MECHANICAL INSIGHTS SYMPOSIUM



November 12-15, 2024

Getty Center
Los Angeles, CA, USA

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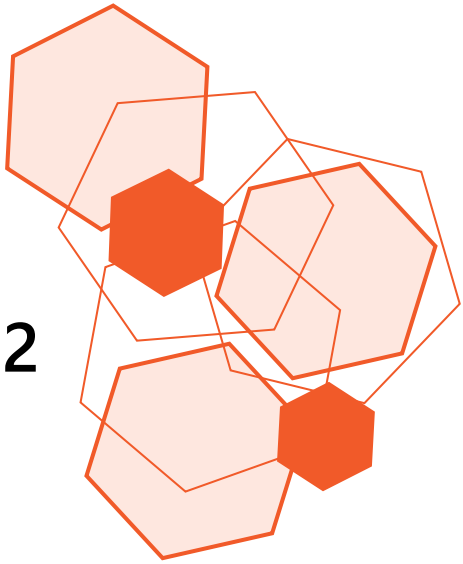
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PROGRAM

	Tuesday, November 12	Wednesday, November 13	Thursday, November 14	Friday, November 15
	Venue: Getty Center, Harold M. Williams Auditorium **no food or drink allowed in auditorium*			Locations Vary
Topic themes:	**Mechanical Testing** →	**Modelling / Predictive Tools** →	**Monitoring / Validation / Synergy**	
7:30-8:00 AM	Registration & Continental Breakfast			Optional Tours *Advanced registration required.* *Your tour details will be emailed to you.*
8:00-8:30 AM		Continental Breakfast	Continental Breakfast	
8:30-9:00 AM	Opening Remarks			
9:00-9:30 AM	1 - Stefan Michalski	8 - Kenneth Shull	18 - Shant Kenderian	
9:30-10:00 AM	2 - Emma Richardson	9 - Naoki Fujisawa	19 - Adam Stieg	
10:00-10:30 AM	3 - Alexandra Bridarolli	10 - Cecil Krarup Andersen	20 - Horst Tratling	
10:30-10:45 AM	Break	Break	Break	
10:45-11:15 AM	4 - Antonio Iaccarino Idelson	11 - Jacek Olender	Panel Discussion	
11:15-11:45 AM	Flash Poster Presentations	12 - Marianne Odlyha		
11:45 AM - 12:45 PM	GCI Lab Tour / Poster Session	Panel Discussion	GCI Lab Tour / Poster Session	
12:45-1:45 PM	Lunch	Lunch	Lunch	
1:45-2:15 PM	5 - Magdalena Soboń	Flash Poster Presentations	21 - David Thickett	
2:15-2:45 PM	6 - David Hauer	13 - Marco Fioravanti	22 - Joséphine Delengaigne and Marie-Laure Gascon	
2:45-3:15 PM	7 - Cécilia Gauvin	14 - Emanuela Bosco	23 - Marie-Noëlle Laurent-Miri	
3:15-3:30 PM	Break	Break	Break	
3:30-4:00 PM	Reception 3:30-5:30 PM	15 - Lorenzo Ripabelli	24 - Constantina Vlachou-Mogire	
4:00-4:30 PM		16 - Michael Kaliske	25 - Sandie Leconte	
4:30-5:00 PM		17 - Łukasz Bratasz	26 - Elke Otten	
5:00-5:30 PM		Panel Discussion	Panel Discussion	
5:30-5:45 PM		Break		
5:45-6:00 PM				
		Dinner in Getty Restaurant 6:00-8:30 PM		

TUESDAY, NOVEMBER 12



TALKS

THEME: MECHANICAL TESTING

1 - The forgotten but most important RH fluctuation (which will increase with climate change)

Stefan Michalski[1]
[1]Independent

At the National Gallery London, the unusually cold winter of 1928-29 caused unusually low RH, which then caused unusually widespread damage to the panel paintings. This event a century ago triggered the first meeting on the topic which we continue to struggle with today. It triggered the first scientific research by experts outside the museum and the first publication (Courtauld, c1934). Unfortunately, the obvious lesson - an unusual climate event is really bad for a collection - drifted into a belief that all fluctuations are bad.Human perception of risks is biased towards the short-term: hourly, daily, seasonal. The analysis of mechanical risks from the entire spectrum of fluctuation frequencies - the goal of this paper - finds that the largest risks by far are the less frequent but more extreme events. These events are necessarily beyond the proofed (previous) fluctuations. The cause can be extreme weather or HVAC system failure (or both). Climate change models are clear: the big change will not be the annual averages so much as the probability and intensity of extreme events.A second phenomenon compounds the significance of extreme fluctuations. Older objects with historic losses will have been restored. The original portions have been proofed, probably crack saturated as well, to the entire history of prior fluctuations, whereas the restorations have not. Control of small fluctuations will save recent restorations, but it does nothing for the proofed original. The original is only at risk from historically unusual fluctuations.How does one mitigate unusual fluctuations? Not by active systems - they are explicitly designed not to control the worst 1½% of conditions - several days per year. It is time for our profession to recognize that both by definition and by reality, extreme events are not controlled by HVAC systems, and that repairs and end-of-life replacement will cause system outages within our lifetimes. The only reliable mitigation is enclosures, and the interesting design question becomes synchronization of the enclosure response times with the probable duration of extreme events.This paper will show that with current knowledge of mechanical response, or even with just widely accepted historical observations, risk analysis clearly establishes unusual events as a far bigger risk than the smaller common fluctuations over which we obsess. In terms of reliability, cost-effectiveness and sustainability, mitigation by enclosures is also the clear winner.

