

MATTING AGENT A matting agent is an additive incorporated into a coating material to reduce the gloss of the dry coating. *Synonym: flattening agent.*

MEDIUM The medium is all constituents of the liquid phase of a coating material. *The medium will include dissolved polymer, solvents, dispersing agents etc.*

MELTING POINT The melting point of a polymer is the temperature at which both amorphous and crystalline components of a polymer have become liquid.

MOIRE-FRINGE ANALYSIS A method to measure shapes and displacements by analysis of optical fringe (stripe) patterns.

MOISTURE CONTENT This may be expressed as the absolute water content (mass of moisture divided by material volume) or a relative moisture content (moisture pressure divided by saturated vapour pressure). *Abbreviation mc. Moisture content is continuously in flux due to the surrounding environment and will set up an internal moisture gradient within the thickness of a piece of wood.*

MOLECULAR WEIGHT The molecular weight is the weight of one mole of the molecules. *Abbreviation mw; synonym: molecular mass strictly, molecular mass is the mass of one molecule and the molar mass is the mass of n (avogadro's number) x molecular mass.*

MONOMER A monomer is a low molecular weight compound which can react with 2 or more other monomers to form a polymer.

MONOMER UNIT A monomer unit is the repeating constituent of a polymer molecule. *Monomers change significantly when they react to form a polymer, so one should not confuse the properties of the original monomer with the structure of monomer units in the polymer.*

MULTI-SPECTRAL AND HYPERSPECTRAL

IMAGING Spatially resolved spectroscopic measurements. The number of spectral bands is higher for hyperspectral imaging.

NATURAL A natural polymer is one that has been prepared from animal or plant material with little or no chemical modification.

NON-DESTRUCTIVE TESTING (NDT) Applying measurement technique(s) that are non-destructive for the object.

NUCLEAR MAGNETIC RESONANCE A research technique that uses the magnetic properties of atomic nuclei in response to characteristic radio frequencies.

OLIGOMER An oligomer is a very low molecular weight polymer whose properties differ significantly depending on the degree of polymerization.

OPEN TIME The open time is the period between applying the liquid to the adherends and the assembly of the joint. *The open time is usually the period until the viscosity of the liquid rises too high to allow it to flow and wet the surfaces.*

OPTICAL COHERENCE TOMOGRAPHY (OCT) Volume resolved material measurement using low-coherence interferometry.

PAINT Paint is a pigmented coating material that forms an opaque coating.

PASTE Paste is semi-solid plastic gel, usually referring to a mixture of starch and water.

PEEL Peel is the force applied to a joint in which one or both of the adherends is flexible and in which the force is concentrated at a boundary line.

PENETRATION Penetration occurs when the liquid material enters a substrate.

PERMEABILITY The ability to let another substance (liquid or gas) pass through it.

PHOTOGRAMMETRY 3D reconstruction techniques based on multiple camera viewing angles.

PLASTICISER A plasticiser is an unreacting additive to the liquid material which makes the resulting solid material more flexible.

PLASTICITY Plasticity is the property which enables a material to retain its shape under a force not exceeding its yield value and to flow above this value.

POLYCONDENSATION Polycondensation is the growth of a polymer by means of condensation reaction for all degrees of polymerisation.

POLYMER A polymer is a very large molecule formed by the reaction of many smaller monomer molecules. *The term can also be used generically to refer to a mass of such molecules.*

POLYMER MOLECULE A polymer molecule has a high molecular mass, formed of multiple repeating units.

POLYMERISATION Polymerisation is the process of converting monomers into a polymer.

POT LIFE The pot life is the time during which a multi-part adhesive can be used after mixing the components. *Synonym: working life.*

PRE-POLYMER MOLECULE A pre-polymer molecule is a polymer or oligomer molecule that can enter into subsequent polymerisation. *Polyester and epoxy resins are made by reacting pre-polymers with cross-linking molecules, frequently also oligomers.*

PRESSURE SENSITIVE ADHESIVE A pressure sensitive adhesive is a visco-elastic material, which in solvent-free form remains permanently tacky.

PRIMER A primer is a coating applied to the substrate, prior to application of the liquid material, to improve the performance of the bond.

RELATIVE HUMIDITY (RH) The ratio of the partial pressure of water in an air water mixture compared to the saturated vapour pressure at the same temperature.

RELEASE AGENT A release agent is a coating intended to prevent or reduce adhesion. *Release agents are used when making or taking a mould.*

RESIN A resin is an amorphous polymer or oligomer. *Resin is increasingly used for low molecular mass materials, such as natural resins.*

RESIDUAL STRESS Stress retained in a material after the external force is removed.

RESTORATION MATERIALS A restoration material is one added to aid the preservation or interpretation of an object.

RETROGRADATION Retrogradation is the change of starch pastes from low to high viscosity on standing. *This frequently involves the exudation of water from the paste.*

SAMPLE A sample is a portion of a material intended to be representative of the whole. *Samples are taken for current or delayed analysis.*

SET A liquid sets to form a solid, when it has developed its cohesive strength and other physical and chemical properties. *Setting may be by chemical (curing), physical (cooling) or evaporation (drying) means.*

SETTING TIME The setting time is the time needed for the liquid to set to form a solid.

SHEAR Shear is the force applied to a joint that acts in the plane of the bond line.

SHEAROGRAPHY Speckle interferometry method for displacement gradient measurement.

SIZE A size is a gelatin which has been applied to a surface to reduce penetration of a liquid or to increase adhesion. *Application of the gelatin solution is called sizing.*

SLIPPAGE Slippage occurs when the adherends move during the bonding process.

SOLVENT A solvent is a liquid that dissolves another material. *The term solvent is sometimes (erroneously) used to mean a mobile liquid.*

SOLVENT ACTIVATED ADHESIVE A solvent activated adhesive is a dry film that is rendered tacky just prior to use by the application of a solvent.

SOLVENT ADHESIVE A solvent adhesive has a volatile organic liquid as the vehicle.

SORPTION Sorption occurs when an added substance becomes attached at a molecular level to another.

SPECKLE DECORRELATION Full or partial loss of an optical interferometric signal when an object is displaced. *The effect is higher measurement noise.*

SPECIMEN A specimen is a portion of a sample used in a test.

STORAGE LIFE The storage life is the time during which the liquid material will remain in useable condition, under specified circumstances. *Deprecated term: shelf life.*

STRAIN Strain is the unit change due to force in the size of a body relative to its original size. *Strain can be measured in tension, compression, torsion etc.*

STRENGTH Ability to withstand a stress without failure.

STRESS Stress is the force exerted per unit area at a point within a plane.

STRESS-STRAIN DIAGRAM A stress-strain diagram is one where stress and strain are plotted against one another.

STIFFNESS The extent to which an object resists deformation in response to an external force.

SUBSTRATE A substrate is a material to which a liquid material is applied. *A substrate can be the object to which an adhesive, coating or consolidant is bonded.*

SURFACE TENSION Surface tension is the energy needed to increase the surface area of a liquid by a defined value.

SURFACTANT A surfactant is a material added to a liquid to lower its surface tension. *Colloquial: wetting agent.*

SYNTHETIC A synthetic polymer is one that has been prepared by technological processes.

