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9 Painted Wood in Historic Buildings with Uncontrolled Environments: Active Deterioration & Passive Conservation

Abstract

Painted artworks are laminate structures, the individual layers of which react differently to variations in hygro-thermal conditions. Timber structures are particularly sensitive to this due to the very different dimensional response of the wooden substrate and the superficial paint layers, which often results in severe damage and loss. In a museum setting this situation can be controlled by mechanical regulation of the environment. However, in historic churches and other buildings without formal microclimatic control, other strategies have to be devised in order to minimise the risk of such damage. This can be particularly difficult where the conditions desired for the comfortable use of the building by visitors come into direct conflict with those necessary for the conservation of the historic fabric and artefacts. Although treatment is often necessary where damage has already occurred, preventing further deterioration generally involves a passive conservation approach. In other words accurately understanding the causes of deterioration, implementing control measures to prevent its recurrence and monitoring the subsequent conditions to ensure that the deterioration does not reoccur.

Introduction

Although the most significant damage to painted wooden objects in historic buildings is generally caused by iconoclasm or change of fashion, almost as destructive, in the longer term, is the effect of uncontrolled environmental conditions.

Painted wooden artefacts are laminate structures involving a number of materials which respond in different ways to changes in the microclimate. It is the variation in dimensional response which underlies most of the deterioration issues facing the conservator dealing with artefacts in buildings with uncontrolled environments.

In order to achieve the best conservation outcome it is important to understand the underlying causes of deterioration, including both the microclimate and the physical response of the wood. Only in this way can practical control measures be designed, which will prevent the continuation of the damage.

Properties of Wood

The physiochemical nature of wood means that although variations in temperature (T) can induce minor dimensional change, it is far more responsive to variations in relative humidity (RH)[1]. Although the extent to which RH affects the wood varies depending on its age and condition, it can be highly responsive to fluctuations in RH, even when extremely old.

The level of dimensional response is largely a function of the moisture content (MC) of the wood[2]. In general the level of shrinkage is proportional to changes in the MC. The dimensional response is also affected by the specific gravity (or density) of the wood. Therefore oak, which has a higher specific gravity than most pine, is subject to greater levels of shrinkage and swelling[3]. However, in order to address the response of the wood to fluctuations in RH it is necessary to consider the equilibrium moisture content (EMC) – that is the balance between the ambient RH and the level of water in the cells at a given temperature. Although EMC is dependent on wood type, a typical value at 20°C and 65% RH would be approximately 12%[4]. Because water molecules within the cell walls are more strongly held by chemical and physical bonds than those in the surrounding air, a greater level of energy is required to desorb them than is required to absorb them in the first place. This gives rise to an hysteresis effect which, in practical terms, means that the EMC, and therefore dimensional changes, may be buffered from short term fluctuations in RH.

The response to moisture is also governed by the dimensions and cut of the individual wooden element. As wood has an anisotropic structure, dimensional change in different planes can vary significantly . In an oak board, longitudinal shrinkage from green to oven dry might be no more than 0.1% – 0.2%. However, radial shrinkage may be up to 5.2% and tangential shrinkage, as much as 10%[5]. The way in which the wood is cut also has a significant influence on the direction of any movement. Therefore, boards which are cut tangentially across the grain are more likely to warp than those cut radially[6]. In addition, the ratio of the exposed surface to the volume of wood influences the level of reactivity to moisture, so that thin boards can be affected more than thicker structural elements[7].

The uneven cycles of movement resulting from fluctuations in RH cause increased stresses across wooden elements which are fixed at specific points, as well as across groups of individual elements which are attached to each other. In both cases, the possibility of cracks occurring around the fixing points is significant. In addition, tightly restrained wooden elements may be at risk as a result of cracking occurring due to compression setting[8].

With many historic artefacts, the situation is further complicated by the fact that the front and the back of the wooden elements are coated with different materials. For instance, a panel painting may be coated on one side with a low porosity paint layer, while the other side is uncoated. This will have a significant effect on the levels of moisture sorption, making the dimensional response harder to predict[9]. The situation can be further complicated by the introduction of moisture sensitive materials as part of historic treatments, which themselves affect the response of the timber[10].

Failure Mechanism

Although paint layers are themselves responsive to changes in temperature and RH, the level of dimensional response is generally considerably lower than that of the timber. Therefore, fluctuations in moisture levels will cause stresses to occur between the timber substrate and the paint layer, ultimately leading to a failure of adhesion, and the delamination and flaking of the paint layer[11]. The damage that this causes to painting on timber building structures and artefacts is widely reported[12].