2 - Materials Research @ IPI: Towards Informed Decision Making and Tangible Outcomes for Sustainable Preservation

Emma Richardson[1]
[1]Image Permanence Institute, Rochester, NY, USA

For over two decades, the Image Permanence Institute (IPI) has conducted preservation research focused on sustainable environmental management in collections storage spaces. IPI's early research on storage enclosures and the inherent vices of photographic materials pointed to the fact that environmental storage conditions are the most important factor in influencing collection materials' longevity. At that time libraries, archives and museums were particularly concerned with the alarming rate at which cellulose acetate-based materials were deteriorating. Accelerating aging studies conducted at IPI demonstrated the potential for low temperature and low humidity storage environments to minimize the chemical decay of cellulose acetate film.

Research initiatives in the early 2000s focused on creating tools and resources that would help cultural institutions monitor and analyze environmental data, resulting in the development of the Preservation Metrics, data-based tools for predicting physical and chemical change in organic, cultural heritage materials. These metrics remain important guideposts today and have inspired other research initiatives to develop metrics for evaluating the preservation quality of different environmental conditions.

Over the past decade, IPI has combined both laboratory-based research and field-based studies to further our understanding of hygroscopic material responses to environmental changes and to develop risk-managed methodologies for testing and implementing energy-saving strategies in collections spaces. A truly sustainable preservation environment program monitors and manages both collections spaces and mechanical system performance to ensure an optimal preservation environment, that is, one that achieves the best possible preservation of collections with the least possible consumption of energy.

Underpinning the safe adoption of sustainable environmental management is the need for a fundamental understanding of how cultural heritage materials respond to dynamic environmental changes, such as the rates of physical change, magnitude of that change, and the impact of cycling, in particular for composite objects. As such, much of IPI's current research takes a three-pronged approach, namely: i) assessing the relationship between moisture content, water activity, relative humidity, and temperature, ii) using dynamic mechanical analysis to interrogate how these factors influence the mechanical properties of new and aged materials, and iii) validating this approach through *in situ* monitoring, coupling digital image correlation with climate controlled chambers to simulate dynamic collection environments.

This presentation will discuss the fundaments of IPI's early Preservation Metrics for predicting mechanical change, including their limitations, before expanding on current research initiatives that are aimed at developing new tools for sustainable environmental management and providing guidance for collection care professionals.

3 - Predicting the long-term mechanical behavior of animal glues using time-temperature-humidity superposition.

Alexandra Bridarolli[1]
[1]The Getty Conservation Institute, Los Angeles, CA, USA

Animal glues have extensively been used by craftsmen to artists. It is found in sizing for painting, lining and retouching adhesive, pigment binder in paint and gesso as well as glue joint for wooden furniture. Conservation practices and artisans' workshops have kept the tradition of using these materials alive due to their excellent workability, stability, and retreatibility. The glues' moisture response and mechanical/adhesive properties strongly depend on the animal and animal parts used in their production. Therefore, depending on the objects treated and or the type of applications, a glue with the appropriate hygroscopic, physical and mechanical properties will be used.

The broad use of animal glues in conservation and art has led to numerous studies looking into their properties, chemical, physical, mechanical. However, the time-dependent properties of these materials have yet to be fully analyzed. Particularly important is to understand how much their stiffness decreases or their strain at break increases with decreasing strain or stress rate. This has practical implications for determining the extent to which larger long-term (seasonal) fluctuations in temperature and humidity are safe for objects containing animal glues.

To evaluate the mechanical response of materials over large time ranges, mastercurves built using the time-temperature superposition (TTS) principle are commonly used. This principle is based on the experimentally proven observation that increasing the temperature of a test performed at a certain rate allows access to the material's response at a virtually lower rate. This can be explained by the fact that increasing the temperature of a material, accelerates the mobility of polymeric chains and, as such, internal processes of reorganization in the material.

In this study we used time-temperature-humidity superposition for rabbit skin glue. Both temperature and moisture content were used to shift the obtained data along the time axis, giving access to long response times (months, years) that could not be accessed by the traditional TTS method. The results show that the stiffness of the RSG tested is only slightly affected by the testing period within the range of interest (seconds to months). This type of study could fill the gap in knowledge in material response to different rate of climate conditions and help improving predictions in mechanical behavior of on materials' and objects' placed in unstable environments.

4 - Design and construction of a biaxial tester for small samples of historical textiles and paintings

Antonio Iaccarino Idelson[1]
[1]Delft University of Technology

The mechanical aspects of canvas conservation and the study of the effects of conservation treatments require the quantification of material properties and mechanical behavior. However, mechanical testing equipment is not often available in a conservation science laboratory, and their limited availability also influences the demand from researchers. The development, construction and use of a biaxial tester is described here, specifically designed for samples of naturally aged canvas paintings. The design is made available opensource, parts are easy to source, and the overall cost is well below that of commercial units.

Four actuators move symmetrically away from the center, each carrying a loadcell and a sample clamp. This allowed the inclusion of an automatic pre-tensioning function providing an even initial distribution of forces while avoiding any unwanted deformation of the sample. The high resolution of displacement and force readings allows precise measurements to be made on small samples. A laser cutter is used to extract samples from the specimen without mechanical damage. This also allows custom-shaping the clamping ends of the small cruciform samples to avoid any uncertainty in the testing directions. Uniaxial tests can also be performed, by using only one of the pairs of actuators, and the displacement can be obtained with the motion of the two actuators or of only one, while the other is locked in position. In this configuration, the main difference from a commercial Universal Testing Machine is that the force value is measured at both ends of the sample.