TACK Tack is the property of a material that enables it to form a bond of measurable strength immediately on contact with another surface. *The tack of a film is related to its viscosity. Tack is commonly tested with a finger.*

TENSILE FORCE A tensile force is applied by pulling along the line of the object being tested.

TERAHERZ (IMAGING) Terahertz radiation has electromagnetic wavelengths between 0.1 And 1 mm. In terahertz imaging spatially resolved information is recorded.

THERMOGRAPHY Spatially resolved temperature measurement used to determine differences in temperature in a material. *Variations in temperature due to differences in heat conduction can indicate a different material or defect.*

THERMOPLASTIC A polymeric material is thermoplastic if it can be repeatedly softened by heating and hardened by cooling. *Not all un-cross-linked polymers are thermoplastics, e.G. Cellulose.*

THERMOSETTING A material is thermosetting if it is cured to a polymer by heating.

Many thermosetting polymers are now available that require heating only to room temperature.

THIXOTROPY Thixotropy is the decrease of apparent viscosity under shear stress, followed by a gradual recovery when the stress is removed.

TOUGHNESS The ability of a material to absorb mechanical energy without fracturing.

THROUGH-THICKNESS Property change or propagation direction through the smallest dimension of an object.

VARNISH A varnish is a clear coating material.

VISCOELASTICITY A material demonstrates viscoelasticity in response to a stress when it has both elastic and viscous behaviour.

VISCOSITY The viscosity of a liquid is its resistance to flow.

WASH-BOARDING The development of a series of regular lines of distortion in a panel as a consequence of restraint.

WATER-BORNE A water-borne adhesive is one where the volatile carrier of the adhesive material is water, either acting as a solvent or as a dispersing phase.

WETTING The wetting of a substrate occurs when a liquid spreads over its surface.

WETTING AGENT A wetting agent is an additive or pre-treatment used to improve the contact between a liquid and a solid. *A wetting agent can be used to help the dispersion of pigments in a medium, or the coverage of a liquid material over a substrate.*

WOOD MOVEMENT The dimensional change of wood, shrinkage or expansion, as a consequence of changes in humidity.

YIELD STRENGTH The yield strength of a material is the stress at which a material begins to deform plastically.



Figure A+B Pieter de Bloot, *The office of a lawyer*. The Netherlands, 1628. Oak, 57 x 83 x 1.1 cm. The support consists of three horizontal oak boards. The reverse of the panel shows traces of wooden blocks and canvas strips formerly attached across the two joints and across two of the cracks. © Rijksmuseum.

Appendix 2

2. Proceedings of the expert meeting, 9-11 January 2011

A first step in the preparation of this research agenda was the identification of essential research topics. To this end we brought together a group of about 30 eminent experts in conservation, wood science, engineering, chemistry, mathematics, and art history. They had the challenging task of understanding each other over this broad range of disciplines and of identifying essential research topics, which will benefit future conservation of panel paintings. They had a 2 ½ day plenary meeting, including some break-out sessions.

Day 1: Sunday, the 9th of January

On the first day of this three-day event, participants visited the Masterpieces exhibition of the Rijksmuseum at the *Philips Wing*. The highlights of the seventeenth century remain visible to the public while the museum's main building is being renovated for the grand reopening in 2013. The group was guided by Paul van Duin and Laurent Sozzani through the furniture and paintings collections, providing the participants with an opportunity to familiarize themselves with some of the panel-related conservation problems that would be the focal point of the meeting. In the evening, the group reunited for dinner, during which they were welcomed by Paul van Duin (Rijksmuseum), Alan Phenix (Getty Conservation Institute) and Louis Vertegaal (NWO). During his keynote speech, Professor Ian McClure (Yale University) provided the audience with a concise overview of recent directions that the conservation of panel paintings has taken and some areas of research that have been pursued in the history of panel paintings conservation.

Day 2: Monday, the 10th of January

Participants of the expert meeting gathered the following morning at the *Ateliegebouw*, which houses the conservation studios of the Rijksmuseum, the research laboratories of the Netherlands Cultural Heritage Agency (RCE, formerly known as ICN) and the conservation studios for the University of Amsterdam's Master Conservation and Restoration Program. The day was divided in a morning and afternoon session, the first being chaired by Dr. Alan Phenix of the Getty Conservation Institute, the second by Dr. Jørgen Wadum of the Statens Museum in Copenhagen. Each session consisted of several short presentations, followed by the chairman's observations and discussion among the participants in the form of roundtable and breakout discussions.

After a short introduction by Phenix, explaining the purpose of the meeting, Professor Anne van Grevenstein of the University of Amsterdam discussed the historical changes in the conservator's approach. This used to be characterized by the craftsman's silence but the profession is maturing rapidly with the emphasis on multidisciplinary collaboration. The current and past treatments of the *Ghent Altarpiece* (Lamb of God) by Van Eyck in the Cathedral of St. Baaf, Ghent, illustrate the value of cooperation between practical conservators and researchers, thus stressing the importance of bridging the gap between both worlds. The existence of this gap was confirmed by most participants and was considered to be the result of limited understanding between scientists and conservation practitioners. This gap emphasized the importance of this expert meeting in bringing scientists and conservators together. Chairman Phenix initiated a discussion on the fundamental principles of conservation, in which issues such as minimal intervention, reversibility and material stability were introduced to scientists who had not been involved in conservation research. Questions and remarks from participants often implied the complexity of conservation treatments, stressing the difficulty of creating a standard procedure in conservation, as each object requires an individual approach. George Bisacca added that conservation is nearly always based on subjective discussions, often relying on the experience of a single conservator. Sozzani stressed that the conservator knows the panel paintings extremely well and therefore he makes the most complicated decisions and carries the highest responsibility. This led to the question of professor Jaap Molenaar whether conservators were willing to accept external advice. Most of the conservators agreed that this has been a problem, but that the attitude is slowly changing. Phenix believes that we are in a transitional phase, in which the conservation field is becoming mature and admitting its own limitations. Or as Van Grevenstein and Dr. Robert Koestler summed up: 'people are starting to speak a common language.'

The second presentation of the morning session was by wood scientist Dr. Joseph Gril of the University of Montpellier. Gril presented the outcomes of his work on conservation issues, focusing on the risk analysis, concerning the stresses which could develop if the Mona Lisa was exposed to exceptional hypothetical microclimatic fluctuations (i.e. during transportation). Modelling proved to be a useful tool to determine possible risks, including the cupping of the panel and the formation of splits. The following discussion was largely of a technical nature. Research parameters were discussed as well as the study of wood on a cellular level. This led to the consensus that very little is known about the chemical aging processes involved in the deterioration of wood. Another important observation was the lack of knowledge on allowable stress levels in wood and the need for research within both areas. Professor Roman Kozłowski added that population research could be a

valuable tool for both scientists and conservators. An inventory of damages could provide scientists with an appreciated set of parameters.

Gril was followed by professor Joris Dik of the Delft University of Technology. Dik provided the audience with a brief survey of techniques that are currently being used at Delft University in the study of art objects. These include modelling and a variety of imaging techniques used in the visual analysis of objects. The short discussion which followed focused on the possibilities of such techniques and their general obscurity among conservators. Koestler suggested a survey of the currently available techniques to inform conservators of the possibilities within their own field of expertise.