Response Times

The period of time that it takes for the wood to respond to changes in the surrounding microclimate varies significantly and depends on numerous factors including the wood type and cut, as well as the paint coatings and the condition of both. Compression setting also appears to have a significant impact on the nature and level of response[13].

Reported dimensional response times also appear to vary depending on the measurement technique used and whether superficial or in-depth movement is monitored. While some research shows that superficial movement happens extremely swiftly, sometimes in a matter of minutes[14], other work suggests that significant movement takes many hours or even days[15].

However, what counts as a significant response in this context depends largely on the ability of the paint layer to withstand the movement. At Peterborough Cathedral, the boards in the ceiling were found to be warping in response to changes in RH, so that the painted surface was concave. Because of the relatively high compressive strength of the paint layer, as opposed to its low tensile strength, (it would break if stretched), significant distortion was necessary before adhesive failure occurred. As a result, it was calculated that the RH would have to remain elevated for a period of more than twenty days to allow sufficient distortion to cause damage to the paint layer[16].

However, many painted wooden objects are far more susceptible to damage than this and it is clear that, to minimise the level of deterioration of painted timber artefacts, it is usually necessary to maintain reasonably stable environmental conditions.

Uncontrolled Microclimates

The environmental conditions in historic buildings are affected by the building structure itself and by artificial influences within it. The building structure, or envelope, separates the unstable external conditions from the internal microclimate. Artificial influences include heating, ventilation, and dehumidification, which may be carried out within the building.

External environmental conditions are generally extremely unstable with large diurnal fluctuations in RH and T. In order to maintain a stable and benign internal microclimate, it is essential that the building envelope is functioning correctly and that the rainwater disposal system is successfully removing dispersed rainwater from the building. If either fail and rainwater is able to enter the building structure, it will not only cause localised damage resulting from salt activity or the movement of other soluble materials, but will also evaporate into the interior, disrupting the stability of the microclimate.

In the case of painted timber artefacts which are part of the building structure, the successful function of the building envelope and the rainwater disposal system are all the more important, as any failure can allow liquid water to reach the wooden structure directly.

The efficiency of the hygrothermal buffering between the internal and external conditions of a well functioning building envelope, can be affected in a number of ways. Buildings with large windows or thin uninsulated walls will provide a less effective thermal buffer than those with small windows and thick well insulated walls. For the less well buffered structures, changes in the external temperature will be reflected more quickly within the building, and the microclimate will fluctuate accordingly.

Large windows can also allow sunlight to fall directly onto the painted wood. Not only is there a risk to photosensitive pigments, but the short term heating from solar radiation can be extremely high, particularly in an enclosed space[17].

Building envelopes which have high levels of air leakage will have reduced hygral buffering (as well as thermal buffering). In other words, changes in the level of water vapour in the external air will be more quickly reflected inside, resulting once again in fluctuations in the internal microclimate. Timber framed buildings, and buildings with loosely fitting roofs, windows and doors will typically have a high level of air leakage. The efficiency of the building envelope can also be reduced by intentional ventilation caused by leaving the doors or windows open, a practice which is often recommended to ‘dry’ building interiors.

However, if the absolute humidity (AH) of the air outside is higher than that within, then encouraging air exchange will simply make the internal microclimate wetter. In extreme conditions, such as ventilating a cold church in the spring with warm moist external air, this can lead to widespread condensation[18].

Active control of the internal microclimate is often carried out for the convenience and comfort of those using the building, rather than for the conservation of the building fabric and the historic artefacts.

A typical example is the pattern of heating commonly adopted in churches throughout the country. Largely for reasons of cost, no heating is used during the week, and then on Sunday morning it is put on some hours before the service and then turned off immediately afterwards. The result is that during the week, the RH may remain high and stable while the T remains low. On Sunday, there is a sharp increase in T and a consequent fall in RH. The absolute moisture content generally increases due to moisture evaporating from the fabric and people ‘breathing’ within the church. Following the service the T will fall, but because of the increase in the AH, the RH will often increase to higher than it was before the service, bringing with it the risk of condensation of the walls and monuments, which will not have had time to increase in temperature[19].

Different heating systems result in different environmental fluctuations. Electric fan assisted convector heaters can produce a far more rapid change in T (both increase and decrease) than for instance, a system of hot water radiators, which have a far slower heating and cooling time. Unvented portable Calor gas heaters produce a swift temperature change but produce a high volume of water, as a result of the combustion process, usually resulting in an overall increase in AH[20].