Clamps are designed and built for the specific needs and are targeted for 25mm or 10mm wide cruciform or uniaxial samples. The space available in the center of the machine is 40 cm, making it suitable for peel tests, which require a standard run of 305 mm, and a dedicated clamp has been made, including the alignment plate required by the ASTM D 903 - 98. A uniaxial version of the device was built, with dimensions and weight compatible with standard airline luggage. This was used during the comparative lining workshop held at the National Gallery of Ireland in May 2023 as part of the Getty Conserving Canvas Initiative to quantify the adhesion of the lining techniques performed. Examples of the results of biaxial and uniaxial tests performed on historic samples and modern lining textiles are presented, along with a selection of the peel test results from the Comparative Lining Workshop.

5 - Risk of fracture in massive cultural objects made of lime wood: a case study of Veit Stoss' altarpiece

Łukasz Bratasz[1], Magdalena Soboń[1, 2]
[1]Jerzy Haber Institute of Catalysis and Surface Chemistry Polish Academy of Sciences, Poland, [2]Wawel Royal Castle - State Art Collection, Poland

Massive cultural objects made of wood are often situated in historic interiors in which they experience uncontrolled dynamic variations of relative humidity (RH). Although the objects usually have acclimatized to the natural climate variability, preventing risks related to any kind of modification of their environment requires an understanding of the object's response to the expected changes. In the present study, an analysis of the risk of cracking related to continuous or intermittent heating, or the transfer to hypothetically ideal conditions in a conservation studio was performed for the case of elements of Veit Stoss' altarpiece (1477-1489) preserved in St. Mary's Basilica in Krakow, Poland. Massive sculptures carved in lime wood and approximately one meter in diameter were analysed. The study aimed at determining safe margins of environment modifications that would not cause propagation of cracks that are known to have accumulated in wood during centuries of the altarpiece's existence. The mechanical properties of lime wood were determined experimentally to feed the numerical model. The energy release rates around the tips of cracks of various depths in a wooden sculpture were calculated using the finite element analysis and compared with the critical value of the parameter triggering the fracture propagation in the material, derived from the fracture energy measurement. It was shown that the church interior housing the altarpiece can be heated to 11 oC during the cold season to provide human comfort. The allowable duration of intermittent heating events to more comfortable 18 oC that would induce drops in RH of up to 40% was assessed as 12 hours.

The study demonstrated that moving the sculptures to the conservation studio would have to be done with extreme caution as it would be connected with risks depending on the depth of existing cracks and the duration of the RH change.

6 - Mechanical research applied to overall structural assessment of large archaeological wooden objects from the Viking age.

David Hauer[1]
[1]Museum of Cultural History, University of Oslo

The Viking Ship Museum in Oslo, Norway, houses the world's largest collections of artefacts from the Viking era. The century old museum, part of the Museum of Cultural History, University of Oslo, is now being considerably enlarged. Prior to the building process small and less fragile objects were moved to safe storage. However, the collection holds the Oseberg, Gokstad and Tune ship, the three best-preserved Viking ships in the world, and three finely carved sledges from the Oseberg finds. For these large, fragile, and structurally complex objects, relocation was associated with greater risk than securing them on site.

The ships and sledges are the only objects remaining within the museum, and it has been of utmost importance to secure them prior to the ongoing construction work. In addition, great care must be taken when these large objects are to be relocated into the new gallery areas. In addition establishing long-term preservation strategies, balancing both the visitor experience and the climate and physical conditions for the objects on display.

Finite element models are developed as a tool for understanding the static and dynamic behaviour of the ships and sledges. In order to get reliable input data for conservation assessment, and element models of the highly heterogeneous objects, innovative mechanical testing and monitoring has been pivotal to assess material and structural characteristics. This includes both static and dynamic measurement data, and climate response.

For static calibration we have applied measurement of weight and load distribution between loadbearing points of the structures, employing load cells. Also, load-deformation measurements have been performed by controlled point loads in selected areas of the structures, where load has been applied and dimensional change measured, in X-, Y-, Z-axis.

For dynamic measurements and structural analysis, a wide range of vibration measurements have been conducted to retrieve information about the dynamic properties, using ODS measurements (Operational Deflection Shape).

For the investigation of how the overall structures of the ships are responding to seasonal climate fluctuations we have applied load distribution monitoring over time. Combined with photogrammetric monitoring, this gives new insight to overall structural behaviour.

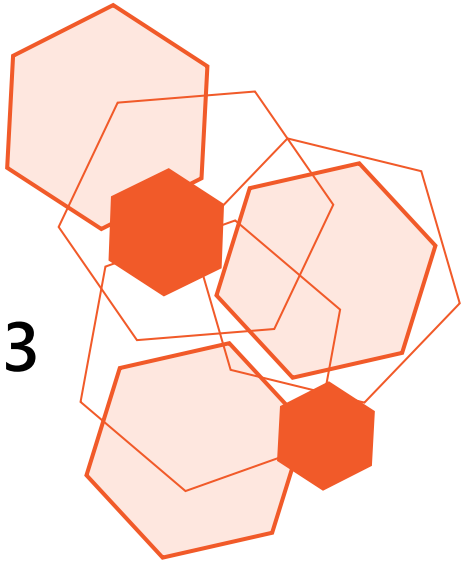
The most important methods from the project will be introduced. Some of the results from our mechanical research will be presented, and how this has formed knowledge-based strategies, and affected decision making facing our present challenges.