The final presentation of the morning session was a joint presentation on conservation materials by Dr. Alan Phenix and Dr. Christina Young of the Courtauld institute London, focusing on adhesives. Phenix started by providing a set of conditions that are required for materials to be used in conservation and some of the problems involved in selecting the proper materials. Young continued with a short overview of currently available adhesives and their pros and cons. This led to the conclusion that no adhesive is considered ideal and that more research is required; not only on the known adhesives, but also on the development of new adhesives to meet the needs of conservators. Several adhesive properties were mentioned during the discussion, such as workability (Bisacca), shelf life (McClure), creeping properties (Jorissen), but also the level of skill of the user (Van Duin). It became clear that among the participants the panel conservators vary in their preference for glues, whereas furniture conservators generally prefer animal glues. It also was noted that manufacturers constantly change their formulas, which makes their product information an unreliable source for conservators. Interest was expressed in the development of special conservation glues, which could be facilitated by the Institute of Adhesives at Delft University, represented by Dr. Hans Poulis.

After lunch, Dr. Jørgen Wadum took the chair for the afternoon session. The afternoon session consisted of four more presentations, followed by a breakout session into three smaller groups. Separate reports follow on the next pages. The four afternoon presentations were all by conservators who presented a variety of treatments. George Bisacca, panel paintings conservator at the Metropolitan Museum of Art in New York, discussed the treatment of two panel paintings by Dürer in the Prado Museum. One of the panels had been fitted earlier with a cradling system that caused significant deformation and cracks. Both panels had different needs and thus underwent different treatments. Bisacca also introduced a

modern support system, consisting of a frame with adjustable springs to restrain thinned panels; a method that received a lot of interest from the participants.

The next presentation by Paul van Duin was on the conservation of the Van Meken cabinet in the Rijksmuseum. Van Duin explained the elaborate construction of the original marquetry doors. Shrinkage of the panels had led to the formation of cracks. These were treated by dismantling the cleats that were restricting the movement of the panels. Subsequently it was possible to rejoin the panels and to reglue the original construction. This made the cracks nearly invisible. Van Duin emphasized that furniture conservation bears a lot of similarities to panel conservation. Apart from the obvious use of a wooden carrier, furniture conservators are often confronted with the same type of damage. He also pointed to the high degree of craftsmanship of cabinetmakers and their excellent choice of materials.

The third afternoon presentation was by Britta New, paintings and panel conservator at the National Gallery in London. New presented the audience some of the current supporting methods used at the National Gallery, such as replacing a failing cradling from a past treatment. The methods have been developed with Ray Marchant who unfortunately was not able to attend the expert meeting. New stressed the importance of flexibility as well as restraint in cradling systems, preventing both new distortions and recurring of older damages. Several methods were suggested, such as the earlier mentioned spring system, as well as the use of laminated materials and plastic foams. It was again brought to the attention of the audience that conservators base the amount of restraint given / provided by a support system for a thinned panel on practical experience. They would welcome scientific help to judge the allowable levels; but this is not yet available. Several attendants suggested that modern cradling systems should be examined on a regular basis to check their effect on the work of art.

The final presentation on Monday was by Jean-Albert Glatigny, the panel conservator currently working on the van Eyck Altarpiece in Ghent. Glatigny presented an overview of the conservation history of this valuable piece of cultural heritage. A remarkable amount of detail about the painting's history is known. The altar piece has survived separation of the panels, fire damage, temporary removal due to war and several invasive past treatments. It is remarkable that the panels have survived so well.

After a short break, three groups were formed for breakout sessions in separate rooms. The sessions were intended to reflect on the earlier presentations and to brainstorm about the needs and possibilities of scientific research.

Group A

The main areas of discussion for Group A were climate issues and dissemination of knowledge. The group agreed that current knowledge on environmental conditions for wooden panels is insufficient. Relative humidity fluctuations were identified as one of the major factors contributing to the degradation of the panel, causing warping, splits and delamination of paint layers. Yet, little is actually known about the allowable levels. Also, the variety in panel thickness and the related reaction time of the wood is a complicating factor. The commonly used term ‘museum environment’ is considered to have little concrete value, differing enormously for country houses, churches, climate boxes, and newer and older museums. Research on climate conditions for wood will allow for a more substantiated environmental policy.

The discussion on knowledge dissemination focused on the use of a database to collect and share information. Again, the value of population research was underlined; gathering simple data from panel paintings as a starting point for fundamental research. Several members of the group stressed the importance of a uniform approach in the collection of data by means of a standard protocol and a common terminology. The importance of knowledge sharing within the conservation field as a whole, the training of young panel conservators, and the importance of networking and interdisciplinary communication were stressed during the knowledge dissemination discussion.

Turning towards the wishes of the conservator, conservators again explained how they require more knowledge in their decision-making process, admitting their own limitations and being able to ask for the help of a specialist. Always asking the question: ‘do we know enough to start treatment?’

Group B

Several topics were discussed by group B, ranging from fundamental science to the human element. Within the fundamental research area, the need for modelling as a decision-making tool was pointed out. Having more details on stress and strain levels within the object could help conservators evaluate the condition of an object. Professor André Jorissen from Eindhoven University of Technology informed the group of the possibilities and limitations of measuring stress and strain levels and the need for combining several analytical models to obtain a realistic model. However, to narrow down the parameters for such research, both Dr. Agnes Brokerhof (Netherlands Cultural Heritage Agency (RCE) and Drs. Wolfgang Gard (TU Delft) agreed that it would be best to first collect existing data before applying this in modelling. Referring to the population research mentioned by Kozłowski, the

group agreed that an inventory of problematic structures (and their conservation history) would help scientists set parameters. However, both McClure and Sozzani noted that not many panels have remained untouched by conservators, and one would have a better chance at finding original panels within furniture and interior fragments, which could be used for actual testing. Bisacca noted that it might be easier to find untreated panels. Another fundamental research area - one that had been mentioned before - is the lack of knowledge about the chemical degradation of wood, especially processes that affect the mechanical properties of wood. The conversation moved from wood-related problems to other materials applied in panel paintings, the group expressed the desire to obtain more insight into the interfaces between paint mediums, such as ground layers, colour layers, and possibly varnishes. On the subject of the applied nature of research, the problem of using commercial adhesives was again discussed by Phenix and Young. Both expressed the desire for having a coordinated adhesive research aimed at conservation, identifying aging factors and even developing new adhesives.

Perhaps the largest portion of this brainstorm session was taken up by discussion on the human factor within conservation research, especially the transfer of knowledge. The group agreed that knowledge sharing is the foundation of research and that this should be promoted as much as possible. McClure and Gard suggested the development of an information exchange network, taking the form of a structured database that would have a low threshold in terms of accessibility and ease of use. The discussion then moved to the education of a new generation of conservators. The group identified a big risk in the recent academic development of the conservation profession. Sozzani and Phenix agreed that academic skills currently tend to outweigh manual skills. They also suggested that the contributing parties could play a part in preventing this loss of balance by giving recommendations to schools and organizing workshops that stimulate knowledge and skills development. The field of panel conservation has addressed some of these issues through the Getty Foundation's Panel Paintings Initiative, which focuses on training the next generation of conservators in the complex and challenging treatment of panel paintings.