The location of heating units in relation to painted wooden artefacts also has a significant effect on how deterioration might occur. For instance, a radiant heat emitter close to a painted screen, or a convection unit below a painted ceiling, may cause considerable localised damage while the general environment is far less significantly affected.

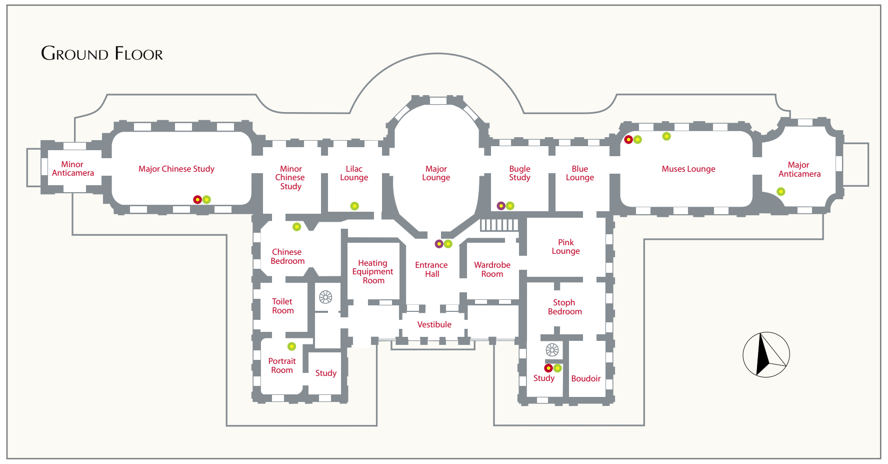
In all cases the fluctuations in the microclimate will increase the stress within the wood/paint laminate structure increasing the risk of failure.

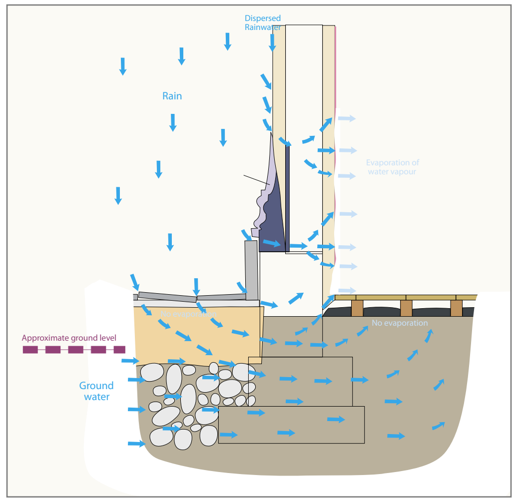
Investigation of Causes of Deterioration

Accurate identification of the specific mechanisms causing deterioration is essential in designing an efficient and effective system of control.

The simplest and most useful tool in assessing causes of deterioration is an assessment of the deterioration patterns and types, which tend to be characteristic of specific moisture sources. The patterns of damage

Figures 1a , b, c & d
Deterioration of the painted panelling at the Chinese Palace, Oranienbaum, Russia, as a result of localised water penetration from the damaged terrace





caused by an unstable microclimate are distinctly different from those caused by water infiltration.

Damage associated with water infiltration is generally localised and discrete. It often involves high volumes of water over a relatively short period of time and generally displays staining caused by soluble materials in the wood, as well as failure of the paint layer. The sources tend to be relatively straightforward to identify, by undertaking a standard building investigation *(Figures 1a, 1b, 1c and 1d above)*.

Capillary rise of ground water, resulting from a failure of the below ground drainage, is also relatively easy to identify, with characteristic patterns of damage at the base of walls and, in some cases, significant rotting of the wooden structure *(Figure 2 opposite)*. Investigation of the water source can be more complex and may require a detailed liquid moisture survey, as well as an investigation of the drainage system.

Figure 2
The screen at St Thomas Becket, Bridford, Somerset, showing patterns of deterioration at the base associated with historic capillary rise of ground water

Establishing whether deterioration is active or historic is not always straightforward, as the deterioration may be visible long after the water source has been controlled. In some cases, deterioration may occur as a result of controlling the moisture source, as the substrate goes through the drying process. In simple cases, superficial electronic readings may be sufficient to establish whether the moisture source remains active. Moisture mapping and comparing patterns of deterioration is a particularly useful tool in this context. However in more complex cases it may be necessary to investigate the physical history of the building to trace the development of the deterioration.