7 - Long-Term Hygromechanical Effects of Freezing Treatment for Disinfestation of 18th-Century Wooden Sculptures

Cécilia Gauvin[1], Gilles Tournillon[1, 2], Leila Sauvage[1, 3, 4]
[1]S-MA-C-H, [2]Atelier Tournillon, [3]The Rijksmuseum, [4]University of Amsterdam

This paper investigates the hygromechanical effects of a disinfection freezing treatment of wooden sculptures from the Isnard organ (1743) at the Madeleine Church in Aix-en-Provence (France). The sculptures were mechanically monitored before, during, and after freezing treatment. Following French regulations, the wooden artifacts were sealed in bags and frozen at -25°C for 24 hours, with a controlled decrease and increase in temperature to prevent reaching the dew point. This procedure ensures that the moisture content remains unchanged. While current research on freezing-induced damage primarily focuses on the immediate impacts, this in-situ monitoring tackled long-term effects. Mechanical testing, such as displacement and strain, was implemented across five field campaigns to analyze physical changes due to unstable climate conditions in the church. It monitored the objects for three months before and after the treatment both unstable and stable climatic conditions, and for three days during the treatment. Crack openings in the radial direction of the wood, as well as bulk swelling and shrinkage in both the radial and tangential directions were recorded in-situ. Results confirm previous studies when comparisons are made under stable climatic conditions. However, under long-term unstable climatic conditions, the strain shows notable differences before and after freezing treatment, suggesting a potential impact of the treatment on the structural behavior of the wooden sculptures.

WEDNESDAY, NOVEMBER 13



TALKS

THEME: MODELLING / PREDICTIVE TOOLS

8 - Museum-Scale Devices for Monitoring Material Aging and Contamination

Kenneth R. Shull[1]
[1]Department of Materials Science and Engineering, Northwestern University

Museums present an interesting array of problems related to the monitoring of the local environment, and the degree to which this environment affects the objects on display. These problems apply to the macro-environment, including the temperature and humidity within the museum, but perhaps more importantly to the local micro-environment created by objects in confined display spaces. The recognition that materials may emit chemicals that affect other materials in close proximity prompted the development of the Oddy test in the early 1970s. This test is based on changes in the appearance of test coupons over time. An emerging goal of our work with the museum community involves the development of a more quantitative and data-rich version of the Oddy test, based on the response of a quartz resonator that is coated with a thin film of an appropriate test material. With recent advances in electronics, the devices are small enough and inexpensive enough to be used extensively in a museum context. The devices measure changes in mass and mechanical properties of the coating, which typically has a thickness of several microns. This presentation will focus largely on results obtained with these devices on the curing of alkyd paints and linseed oil, and on the diffusion of plasticizers into cellulose acetate. These examples will be presented in the hope of seeding further discussion about the potential utility of these devices within the museum community.

9 - Nanoindentation of historic materials

Naoki Fujisawa[1]
[1]Getty Conservation Institute, Los Angeles, CA, USA

The development of effective conservation strategies for precious artworks typically requires detailed mechanical analyses of its constituent materials performed in a minimally invasive manner. This obvious restriction limits the volumes of original materials available for analysis, disqualifying conventional tensile and compression testing that would require the destruction of macroscopic sample sizes. Nanoindentation enables direct mechanical characterization of small-volume samples due to its ability to control the indent size at a nanometer resolution. For a realistic sample with a rough surface, commonly encountered in heritage conservation, however, the rule of thumb dictates the depth of indentation be at least ~20 times the roughness depth to negate the surface roughness effect. A deep indentation of a small sample would in turn result in probing the combined response of the sample and its surrounding embedding medium, rather than that of the sample itself. To address this problem, a method to characterize small volumes of embedded, homogeneous material with a rough surface was developed back in 2019. The method is based on modelling the elastic response of the composite structure using the concept of structural compliance and dealing with the problem of the indenter tip contacting a rough sample surface through introducing the concept of effective contact point. This talk presents the recent effort at GCI in extending the existing sharp nanoindentation methodology to be able to probe individual phases identified in realistic historic materials. Such a methodology, capable of analyzing individual phases in small volumes of heterogeneous materials, will open opportunities for more comprehensive investigation of historic oil paints with heterogeneity, for example, resulting from the formation of metal soaps and ion migration.

10 - Nanomechanical properties of paint from authentic paintings

Cecil Krarup Andersen[1], Alexandra Bridarolli[2], Naoki Fujisawa[2], Kristian Præstholm[1], Mikkel Scharff[1], Michal Lukomski[2]
[1]The Royal Danish Academy, Denmark, [2]Getty Conservation Institute, USA

Computational models are becoming an increasingly larger part of predictive analysis and preventive conservation for cultural heritage. The Copenhagen painting model (Lee et al 2022) showed how a relatively stiff lower ground layer can help avoid cracks and delamination. However, accurate model predictions require accurate material property data and so far, predictive models have relied on data from model paint tests. While these represent an invaluable source it is unclear to what degree they represent the range of mechanical properties that can be expected from older paints in historic paintings. The analysis of paint from authentic paintings represents a challenge since samples cannot be tensile tested and are less homogeneous than paint samples produced for research. This work presents nanomechanical tests on samples from paintings up to 157 years old to test the hypothesis that the mechanical properties of these paints could be related to the paint samples cast for research purposes.