Group C

The discussion in group C mainly focused on the area of knowledge transfer. Realising the importance of building a general resource guide, several participants provided the group with their view of the form that such a database should take. Professor Kozlowski had introduced the idea for an open, web-based database; a tool he had already used in experiments for his research. Dr. Hans Poulis warned that building a database does not guarantee user-friendliness; too many databases

have been made that are hardly ever revisited. Being extensive, constructive, and easy to use, is something that is not easily achieved.

Poulis therefore suggested a Wikipedia-like expert platform to facilitate interaction between conservators and scientists. Professor Eric Postma from Tilburg University is currently involved in the CATCH-program (Continuous Access to Cultural Heritage), which similarly aims to make information on cultural heritage easily available by sharing information between specialists.

Several participants pointed to valuable resources for the coming database. An already useful effort within this field is the bibliography of literature on the conservation of panel paintings and related objects that the Panel Painting Initiative produced, which was funded by the Getty Foundation. A general catalogue of techniques for panel paintings and its conservation would also be useful. Dr. Koestler, from the Smithsonian Institution, informed the group that there is a lot of unpublished research material from the retired climate expert Mecklenburg, which the Institute would be willing to share with the coming Science4Arts projects. One of the current focal points of the Smithsonian's research is on the ageing and dating of proteins, for example the frass of wood boring insects. It was also noted that CCI published a huge report on adhesives in *Studies in Conservation* (2000 / 2001) and is organizing a conference about adhesives in conservation from the October 17th to 21st 2011.

A final need was raised to develop new imaging techniques such as simple instruments for conservators, i.e. interferometric techniques.

After sharing their findings with the other groups, the day was concluded with a brief discussion on the outcomes of the breakout sessions. Thanking all the participants for their input, chairman Wadum ended the first day of the meeting.

Day 3: Tuesday, the 11th of January

On the second day of the meeting, the morning session was chaired by Professor Rint Sybesma from the Eindhoven University of Technology and the afternoon session by Professor Luca Uzielli from the University of Florence. After a brief introduction of the final day's program by chairman Sybesma, professor Uzielli was introduced as the first speaker. Giving the audience a short overview of the recent activities of COST IE0601 "Wood Science for Conservation of Cultural Heritage (COST is an intergovernmental network for Cooperation in Europe for Science and Technology), Uzielli, chairman of COS IE0601 T, summed up past successes and future objectives for the project, ranging from fundamental research to the

stimulation of knowledge transfer. Uzielli and later chairman Sybesma both noted that the COST-objectives bear striking similarities to the aims of this expert meeting and suggested they could be used for the afternoon breakout sessions. Uzielli also briefly mentioned the very interesting results emerging from the “Deformometric Kit” a piece of equipment and a method developed by his research group to monitor the actual deformation dynamics of original panel paintings in their normal exhibition conditions.

The second speaker was Dr. Roger Groves of the Delft University of Technology. Dr. Groves, who specializes in laser-based measuring instruments, introduced the audience to several new imaging techniques that could be very useful within the field of conservation, specifically the cutting edge Multi Encode EUFP6-project; a portable measuring instrument that can detect strains and defects within a wooden substrate. It was again mentioned that these new imaging techniques could be very useful, but remain relatively unknown within the conservation field. Summing up the possibilities and limitations for these techniques would help make them more easily accessible for conservators.

The third presentation was by Professor Roman Kozlowski of the Institute of Catalysis and Surface Chemistry in Krakov, Poland. One of the major challenges that Kozlowski experienced in his work was making his research accessible and understandable for non-scientists. He therefore posted two proposals that could be beneficial for the Science4Arts project. The first is the creation of a web-based tool that would allow scientists and conservators to make easy predictions on damage risks by combining strain numbers and climate changes within the program. The second proposal concerned a large scale monitoring project of panel paintings at regular time intervals, which would be able to trace physical damage development by use of laser interferometry. Kozlowski also showed an exaggerated animation of a moving panel over a certain lapse of time, shocking the attendants with the enormous cupping that occurred.

The final presentation of the morning session was by Dr. Agnes Brokerhof from the Netherlands Cultural Heritage Agency (RCE formerly the ICN). Brokerhof’s lecture concerned risk analysis on a level of management decisions. Dealing with abstract terms such as degree of loss and object value, Brokerhof informed the audience on how a risk magnitude can be determined and can be used to help set priorities on a management level. Often indicating that our priorities are at times unbalanced: a small crack because of humidity fluctuation is hardly as bad as a fire burning down the entire museum. Being a mathematician, professor Molenaar from Wageningen University pointed out that these numbers have no absolute meaning; they are relative and are only intended to be used as an indication.

After the morning presentations, a round table discussion was initiated by chairman Sybesma. Having noted the similarities between the COST-objectives and the Scienc4Arts program, Sybesma proposed streamlining the discussion along the objectives mentioned in the presentation by Uzielli: knowledge, consolidation, managing risks, allowable climate variations, non-destructive tools, past conservation efforts, modelling, and guidelines. Addressing the issue of knowledge transfer, George Bisacca stressed the importance of bridging the gap between science and conservation by visualizing the data to make it understandable for conservators. Alan Phenix agreed, suggesting that it should be part of the knowledge transfer strategy to produce easily accessible literature for conservators.

An issue that came up during the discussion was that it sometimes remained unclear for scientists what kind of information conservators required about the panels that the scientists could provide. Especially for the engineers, who require a clear set of parameters in order to apply modelling. The large degree of subjectivity and the many parameters within the decision making processes in conservation proved to be a difficulty for the engineers. An answer given by Uzielli during the following discussion was perhaps one of most fundamental research objectives: ‘we need to understand what the need of the panel is’. Wadum expressed the same perspective, asking, ‘what are the consequences for the panel of *not* taking action?’ Combining the panels’ needs with the issue of subjectivity, Phenix stressed that conservators ‘need a scientific basis in order to make well-considered choices in conservation’. Koestler later stated that conservators do not always need exact numbers, just tools that will help them decide. Also addressing the apparent gap between scientists and conservators, Dr. Bart Ankersmit pointed out that many experts tend to remain within their own area of expertise, whereas admitting our own limitations will give us an incentive to look for new areas of research. ‘We need to consider what we do *not* know.’

Although there are many things that currently are unknown, many attendees indicated that there are a lot of things that we *do* know, or at least can find out easily. A great deal of research has already been done that is just waiting to be discovered. Both Brokerhof and Koestler suggested that a good start would be to make an inventory of the available research data. Ir. Frederik de Wit from Delft University of Technology added that some research questions may not even require fundamental research to be answered, but simply a literature study.

After focusing on theoretical modelling, Professor Ian McClure redirected the discussion towards the area of data collection and measurement. McClure encouraged conservators to start collecting relevant data for scientists to work with. He

felt that one problem conservators might encounter is the design and use of the most efficient means for recording particular projects. For example, the conservator might know that measurement of very small movements in wood should be undertaken, but be unaware of the best way of achieving this. This is where contact with a scientist with experience of conducting such small measurements would be of great help, even if the scientist was not an expert in wood technology. In this instance some sort of network might work well.

The attendants agreed that theoretical science and applied science must be brought together in order to formulate more specific research questions. In addition to the population studies on past treatments and kinds of damage mentioned earlier historical construction methods were now included. Paul van Duin added that old photographs and treatment reports could provide a valuable source of information regarding when specific damage has occurred and if and how this was treated.