Damage associated with unstable microclimatic conditions is generally more complex to investigate. As with liquid water cases, the first stage is to establish the types and patterns of deterioration, in order to begin to narrow down the probable causes. Typically, microclimatic damage to painted timber is widespread and evenly distributed *(Figure 3)*. Superficial moisture readings tend to be relatively low and even across large areas, rather than high and localised, as in the case of liquid water sources.

In addition to the assessment of the building envelope and

Figure 3
Details of the screen by G F Bodley at St Michael's Church, Cambridge, showing widespread and even delamination caused by adverse micro-climatic conditions

Figure 4a
(Above) Detail of the painting on the underside of the Balck Prince's Tester, Canterbury Cathedral

Figure 4b
(Below) Linear displacement transducer, measuring movement on the upper side of the tester

its anticipated buffering efficiency, an examination of artificial influences, including heating and ventilation, should be undertaken at an initial stage. Correlating the history of deterioration with changes in building use and condition is also a useful tool in determining when and how deterioration occurred.

While in some cases, this might give a clear indication as to whether the deterioration is active or historic, in other cases it may be necessary to undertake a period of environmental monitoring to establish the current microclimatic conditions. Of course monitoring the microclimate only provides indirect data on whether a wooden object is moving or deteriorating. In order to establish with certainty that movement is taking place at a level that may cause damage, it is necessary to measure the dimensional variations of the object itself. Undertaking monitoring with the necessary level of accuracy in field sites is complicated and is relatively rare. Two cases where this has been done are on the painted wooden ceiling at Peterborough Cathedral and on the tester of the Black Prince's tomb at Canterbury Cathedral. In both cases, linear displacement transducers (LDTs), were mounted across areas of wood where damage to the paint layer had been observed and movement was recorded in conjunction with RH, T and surface temperature (ST) *(Figures 4a, b above, & c, opposite)*.

Control Measures

The primary aim of a control system is to minimise environmental conditions which will cause the wooden structure to significantly change dimensions, or otherwise deteriorate.

Environmental control can be separated broadly into passive and active measures. Passive control measures generally involve the control of sources of environmental instability, while active measures involve the control of the resulting microclimate. Most cases require a combination of the two approaches, but the balance between the two in any particular case depends on the type of building and its usage, the nature of the damaged artefact and inevitably, financial resources.

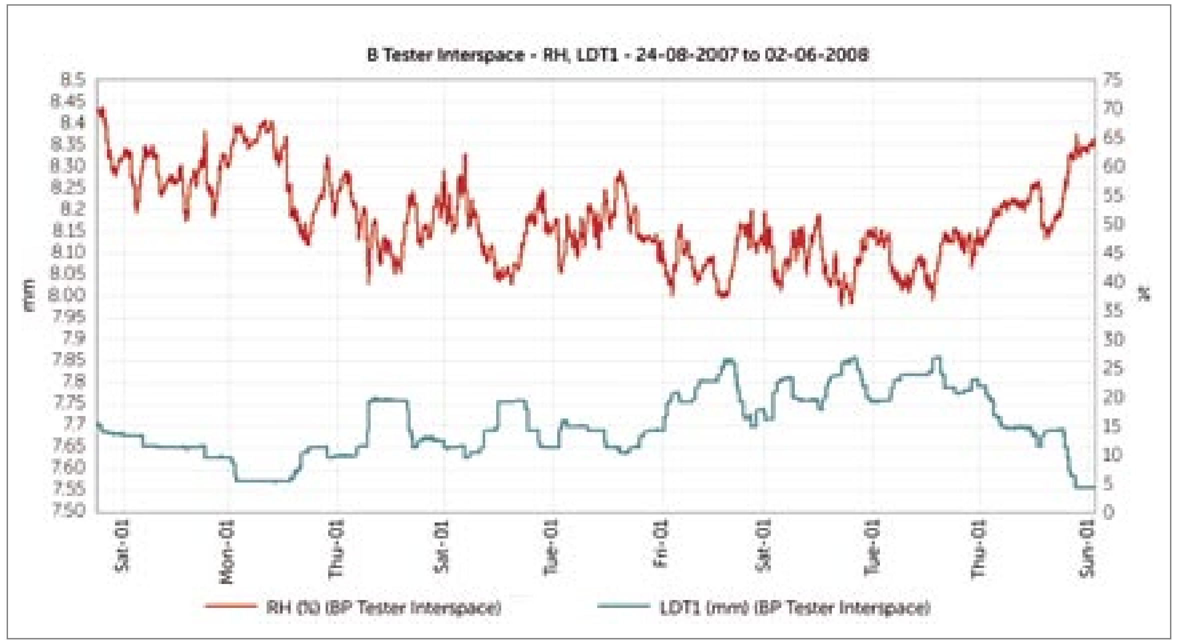


Fig 4c
Data demonstrating the correlation between long-term fluctuations in relative humidity and the movement of the timber on the tester