The results showed large variability in storage modulus both in the same sample -indicating poor homogeneity- as well as between the original paint samples. A lower ground layer with earth colour and silicates from F.T. Kloss “A frigate in a bay” 1865 was expected to have relatively low modulus based on tensile tests on oil paint samples from the Mecklenburg’s Paint Reference Collection. Surprisingly, the ground layer was shown to have a higher modulus than almost all other paints analysed, including the lead white upper ground layer on the same painting. The results suggest that, apart from pigments, fillers, and oils, the presence of other organic compounds e.g. protein-based additives (Di Gianvincenzo et al 2023) which are difficult to detect may help explain unexpected mechanical properties.

This research represents a first step into a new realm of “real” paint properties and stressed the complexity of the challenge. Since tensile tests cannot be used on the small paint samples, nanoindentation on cross sections proved to be a most valuable tool for understanding the properties of paints removed from paintings. Ultimately, this information can be used to update current and future computational models of paintings for more accurate predictions.

References

Lee, D.-H., et al (2022). Numerical modelling of mechanical degradation of canvas paintings under desiccation. Heritage Science, 10(1), 1-13.

Di Gianvincenzo, et al. (2023). Proteomic identification of beer brewing products in the ground layer of Danish Golden Age paintings. Science Advances, 9(21), eade7686

11 - Invasive to Non-Invasive: Coupling DMA with DIC to interrogate the mechanical response of plastic composite objects during dynamic environmental management

Jacek Olender[1], Emma Richardson[1], Meredith Noyes[1]
[1]Image Permanence Institute, RIT

As our understanding of the material science of collections has developed over the decades, it is recognized that the majority of museum and archive collections can be safely exposed to some degree of dynamic change to their immediate environment, safely broadening the recommended range of temperature and relative humidities. Simultaneously, there are still gaps in the field's understanding of the physical consequences for certain classes of materials as they respond to changes in atmospheric moisture. One such class are hygroscopic plastics and plastic composite objects.

Image Permanence Institute (IPI) at RIT, Rochester, NY is currently conducting a three-year research project to study the relationship between equilibrium moisture content (EMC) and the physical stability of plastics objects found in museums, through systematically investigating the mechanical response of plastics caused by changes in the surrounding environment. Coupling dynamic mechanical analysis (DMA) with digital image correlation (DIC), this research investigates the response of cellulose acetates (CAs) films and polyurethane foam to changes in the surrounding environment. This is with a view to correlate EMC with the polymers' hygroscopic expansion coefficient and fatigue, in control surrogates and naturally aged, historic materials. The ultimate aim is to inform sustinable environmental management of historic plastics and plastic composites, such as seasonal setpoints.

In this presentation, we discuss data pertaining to multiple combinations of cellulose di- and tri-acetate produced in the laboratory and plasticized with two common additives in varied amounts. Additionally, each film was tested with and without presence of paint, created from historic animation paint recipes. Films were tested with invasive and non-invasive methods. Firstly, in DMA, under low tensile stress (0.001 MPa), where they were dried in pure nitrogen atmosphere and then slowly humidified, allowing them to equilibrate in five subsequent levels of RH, representing critical thresholds for collections storage (20%, 30%, 50%, 70%, and 80%) in both humidifying and drying. Secondly, examination of CA film was conducted in a climate-controlled chamber using DIC, following systematic and real-life-derived environmental profiles.

This data allows us to quantify changes introduced by the presence of different plasticizers and identify regions in the environmental conditions where various factors have greater influence. Additionally, we can identify regions of linear and non-linear dimensional response to changes in the environment. The presence of these regions of non-linearity makes it critical to identify relevant thresholds and acceptable rates of change to support future models and guidelines for collections care of plastic composites.

12 - Dynamic Mechanical Analysis (DMA) and its role in paint tempera dosimetry

Gary Foster[1], Charis Theodorakopoulos [2], Marianne Odlyha[3]
[1]University of Sheffield , [2]University of Northumbria, [3]Birkbeck University of London

In the ERA project (Environmental Research for Art Conservation) test tempera paint samples were prepared and some were exposed to accelerated ageing (light , heat, pollutants) and others were exposed in frames in major art galleries, a chapel housing a collection of artworks, and a historic castle where environmental conditions were recorded. The sites were selected on the basis of the wide range of environmental conditions. Analysis post exposure involved an interdisciplinary approach using mass spectrometry , thermal and spectroscopic analysis. The data obtained from DMA will be presented here. Tempera paint based on whole egg was prepared according to traditional recipes and then spread onto Melinex substrate. A selection of pigments was used including smalt, Sienna, azurite, lead white, and Naples yellow. Strips of the differently pigmented materials were cut to about 15mms and mounted in a frame for site exposure. For DMA analysis samples were then cut from these strips. Measurements were made in bending mode at 1Hz from -100°C to 150°C. The best response came from smalt tempera samples and this can be explained in terms of good mechanical integrity of the coating which is determined by factors such as pigment reinforcement and adherence to the substrate [1]. In chemical terms, a stronger response indicates the formation of a polymer network. Cobalt ions interact with egg yolk lecithins to form network structures composed of cross-linked aggregates which will increase the mechanical integrity of the film. The high pigment volume concentration in the smalt tempera sample is another factor that affected its mechanical properties. All the pigmented tempera samples used in this study contained, on an average, approximately 90 wt.% pigment as determined by thermogravimetry (TGA). Specific indicators for change by DMA of the paint tempera films were identified as changes in the glass transition temperature (observed as tan d peaks) of the paint tempera samples. Analysis of ageing effects was conducted by measuring either a shift in peak position to higher temperatures or calculation of peak ratios, based on 2 peaks, or the ratio of intensities at selected temperature regions (e.g. -20°C) and peak maximum. Data will be presented for smalt, azurite and Naples yellow samples and will show that differences were observed between sites with varying environmental conditions.