After lunch, Professor Luca Uzielli took the chair for the last afternoon of the expert meeting. The two final presentations of the day were both on theoretical modelling, the first on environmental modelling by Dr. Henk Schellen, the second on wood behaviour by Professor André Jorissen, both from Eindhoven University of Technology. Schellen explained several physical modelling systems that can be applied to create a range of scenarios to determine risk factors. Ranging from outdoor climates to micro climates, Schellen demonstrated how modelling can be used to make a complete climate mapping of an environment. Jorissen went into more detail on the actual physics behind modelling, explaining the difference between analytical, numerical and experimental modelling. Jorissen emphasized that modelling is only a theoretical simulation of reality, to be used as a design aid, not as a means.

The second breakout session had a more structured approach than the brainstorm session of the previous day. Having formed three new discussion groups, chairman Uzielli gave each group a specific area for which they had to define a research agenda. The three subjects were adhesives and consolidants, mechanical behaviour, and paint layers and interface. Every group was asked to indicate fundamental and practical research, as well as knowledge transfer within this particular field.

Group A: Consolidation

Group A defined the range of properties of adhesives that are essential for conservation purposes such as: penetration, strength, flexibility / stiffness, gap-filling, interaction with residues, interaction with different wood species, interaction with

paint layers, constraint on panel, set-time, shelf-life, retreatability, reactivation, reversibility, effect of glue / consolidant on surrounding area and other parts of object, ageing / durability (long-term performance, predicting failure), reaction to humidity changes, and susceptibility to fungi / insect attack. Depending on the specific conservation purpose, the required properties differ, penetration is sometimes but not always necessary, the strength of a glue should not exceed that of the materials that are bonded, a stiff glue is sometimes required, while at other times flexibility is more important, a rapid setting glue can be preferable, but for complicated joints / constructions a longer workable period is required.

A combination of fundamental and practical research (cooperation between conservators, engineers, and chemists) was considered essential in the desired modification of older glues or the development of new glues. Conservators need to clearly define the properties they require for a specific glue in order for chemists to suggest material modifications. Modelling could be used to predict the outcomes of these modifications.

As a starting point for adhesive research, research into the literature on research data was considered most useful. Additionally, collecting product data from the adhesive industry could prove to be a valuable source. This would allow scientists to examine claims of manufacturers and evaluate suitability of a glue for conservation purposes. Similarly, a review of the effectiveness of past adhesive treatments would also help to better define the desired properties.

The eventual development of new adhesives would require a practical initiative in the knowledge transfer area. Accessible reports and workshops on how to use new glues were considered the best methods for conservators to familiarize with new products.

Group B: Mechanical behaviour

Group B agreed that the study of mechanical behaviour would require the combination of fundamental and practical research. As a foundation for fundamental research, the observation of the past was considered an important first step, consisting of object description and anamnesis (diagnostic of the condition), the development of diagnostic protocols and the evaluation of case studies that focus on climate conditions and past interventions to help identify patterns.

Understanding the behaviour of paintings on wooden panels and the underlying mechanisms would lead to extensive modelling. A team studying the use of modelling would need to be interdisciplinary to ensure the proper understanding of essential questions and the development of models that are relevant and

realistic. This would -of course- also require research into the different approaches to modelling (analytical, numerical, and experimental) and studies on all parameters that have significant influence on the response of the panel. Therefore, modelling shouldn't be limited to internal factors, but should include a range of external factors, such as climate conditions, treatment variables, and degrees of restraint as a consequence of auxiliary support systems.

Experimental studies can help to evaluate the reliability of models. Using data collected from mock-ups or replicas, or (non-destructively!) from original panel paintings, models can be systematically refined. Actual testing can be used to examine and visualize the physical and chemical aging of panel paintings, such as time-related effects (e.g. fatigue, crack propagation) and the direct response to environmental conditions, chemical changes, and influence of wood movement on pictorial layers.

Transfer of knowledge within the area of mechanical behaviour was also discussed. A web-based toolbox was again suggested as a general resource guide for conservators and specialized research teams. Workshops on the behaviour of wooden panels, or a general increase in the understanding of the subject, would greatly benefit the conservation field. Therefore, the development of a transferable teaching module and related publication will help the training of current and upcoming conservators (i.e. the STEP-program was mentioned: Structural Timber Education Program).

Group C: Paint layers and interface

Addressing the subject of paint layers and interfaces, chairman of the group, Sybesma, started by asking for the personal experience of conservators related to this subject. Elisabeth Grall pointed out that a lack of adhesion always proves to be problematic during conservation practice. The group agreed that very little is actually known about adhesion loss of different paint mediums and there is a great need for knowledge about the underlying processes of different type of damage such as delamination, permeability, and flaking. On a more practical note, Grall added that an imaging technique to identify areas with low adhesion would greatly benefit the conservation of painted objects. Similarly, the formation of cracks and crack propagation (in paint layers) was mentioned by Dr. Bart Ankersmit as an area that has seen little research. The group expressed a particular interest in the flexibility of paint layers, particularly under the influence of time. All these problems can be traced to the underlying chemical and physical degradation processes of the applied materials, which would require fundamental research.

The population research was again mentioned as a useful method to set parameters for fundamental research. Another recurring topic was the relationships between construction methods, materials used in past treatments, and damage types. Conservators should be able to identify very specific damage types within their work.

During the discussion concerning knowledge transfer, several members of the group mentioned the barriers between conservators and scientists as a major problem. Causes such as (a lack of) time, distance, and bureaucracy were mentioned, as well as a general lack of understanding about subjects that fall outside one's own scope. Therefore, it was even suggested that intermediates might be required to bring the different fields together. Conservation scientists could play a major role in bridging these gaps. Finally, going back to the lack of knowledge on chemical and physical degradation of paint layers, both Frederik de Wit and Sebastian Schöder were adamant that a lot of earlier executed research would be able to help us on the way. As most of this research is unknown or inaccessible for many participants, nearly all topics would greatly benefit from a major literature study that could save a lot of work in the long term.

After each group presented their conclusions to the larger group, professor Uzielli gave a short recap of the results of the day. Thanking all the participants for their valuable input, the expert meeting was rounded up by Paul van Duin (Rijksmuseum), Alan Phenix (GCI) and Nico Kos (NWO).

Conclusion

The meeting addressed essential research topics that should contribute to an increased knowledge base for implementing new conservation strategies and making informed choices on the best approaches to the conservation of panel paintings and related works of art. Key realizations of the meeting were the following:

- Wood used as supports for paintings suffers chemical and microbiological degradation, which may influence the physical properties and environmental response of panel paintings;
- The interface between ground and panel is an important factor in the stability of the panel painting; the challenges of understanding the dynamic mechanical effects occurring at that interface; the influence of measures (including consolidation) intended to mitigate ground / panel interfacial failure modes;
- Time-related effects (loading history, environmental history) and time-dependent behaviour (permanent wood shrinkage, creep, stress relaxation, fatigue, crack

propagation, interfacial failure, etc.) strongly influence the condition of the objects;

- The response of panel paintings to environmental conditions (temperature and relative humidity) needs to be investigated by systematic collection of new data and evidence to guide and inform understanding of allowable / tolerable temperature and humidity conditions for panel paintings;
- Specific attention is needed for dissemination and knowledge transfer of research results to promote the transmission of “research into practice”.