With historic buildings, the most important aspect of passive control is to ensure that the building envelope and rainwater disposal system are functioning correctly. Extensive research had been undertaken on the impact of building repairs in both modern and historic structures and the methodology and treatments are well established[21]. If this is achieved, then the first consequence is that all liquid water sources will be eradicated. Secondly, it will mean that the building envelope will provide the highest level of hygrothermal buffering possible.

However, depending on the nature of the building structure, this may not be sufficient to stabilise the microclimate to the extent necessary to prevent the deterioration of the artefacts. If not (and this should be evident from the environmental monitoring data) then it may be necessary to implement measures to increase thermal and/or hygral buffering by measures such as the use of thermal insulation.

A further passive measure is the installation of porous materials which absorb and desorb moisture with a level of hysteresis, so that fluctuations in RH caused by an inefficient building envelope, or other artificial influences, can be reduced. As discussed above, wood itself has this ability, as does lime plaster, and plastered or timber panelled spaces often display the ability to self–equilibrate in this way. However, other porous materials, including some insulation types, display the same characteristics and can be used to significantly increase thermal insulation and RH buffering[22].

The most common form of active environmental control is heating. As discussed above, this is generally used to modify the microclimate to produce thermal comfort, rather than stable RH conditions of the type required to prevent the deterioration of painted wooden artefacts.

Various approaches can be taken to the use of heating for RH conservation. The system adopted by the National Trust is to use humidistat controlled heating so that the system responds to, and minimises, changes in RH[23]. However, this, almost inevitably, leads to temperature levels below those normally required for thermal comfort.

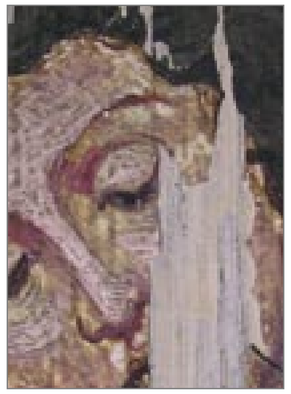
The use of localised radiant heating sources which produce thermal comfort for people within a cold building, but which have a minimal effect on the surrounding microclimate, is an approach which has been extensively researched. It is currently the subject of a major European Union funded project[24]. English Heritage is presently carrying out research into systems for localised heating and also for heating which maintains stable RH at thermal levels considered comfortable for building use.

The other main approach to active environmental management is the control of water vapour. Most systems involve the use of dehumidifiers (or in some case humidifiers) and while there are certain unusual cases where this may be of use[25], particularly for periodic use, in general they are not suitable for long term use in this context.

A more imaginative solution is the use of, what might be termed, conservation ventilation. This is a mechanical system which measures the relative internal and external environmental conditions and encourages air exchange only when an influx of external air would improve the internal conditions. A system of this kind was developed at Zillis Cathedral in Switzerland[26], and is currently being tested at Cormac's Chapel in Cashel, Ireland.

In some cases, modifying the whole of the microclimate within a building is not practical and it is necessary to isolate the artefact within a controlled enclosure. This obviously has very significant ethical and aesthetic implications and while environmentally controlled chambers are common in museums, in historic buildings they are extremely unusual. However, there are some cases where they have been employed such as the Thornham Parva Retable[27] in Suffolk, and the Westminster Retable.

Conclusion



The microclimatic conditions in historic buildings with uncontrolled environments pose a genuine risk to the stability and long term conservation of painted wooden artefacts. However, the microclimatic response of any particular artefact will vary depending on the original materials and construction techniques, the manner and location in which it is displayed and the nature of any previous treatment. Therefore, some artefacts will be far more robust than others and able to tolerate less benign environments. However, in general, successful long-term conservation of painted wooden objects is largely dependent on stable environmental conditions.

Both passive and active control measures can be adopted in order to achieve these conditions. In most cases, passive measures should be implemented as a first stage and active controls put in place, only if passive measures alone do not achieve an acceptable result.