[1] Odlyha et al., Dosimetry of paintings: determination of the degree of chemical change in museum exposed test paintings (smalt tempera) by thermal analysis Thermochimica Acta 365 (2000) 35-44

13 - Complexity In The Hygro-Mechanical Behaviour Of Wooden Panel Paintings: Undeniable Presence And Implications For Modelling And Conservation.

Marco Fioravanti[1]
[1]University of Florence

In recent years, much research has been devoted to systems that exhibit complex outcomes and characteristic behaviours. These include evolution that is highly sensitive to initial conditions, the presence of multiple independent interconnected components, and the ability to interact with the environment by exchanging matter and/or information. The evolution of such systems is typically non-linear, with multiple pathways by which the system can evolve in the domain of randomness.

Wooden panel paintings (WPPs) have many analogies with such systems: the layered structure is made up of different materials (interconnected components), the quantity and disposition of which has changed over time according to the pictorial school (initial conditions), and that establishes a continuous moisture exchange with the conservation environments (environmental interaction). Despite the reduced number of variables involved (wood anatomy, material stiffness and hygroscopicity), the hygromechanical behaviour of WPPs is that of a complex system with marked non-linear behaviours.

This contribution considers the implications of this epistemological assumption for the modelling and the definition of the conservation strategy, paying particular attention to the importance of 1) the knowledge of the constitutive material properties and the physical laws governing their behaviour, and 2) the knowledge of the boundary conditions describing the state of the system (each individual WPP) at a given time (i.e. the actual values of stiffness and moisture diffusion).

This is because the evolution of each WPP over time is subject to the effect of randomness, which, even for the same initial condition (same construction typology), may provide quite different behaviours after the effects of many centuries of material ageing, exposure to different conservation environments and remedial conservation treatments.

Randomness and modification of the initial boundary condition make the application of constitutive laws very challenging, at least to understand or predict the behaviour of a WPP in response to external stimuli (physical or mechanical).

14 - Advancing our understanding of the chemo-mechanical response of oil paint(ings): an integrated numerical-experimental study

Emanuela Bosco[1]
[1]Eindhoven University of Technology

Oil paintings age and degrade over time due to complex chemical and physical processes, affecting their appearance and longevity. This research aims to improve our understanding of the chemo-mechanical behavior of oil paintings through an integrated numerical-experimental approach. This presentation focuses on two main topics.

First, the formation and growth of metal soaps and their consequences on the mechanical response of oil paint are investigated through a coupled chemo-mechanical damage model [1]. The model is applied to analyze two case studies representative of typical metal soap-related degradation processes observed in oil paintings, revealing the influence of the growth of crystalline metal soap on the deformation of the paint surface and the consequent development of cracking and delamination patterns.

Second, to provide accurate input parameters for the model, a new experimental methodology is proposed to characterize the time-dependent mechanical and chemical properties of small-scale paint samples subjected to natural and artificial aging. This methodology combines micro-tensile testing [2] with real-time in-situ microscopic inspections based on digital image correlation. Chemical analyses of the paint samples finally provide insights into the relation between the chemical and mechanical responses.

References

1. Eumelen, G.J.A.M., Bosco, E., Suiker, A.S.J., Hermans, J.J. (2023). Chemo-mechanical model for degradation of oil paintings by amorphous and crystalline metal soaps. European Journal of Mechanics/A Solids. 97, 104827.
2. Maraghechi S., Bosco E., Suiker A.S.J. and Hoefnagels J.P.M. (2023). Experimental characterization of the mechanical response of natural fibres: an in-situ micro-profilometry approach. Cellulose. 30, 7, p. 4225-4245.

15 - The "Zero Stress Level", does it exist? Experimental analysis on historical wooden panel paintings and numerical non-linear simulations

Lorenzo Riparbelli[1], Łukasz Bratasz[2], Michał Łukomski[3], Marco Fioravanti[1]
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Standards practice for conserving Wooden Panel Paintings (WPPs) in museums, churches, and collections prescribe to maintain specific environmental parameters: a temperature of 20°C ± 2°C and a relative humidity of 50% ± 5%, as per AA category of ASHRAE standards. Although not officially mandated, these conditions are also often included in loan agreements between institutions. The rationale behind maintaining specific environmental parameters for WPPs is based on the hypothesis that there exists an optimal condition for the preservation of the art pieces where the paint layers of the WPPs experience minimal stress and deformation, ideally as low as possible. This study aims to explore the existence of such a condition through experimentation on historical paintings, quantifying and measuring this state, and understanding its dynamics through numerical simulations.

The study is structured around the following hypotheses, supported by literature:
1.Micro-cracking in Paint Layers: Paint layers experience micro-cracking.
2.Stiffness Influence: Paint layer stiffness significantly influences deformation dynamics under thermo-hygrometric variations.
3.Crack Dynamics and Stiffness: Crack dynamics affect stiffness, with different states when cracks are open or closed. Alternatively, a damage model shows reduced stiffness in the damaged state, restored upon crack closure.
4.Zero Stress Transition: The transition between compression and tension in paint layers is characterized by a zero-stress condition due to their thinness.
Based on these hypotheses, we propose that subjecting a painting to equal magnitude humidity changes—first increasing, then decreasing—will show observable differences in deformation behavior if the zero-stress condition for a painting falls within the humidity variation range; this will manifest as differences in measured deformation patterns between the humidity cycles.