The conservation of panel paintings and related objects
Research agenda 2014-2020

Appendix 2
Proceedings of the expert meeting, January 2011
Dave van Gompel and Paul van Duin
with contributions from Matthias Ubl and Alan Phenix

Appendix 3

3. Author biographies



Mr. Paul van Duin

Paul van Duin studied psychology at the University of Utrecht before switching to furniture conservation in 1980. He graduated at the Opleiding Restauratoren in Amsterdam. He worked from 1984-1989 as a furniture conservator for the British Royal Collection and is since 1989 head of furniture conservation at the Rijksmuseum Amsterdam. He is advisor of the Panel Paintings Initiative. Paul van Duin was project manager for the Ateliergebouw which opened in July 2007 and houses the Rijksmuseum conservation departments as well as the research department of the Netherlands Institute for Cultural Heritage and the Master Programme in Conservation and Restoration of the University of Amsterdam.



Mr. Dave van Gompel

(report of the expert meeting)

Dave van Gompel has a Bachelor's degree in art history from the University of Amsterdam. He trained as a furniture conservator at the Dutch Institute of Cultural Heritage (ICN) and obtained a Master's degree at the University of Amsterdam in 2010. He was a furniture conservation intern at the Rijksmuseum Amsterdam and at 'Hoving & Klusener' in Amsterdam, and a furniture research intern at the Dutch Royal Tropical Institute. He is currently furniture conservator at the Rijksmuseum.



Prof. Anne van Grevenstein-Kruse

Anne van Grevenstein-Kruse trained as a conservator of paintings and polychrome sculpture in Brussels, Rome and Munich. After obtaining a degree in art history at the University of Brussels, she was appointed head of the conservation department of the Frans Hals Museum in Haarlem in 1983. In 1987 she became the director of the Limburg Conservation Institute in Maastricht where she initiated the first post-academic training program in conservation (paintings, historic interiors and contemporary art). She coordinated major conservation projects within an interdisciplinary and scientific setting (NWO Molart and De Mayerne programs). Since 2007 she is professor in the "Practice of Conservation and Restoration" at the University of Amsterdam.

Dr. Roger Groves

Roger Groves is assistant professor and head of the OptoNDT Laboratory, Faculty of Aerospace Engineering, TU Delft. He obtained his PhD optical instrumentation in 2002. Since 2005 he is developing optical instrumentation for the structural diagnostics of canvas and panel paintings. Aim is to detect discontinuities in the painting structure using very gentle loading and nanometre displacement sensitive holography and interferometry instrumentation. Second technique is terahertz imaging for the determination of bulk structural discontinuities. Partner on EU FP6 Project 'MULTI-ENCODE – Multifunctional encoding system for the assessment of movable cultural heritage' whilst at Universität Stuttgart. He has international collaboration in this field with National Gallery, Athens; Tate, London; IOF Fraunhofer Institut, Jena; AIDO, Valencia and FORTH, Crete.



Mr. Velson Horie

Velson Horie is a strategic planner with an international reputation in project management, research, and teaching. After a degree in chemistry, he trained in archaeological conservation at the Institute of Archaeology (London). For 28 years he was Keeper of Conservation at The Manchester Museum, The University of Manchester, then was the research project manager at the British Library coordinating an international and interdisciplinary study on the natural ageing of books. He has carried out conservation, research, and professional coordination primarily with organic materials, such as polymers, preserved animal skin, movie film, and degraded wood. He has upwards of 80 publications and editorships, including Materials for Conservation.





Dr. Nico Kos

Nico Kos studied chemistry in Leiden. After graduating in 1975 (cum laude) he worked as a researcher at Wageningen University, where he obtained his PhD in 1981. After a short postdoc period in Wageningen, he worked at the policy department of this University, and later of the Technical University Delft. Since 1986 he works at the Netherlands Organisation for Scientific Research (NWO), where he is presently senior manager (international) programme innovation at the chemical and physical sciences division. He was involved as academic secretary in two programs concerning molecular studies of art objects, especially paintings, MOLART and De Mayerne.



Ms. Britta New

Britta New initially trained in the conservation of easel paintings at the University of Northumbria, Newcastle. She went on to an internship at the Hamilton Kerr Institute, Cambridge, focusing on the structural repair of wooden panels and working closely with Ray Marchant. This internship culminated in freelance work at the Institute and Ebury Street Studio, London. In 2006 she began working at the Royal Collection, Windsor and in 2007 she was appointed Assistant Conservator at the National Gallery in London where she works, with a particular interest in wooden panels, on both the structural and aesthetic conservation of paintings.

Dr. Christina Young

Christina Young is a senior lecturer in easel painting conservation, conservation scientist and structural conservator at the Courtauld Institute of Art, London. She has a BSc in Physics, an MSc in Applied Optics. She gained her PhD in 1996 from Imperial College, London. She then joined Tate as a Leverhulme Research Fellow, moving to the Courtauld Institute in 2000. Christina supervises and undertakes structural conservation treatments for both canvas and panels, and is active in research in conservation mechanics, optical monitoring techniques, methods/materials for structural conservation, the conservation of modern and contemporary art, and significance of scenic art.



Kate Seymour, MA

Kate has an MA in Art History from the University of Aberdeen (1993). She began training as a paintings conservator in Florence completing a three year diploma at the Istituto per l'Arte e il Restauro (1997) and continued at the University of Northumbria at Newcastle, gaining an MA the Conservation of Easel Paintings (1999). On graduation, she moved to the Netherlands to work as a Paintings Conservator at the Stichting Restauratie Atelier Limburg (SRAL) in Maastricht, where she is now the Head of Education. Her position entails teaching and lecturing on a variety of subjects, both academic and practical, throughout the 2-year Master of Arts in Conservation Studies at the University of Amsterdam. She also supervises and guides project and research work by the postgraduate students specializing in the structural treatment of both canvas and panel paintings.



Participants in the expert meeting 9-11 January, Amsterdam

The foundations for this report were laid by a meeting where about 30 international experts, including the authors, from different backgrounds came together to identify essential research topics concerning the conservation of panel paintings. On the basis of this outcome the authors have taken up the challenge to develop this research agenda. The experts have provided valuable comments on these texts.



Dr. Bart Ankersmit

After a PhD in Inorganic Chemistry Bart Ankersmit started working at the Central Laboratory for Objects of Art and Science (now Cultural Heritage Agency: RCE) in 1996. He started with a 4 years EU project on the preventive conservation of silver artifacts. Subsequently his interests shifted to collection risk management. At this moment he works as a senior scientist on the development of a risk management tool and more specifically on the risk of the indoor climate. In 2009 Bart published the new climate guidelines for Dutch museums, in which a decision making process is presented that combines the value of the building and the objects with climate risks to find an optimum mitigation strategy.



Dr. George Bisacca

George Bisacca graduated cum laude from Middlebury College in 1977. He received a grant from the National Endowment for the Arts in 1979 to pursue an interest in the history of picture frames, with practical training in woodcarving and gilding from local Florentine craftsmen. He joined the Metropolitan Museum of Art as Assistant Conservator in November of 1983 and was promoted to full Conservator in 1986. During his employment at the Metropolitan, Mr. Bisacca has been invited to work on panel paintings from other international institutions including The J. Paul Getty Museum, the National Gallery of Art, the Norton Simon Museum, the Kunsthistorisches Museum, the Philadelphia Museum, the Chrysler Museum, and the Indianapolis Museum of Art.