In order to design an efficient system of controls, it is necessary to have a clear understanding of the deterioration mechanisms. Therefore, a detailed and iterative investigation of the artefact and the causes of deterioration is a prerequisite for any successful intervention. While this may involve detailed materials analysis and environmental research, in many cases it simply involves a careful examination of the object and the building structure and the way that the two interact.

Much of the passive control approach is related to the building fabric. To achieve a stable microclimate, it is essential that the building structure is well maintained and the building envelope and rainwater disposal system function efficiently. Modifications can also be made to improve the performance of the building envelope and the way that this buffers the internal conditions from those outside.

Active controls often involve the use of heating systems to stabilise the microclimate, although the situation is complicated by the desire to produce thermal comfort for people using the building. Whilst the two aims are not mutually exclusive they do conflict in many areas, and extensive research is being undertaken to develop systems which satisfy both requirements.

More difficult cases can involve the use of direct moisture control, or the use of climate controlled cases. In extreme cases, it will be impossible to control the conditions and the removal of the artefact may be the only way to ensure that the artefact survives. However, the common theme in all of these cases is that, in order to achieve a successful outcome, it is essential to understand the underlying causes of deterioration and the effects of the control measures.

End Notes

1 Mecklenburg. 1994.
2 The MC is the ratio of the weight of water in a piece of wood to the weight of the dry wood, usually expressed as a percentage.
3 Hoadley. 1998. p3
4 Knut 1999, p.20
5 Op. Cit. Hoadley. p15
6 Brewer. 1998. p448
7 Wadum. 1998. p498
8 Compression setting occurs as a result of the compression of the cellular structure caused when wood expands under restraint, in response to an increase in RH. When the RH is reduced, the wood may have lost volume and will try to pull away from its fixing points.
9 Brewer. 1991. pp9-23.
10 Hessian attached with animal glue was sometimes used in the nineteenth century to strengthen timber structures, such as the painted wooden roofs at Peterborough and St Alban's Cathedrals. Collagen glues are very hygroscopic and particularly susceptible to fluctuations in relative humidity, which can cause significant expansion and contraction. Horie. 1987. p142.
11 The precise point of failure is also effected by the elasticity of the paint layer which is partly a function of temperature. Therefore, the tolerance of a particular painted wooden object to dimensional change will vary with temperature.
12 Olstad. 1994. Legrum. 1994.
13 Compression setting occurs when the expansion and contraction of wood causes damage to the cellular structure.
14 Olstad. 2007.
15 Knight. 2007. pp85-88.
16 Brewer, J A. November, 2000. *Observations on Wood Effects for the Nave Ceiling of Peterborough Cathedral,* unpublished report.
17 Sunlight falling on the back of the painted ceiling boards at Peterborough Cathedral regularly caused the surface temperature to rise to almost 40°C.
18 Curteis. 2004.
19 Curteis. 2003.
20 Calor gas is a LPG (liquefied petroleum gas) consisting of approximately 90% propane, 8% propyne 8% and 2% butane. Pers. Comm. Calor Gas Technical Services. Each 1kg of gas burned produces about 800g water.
21 Trotman. 2004. CIBSE. 2002.
22 Padfield. 1998 and 1999.
23 Staniforth. 2004. pp123-128
24 Camuffo. 2004.
25 Lithgow. 2007.
26 Blauer. 2001.
27 Massing. 2003.

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Picture Credits

Hugh Harrison

10 Polychromed Timber Conservation Solutions

Abstract

Conservation of polychrome woodwork is a complex discipline which involves two specialist conservation professions, that for woodwork and that for the polychrome.

In the conservation of painted timber the timber conservator has to understand that in this case whether the timber is structural or decorative the primary aim of its conservation is the 100% retention of whatever polychrome survives. Timber is a flexible material whose characteristics are determined by ambient relative humidity and as each specie of timber reacts differently to these conditions there is a basic conflict with the paint layers which are inflexible and do not generally react to environmental conditions. As the timber conservator should understand his/her materials, it is within the scope of his/her work to resolve these problems to enable the inert paint layers to survive.

The work of the timber conservator is in two parts. The first is in the assessment of the project and how the timber is affecting the polychrome. The second part is the formulation of different systems of repair to best enable the future survival of the paint layer. My paper aims to set out these aspects of the timber conservator's work and to show some different solutions for repairing timber ensuring the complete survival of the existing polychrome.