Experimental evidence confirms this method, enabling non-linear numerical modelling and its calibration, leading to the following conclusions:
1.The phenomenon **exists and is measurable**.
2.It is possible to determine experimentally a narrow humidity range where the stress in the paint layer is nearly zero and no internal coactions between wood and paint layers are present (**zero stress level**).
3.A zero-stress state can be analytically defined **for numerical models**.
4.This state is resulted to be **case sensitive** (different for each WPP)
5.The **compression set** state (irreversible deformation) can be quantified by difference
6.This study opens to the discussion on the need to **calibrate the conservation humidity range** considering the specificity of each WPP.

16 - Towards Digital Twins for Panel Paintings: Finite Element Analysis of a Prototype at Climatic Loading

Michael Kaliske, Daniel Konopka[1]
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Preventive conservation of wooden cultural heritage objects in unstable environment needs reliable information about the individual object's structural behaviour for a future load case. It is a very challenging task to yield a reliable prediction, especially for wide climate corridors. This contribution presents our current developments towards a Digital Twin for valuable panel paintings and its potential as a reliable risk assessment and damage prevention tool for the individual object.

The information on the analysed object is generally very limited. An uncertain loading history meets unknown current properties of an aged material in a pre-damaged structure, not to mention the uncertain future. Different strategies to reduce or to consider the uncertainty in the structural analysis are known. Although using generalised knowledge is a good basic approach, structural analysis of the individual object is only possible with numerical simulation of an adequate model, e.g. by the Finite Element Method (FEM). However, reliable analysis of long-term processes considering uncertain history, pre-damage and climate remains challenging.

Detailed information of the real object is mandatory, e.g. by detailed material analyses or controlled experiments in a safe range to identify the real structural response at defined loading. Appropriate monitoring of the object in-situ can also help to characterise the structural behaviour, but may not be sufficient to reliably detect damage in advance.
Thus, a next step within preventive conservation is to use all this information to couple the real object with its digital representation within the framework of a Digital Twin. There, the numerical simulation of the behaviour under possible future load development is calibrated regularly by monitoring data. Digital Twinning, when coupled with uncertainty analysis, has the potential to analyse the current risk of future damage and to output certain decision recommendations to prevent a critical development.

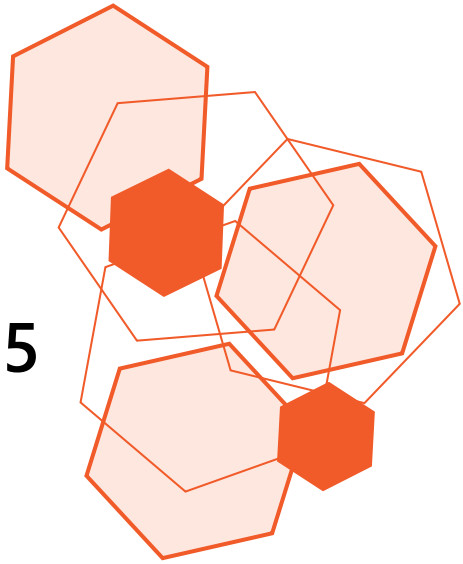
Within the developments towards a Digital Twin, the comprehensive transient structural behaviour of panel paintings at mechanical and climatic loads is analysed by the FEM. Hygro-mechanical material models for wood, bondlines and coatings are applied, describing the moisture transport, the short- and long-term behaviour, including ductile and brittle failure. Replicas of different panel paintings made of lime wood serve as real objects that are exposed to standard and extreme climates in validation experiments. The monitoring is performed by continuous, partially invasive climate and length sensor measurements as well as 3D photogrammetrical deformation measurements. The analyses are evaluated with respect to (irreversible) deformations, moisture, stresses and damage potential in all components.

17 - What do we know about object vulnerability to environmental variations

Łukasz Bratasz[1]
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The debate about the more responsible use of energy in museums should be structured with three distinct questions: what do we want? ...know? …can? Recent scientific research addresses generally the second one and shows that objects are much less vulnerable to environmental variations than previously assumed. The presentation will review the risks related to climate control and demonstrate that it doesn't reduce overall risk to the collection and has a very low benefit-cost ratio. A list of gaps in knowledge impeding reduction of energy consumption will be discussed.

THURSDAY, NOVEMBER 15



TALKS

THEME: MONITORING / VALIDATION / SYNERGY

18 - NDE at its Extreme - Applications for Space Explorations

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The Aerospace Corporation is a Federally Funded Research and Development Center FFRDC supporting the US Air Force space program, now Space Force. A variety of challenges come to the labs in support of the different programs. At times, these challenges require solutions that can only be brought forth through a multidisciplinary team of innovative NDE scientists and engineers. Three examples will be provided in this presentation. In the first example, an eddy current technique is developed to detect dimpling in carbon fiber facesheet/honeycomb sandwich structure. The area of concern traversed a transitional section between two honeycomb thicknesses and covered with cork. The eddy current technique is calibrated to measure liftoff from the conductive fiber layer at the two thicknesses and extrapolated for the transitional region. Accuracy of the measurement is 0.005", largely due to the roughness of the composite surface. In the second example, an ultrasonic technique is developed for detecting kissing unbonds between the Orion heatshield blocks and composite substrate. The heatshield material is highly attenuating and inhomogenous making the ultrasonic technique nearly impossible. The technique requires the use of high damping low frequency transducers, coupling of water and alcohol, normalization of signals to eliminate inhomogeneity of the heatshield material, phase analysis, SAFT and other signal processing tools. All are built into a custom software, which displays the c-scan image in real-time during a hand scan. In the third example, an ultrasonic signal processing technique is used to assess the degradation of rubber. The rubber is between a solid rocket motor structure and launch vehicle. Some extent of cavitation and porosity are expected in the rubber. The attenuation they cause on the ultrasonic signal varies with pressure on the rubber layer. To evaluate degradation or increase in cavitation, a composite scan from multiple scans is made to reflect the worst attenuation for each pixel. Statistical evaluation is then made to represent the attenuation levels of good and bad areas. A new parameter is then generated to represent the wholeness of the scanned area and an empirical mathematical relationship established between this parameter, aging and strength of the rubber layer.