Dr. Agnes Brokerhof

Agnes W. Brokerhof studied chemistry (MS) and art history (BA) and is senior conservation scientist at the Netherlands Cultural Heritage Agency (RCE formerly known as ICN) in Amsterdam. Her areas of expertise are preventive conservation, cultural value assessment, and collection risk management. As RCE's program manager of 'Collection Risk Management' she works with her team on the development of a user friendly methodology for risk assessment with the accompanying tools and on making available knowledge applicable for risk management.

Prof. dr. Joris Dik

Joris Dik received his secondary education in Aachen, Germany, Den Bosch and The Hague, the Netherlands. He studied art history and classical archaeology at the University of Amsterdam and received his M.A. in 1997. In '95/'96 he was a Getty Graduate intern at the J. Paul Getty Museum in Los Angeles. After returning to the Netherlands, he worked on a PhD in chemistry, graduating in early 2003. He was then hired by the group of Barend Thijssen to set up a research line in materials in art & archaeology. He was promoted to associate professor in 2006.



Drs. Wolfgang Gard

Wolfgang Gard graduated in wood science and technology at University of Hamburg, Germany. He has 15 years' experience in international wood research with a focus on wood drying and surface treatment of wood at the Dutch research institution TNO, Netherlands. For 5 years he was responsible for innovation and technology transfer for the wood and furniture industry at Wood Industry Centre of Technology, Lemgo/ Germany. Since 2005 he is senior research scientist at Delft University of Technology. His fields of expertise are biological durability of wood, wood - moisture relations, mechanical properties of wood and wood based panels, wood anatomy, wood fibre properties, service life prediction of wood products and organic surface coatings on wood



Mr. Jean-Albert Glatigny

Jean-Albert Glatigny is a conservator-restorer specialized in the study and treatment of wood supports. After studying cabinetmaking, he received four years of training in the polychrome wood sculpture and easel painting conservation workshops of IRPA/KIK. He subsequently expanded his knowledge at the Rijksmuseum in Amsterdam, at the Centre de Conservation du Québec, at the Institut Français de Restauration d'Oeuvres d'Art in Paris, and at the Laboratory of Wood Biology of the Royal Museum for Central Africa in Brussels. At present, in addition to his activities as conservator-restorer for IRPA/KIK and for many Belgian and European museums, he teaches at several conservation schools, participates in studies of works of art and conducts research on historical woodworking.





Ms. Elisabeth Grall

After studying law, Elisabeth Grall studied history of art, then learned restoration techniques in the furniture department at INP in Paris. Since 12 years she is as private conservator in Paris, mainly working for major French museums and historical monuments but also for private collectors. She treats different kinds of wooden works of art: painted wood panels, frames, furniture and marquetry. This variety of work allows her to adapt techniques and to be in touch with a lot of different professionals. She is interested in historical and contemporary materials that can improve conservation work.



Dr. Joseph Gril

Joseph Gril is a specialist of rheological modeling and structure/properties relationships in wood. He leads a research group devoted to basic and applied knowledge on wood as a material, tree biomechanics, supporting research in developing countries, introduction of wood culture in the university curriculums. He has contributed significantly to the progress of wood mechanics in Europe by an active networking activity through the COST system. He established many collaborations with wood scientists, in Europe, Japan, China, Morocco, Iran, etc. where he usually contributes through data analysis and modeling.



Prof. dr. ir. André Jorissen

André Jorissen is a structural engineer educated at Delft University of Technology. Working for H.E. Lüning Structural Engineers he was involved in the design of mainly timber structures. After five years he joined ABT, a much larger structural design office where he was involved in the design of steel, concrete, timber, glass and composite structures. He worked for ten years for ABT, interrupted for four years to carry out research into multiple bolted connections in timber structures which resulted in a PhD degree. He is professor of Structural Design, chair Timber Structures, at Eindhoven University of Technology. He combines this with a position at SHR, a private research company mainly working directly for the wood processing and timber industry.

Dr. Robert Koestler

Robert J. Koestler earned a doctorate in biology (cell biology and electron microscopy) from the City University of New York in 1985. He has worked for more than 35 years in the museum field, first at the American Museum of Natural History and then at the Metropolitan Museum of Art. He serves as editor-in-chief of the Elsevier journal *International Biodeterioration and Biodegradation*. Since August 2004 Koestler has been the director of the Smithsonian's Museum Conservation Institute. In 2010 he was invited by the French Ministry of Culture to serve on the Conseil scientifique de la grotte de Lascaux.



Prof. dr. Roman Kozłowski

Roman Kozłowski graduated in chemistry at the Jagiellonian University in Krakow, Poland in 1970. He received his PhD in 1974 from the same university. He is a professor at the Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences in Krakow where he has worked since 1986 in the field of heritage science. He has been coordinator and principal investigator in several research projects within the Framework Programmes of the European Commission. His research focuses on microclimatic monitoring, response of materials to changes in environmental parameters, composition and porous structures of historic materials, and their interaction with moisture.



Prof. dr. ir. Jan-Willem Gijsbert van de Kuilen

Jan-Willem Gijsbert van de Kuilen is professor for Timber Structures & Wood Technology at Delft University of Technology. Since 1989 a large number of research projects have been carried out focussing on the behaviour of time dependent aspects including biological degradation and physical aspects such as temperature and moisture variations. This has led to models describing the long term variation of wood deformations under different loads and climatical influences as well as reliability equations for the assessment of strength and residual service life of structures. In addition, the behaviour of timber joints has been studied with large series of experiments as well as finite element modelling tools.





Mr. Ian McClure

Ian McClure is a graduate of Bristol University and Edinburgh University. After training and working as a conservator at Glasgow art Gallery he was appointed Director of the Hamilton Kerr Institute, University of Cambridge, in 1984, and also Assistant Director for Conservation at the Fitzwilliam Museum in 2004. He was appointed Chief Conservator at Yale University Art Gallery in 2008. He is currently working with the Head of Preservation at the Yale Library to plan and develop a new shared conservation and research facility for all the University's collections.



Prof. dr. Jaap Molenaar

Jaap Molenaar studied mathematics and theoretical physics at Leiden University, The Netherlands, and wrote a PhD thesis on solid state physics. For more than a decade, he was involved in mathematics consulting and received the Neways Award for his work on academic knowledge transfer to industry. Jaap specializes in the modelling of dynamical systems with a focus on differential equations and has published several books on this topic. In 1999, he became professor at Twente University and since 2006 he holds a chair in Applied Mathematics at Wageningen University and Research Centre. There, he is head of the Department for the Mathematical and Statistical methods for the Life Sciences.



Dr. Alan Phenix

By background, Alan Phenix is a paintings conservator, conservation educator and conservation scientist. He is presently 'Scientist' at the Getty Conservation Institute, Los Angeles, working partly for the Collections Research Laboratory and partly for the Modern & Contemporary Art Research group; his current work mostly involves paint analysis and materials testing. Alan has a bachelors degree in chemistry & colour chemistry (Leeds University, UK) and a post-graduate in the conservation of easel paintings (Courtauld Institute of Art, London). He worked as a paintings conservator at the Tate Gallery, London and at state museums in Australia. In 1997/8 he spent 15 months on secondment to the NWO-funded MOLART project managed by the FOM Institute for Atomic & Molecular Physics, Amsterdam. He is co-editor of the volume of proceedings of the 2009 second Getty Panel Paintings Symposium.

Prof. Eric Postma

Eric Postma is full professor in Artificial Intelligence at Tilburg University, the Netherlands. His research interests are the development and application of digital methods to the analysis of (digital reproductions of) paintings. In 2000 he initiated a research project on the analysis of the detailed visual characteristics of impressionist paintings. During the past 11 years the project evolved into an international consortium of computer science and mathematics researchers that analyse paintings by Van Gogh and other painters. His current work focuses on the development of methods that can help art historians in the quantification and comparison of the visual structure of paintings.



Dr. Hans Poulis

Dr. Hans Poulis studied experimental physics at the Leiden University, where he obtained his MSc degree in 1987 on adhesive bonding of membranes for use at cryogenic temperatures. He worked during two years for Phillips in Paris on microwave amplifiers, and received his PhD degree on the topic of "Small Cylindrical Adhesive Bonds" at Delft University of Technology in 1993. He ran a private company for 10 years successfully and generated a number of European projects during that time. He returned to DUT in 2006 as the director of the Adhesion Institute (Hechtingsinstituut), and was involved in a number of art-restoration projects with the ICN (Instituut Collectie Nederland). Since 2009 he is studying for a MBA degree at Webster University.



Dr. ir. Henk Schellen

Since 2004 Henk Schellen is an associate professor on building physics of monumental buildings at Eindhoven University of Technology. He is specialized in heat and moisture transfer in buildings. His main expertise is on building physical measurements and simulation. His research resulted in a PhD thesis "Heating Monumental Churches; Indoor Climate and Preservation of Cultural Heritage". Henk advises on building physical and indoor climate problems in Dutch monumental buildings like the Anne Frank House, the Rembrandt House, Maurits House, Fortress Fort Aan de Hoek van Holland and some 30 monumental churches.





Prof. dr. Sebastian Schöder

Sebastian Schöder has studied physics at the University of Stuttgart. He made his PhD at the Max Planck Institute for Metals Research, in the department of Prof. Helmut Dosch and at the European Synchrotron Radiation Facility (ESRF), where he used high energy synchrotron radiation for investigations of buried interfaces of ice and soft matter. After finishing his thesis he worked as a post-doc at the microfocus beamline ID13 of the ESRF and was in charge of the commissioning of the new nanobeam goniometer. Since October 2010 he is working at the Synchrotron SOLEIL as beamline responsible for the PUMA beamline, which will be optimized for ancient materials and cultural heritage research and feature both full field imaging



Mr. Laurent Sozzani MSc

Laurent Sozzani is Senior Painting Conservator in the Rijksmuseum, Amsterdam where he started in 1990. He has a BA in fine arts at San Diego State University and a MSc in Art Conservation at the Winterthur Museum/ University of Delaware. Following two years working in the private studio of Perry Huston and Associates in Fort Worth, Texas, in 1986 he began a two-year advanced fellowship in paintings conservation at the Metropolitan Museum of Art, followed by two large restoration contracts. While working at the Rijksmuseum he has also worked at the Museo d' Arte in Sao Paolo (MASP), Brazil, and other Brazilian and Latin-American foundations and Dutch museums. He is particularly interested in the ethical boundaries of aesthetic treatments.



Prof. dr. Rint Sijbesma

Rint Sijbesma is full professor in Supramolecular Polymer Chemistry at the Eindhoven University of Technology since 2006. Between 1987 and 1992, Sijbesma worked on synthetic receptor molecules at the University of Nijmegen, where he obtained his PhD degree in 1992. Subsequently, he moved to the University of California, Santa Barbara (UCSB) to work as a postdoctoral researcher on the organic chemistry of C60 (buckminsterfullerene). In 1993, he joined the TU Eindhoven. In 2002, he became senior lecturer, and received a 'Pionier' grant from the Dutch Science foundation (NWO) to set up a research line in the area of 'Functional Self-Assembled Polymers'.

Dr. Matthias Ubl

Matthias Ubl studied art history at the University of Heidelberg (Ruprecht-Karls) and London (UCL). At the Albert-Ludwig Universität Freiburg in Breisgau/ Duitsland he obtained a PhD about the Brunswijkse Monogrammist, an anonymous Dutch artist. Since 2009 he is working as an Junior Conservator at the Rijksmuseum Amsterdam. Besides his daily work schedule he also works on a catalogue about Dutch Art history II (artists born between 1500 – 1570).



Prof. Luca Uzielli

Luca Uzielli is a mechanical engineer and full Professor of Wood Technology, University of Florence. He was Chairman of COST Action IE0601 “Wood Science for Conservation of Cultural Heritage” from 2007-2012. He participated in Standardization Committees (UNI, CEN, ISO) in the wood sector. Presently he is dealing mainly with technological assessment of the wooden supports of panel paintings; relationships between environmental hygrothermal parameters, their fluctuations, deformational dynamics, strains and stresses, damages to paint layers, structural timber. He leads a research group monitoring Beato Angelico's panel paintings in San Marco Museum (Florence), and participating in the monitoring of the “Mona Lisa” in the Louvre Museum.



Prof. Jørgen Wadum

Jørgen Wadum is Keeper of Conservation at the National Gallery of Denmark, Copenhagen. Since 2012 he is professor in Conservation and Restoration at the University of Amsterdam. He trained as a flower painter, an art historian and as a paintings conservator. Since 1980's he has specialized in the painting techniques of the 16th and 17th century Dutch and Flemish artists. He has published and lectured extensively internationally on a multitude of subjects related to this and other issues of importance for the understanding and keeping of our cultural heritage. Wadum holds positions in several international organisations and committees among which he is co-Chair of the Advisory Group for the Panel Paintings Initiative.





Ir. Frederik de Wit

Frederik de Wit studied materials science and engineering at Delft University of Technology, where he obtained his MSc degree in 2004 on the topic of adhesion of epoxy coatings on aluminum alloys in the Corrosion Technology and Electrochemistry group. In his PhD work, he continued research on (de)adhesion of molecules and coatings on aluminium alloys. The focus of this research was to understand how molecular bonding is coupled to macroscopical adhesion. He started working in 2009 for the Hechtingsinstituut as a researcher and project manager, where his main task is to extend the scientific collaboration inside and outside the university.

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Figure A+B Anonymous, Vanitas still life with books.
The Netherlands, 1633. Oak, 73.5 x 70 x 1.2 cm. The support consists of three vertical butt-joined boards. As ground and paint layers extend over all edges except at the top, this side was trimmed, also removing part of the bevelled edge. The reverse of the panel is covered with a thick layer of wax. © Rijksmuseum.

Colophon

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Jan van Huysum. Still life with flowers. The Netherlands, 1723. Mahogany, 81 x 61 x 1.5 cm.
The reverse of the panel painting is during a former treatment covered with a thick layer of wax.
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Hubert and Jan van Eyck: Adoration of the Mystic Lamb
Saint Bavo Cathedral, Ghent, © Lukas - Art in Flanders VZW
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