19 - (Re-) Opening doors to nanomechanical characterization of complex materials through atomic force microscopy

Adam Stieg[1]
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The structural, material, and mechanical complexity of cultural heritage materials necessitates access to non-invasive characterization methodologies. Atomic force microscopy (AFM) oMers unparalleled capabilities for the nanomechanical characterization of diverse materials types under a wide range of experimental conditions. Despite its capacity for non-destructive, quantitative measurements, the technique's use has been limited due to instrumentation designs rather than the core methodology.

Historically, AFM instrumentation was developed based on key performance metrics that maximize topographic imaging resolution on relatively smoot, flat samples. Piezoelectric scanner designs have generally focused on sub-atomic positional control of the AFM probe at the expense of available range in all dimensions (X/Y/Z). This approach imposes restrictions on the types, size and roughness of samples once could hope to measure. Recent developments in positioning and scanning over large areas alongside correlation with optical techniques via direct image tiling and overlay provides easy navigation and automated structural mapping of large, rough samples over centimeter areas.

Extensions of the AFM toward mechanical profiling through force spectroscopy (force distance curves) and nanoindentation enable quantitative measure of elasticity, stiMness, and adhesion at single locations across a sample surface. While collection of multiple, spatially defined force curves through force-volume imaging provided the first nanomechanical maps possible, its slow speed rendered detailed mapping impractical. More recently, dynamic modes of AFM-based microrheology provide high-resolution mechanical maps of local viscoelasticity, energy dissipation, and time-dependent deformation at every point in the imaging area. These emerging techniques also enable acquisition of multidimensional information sets to enable machine learning approaches to data fusion and analysis.

Building from our first experience working with cultural heritage materials in 2011 and multi-year collaboration with the team at the Getty Conservation Institute, we see the development of new methods, instrumentation, and data tools as way to re-open doors to AFM-based nanomechanical characterization.

20 - Acoustic Emission Monitoring in cultural heritage applications

Horst Trattnig[1]
[1]Vallen Systeme GmbH, Wolfratshausen, Germany

A reliable prediction of early-stage damage, the progression of defects or to confirm certain predictions at an early stage, is a key discipline in cultural heritage research. The Acoustic Emission (AE) method is one of the tools that fulfills this requirement, because it's a highly sensitive technique. It is already applied to many projects in the cultural heritage community in the US, Europe and Australia. Some worldwide applied applications are, the monitoring of crack development in wood at changing temperature and humidity in museums, the inspection of Termites in wood, or the inspection of insect infestation in roof trusses or wood frames of heritage automobiles. The following tow pictures are showing a monitoring project at the V&A museum in London and the inspection of an insect infestation at a Mary Statue at a church in Germany.

But every Acoustic Emission application has its own way! For established applications, you can probably take a shortcut, by consulting experts in this field. But finally, it is also an investment in terms of time and budget. AE Sensors, data acquisition systems and software are not comparable with standard measurement equipment and gaining experience is a journey of months and even years.

That's why the Vallen Systeme Team is dedicated to transferring knowledge to our customers. This process begins with the project kick-off, where we aim to understand the application, share our insights on its feasibility, and recommend a system configuration tailored to your specific challenges.

Universities and research groups play a crucial role at Vallen Systeme, as they are instrumental in shaping the future of society, technology, and our environment. To support these efforts, we provide Letters of Intent (LoI), participate in funded projects, and attend conferences.

21 - Assessing climate damage prediction with Acoustic Emission for wooden furniture

David Thickett[1]
[1]English Heritage Trust

A number of methodologies are now available to predict risk of damage to wood from climate data. The results from three; IPI dimensional change index, climate toolbox and Herie restrained wood module have been compared to acoustic emission monitoring of 21 pieces of wooden furniture. The pieces were selected to be more than 5mm thick and of species contained in the Herie restrained wood module. Monitoring was undertaken for 14 months with Physical Acoustics PCII and PAC systems with WD sensors using anticorrelation and additionally signal location in a few instances. On several pieces of furniture longer transmission distances than reported previously were observed, the impact of shellac layers on surfaces was investigated. External amplifiers allowed placing the AE central unit near one of the few electricity sockets present in historic interiors and placing the sensors on objects up to 20m away (the distance was only constrained by the cable length which could have been significantly longer). This setup also allowed hiding the central unit, so as not to interfere with the public's perception of the historic interiors. Temperature and RH data was gathered with Rotronic hygroclip II probes on a radiotelemetry system or Rotronic HL20D loggers. Some of the hygroclip probes were on leads to allow placement near the acoustic emission sensors. Error propagation into the predictions was tested by modifying the RH values by 1 (the hygroclip error is 0.8%), 2 and 3 %. Significant differences in performance of the three methods tested was observed. In some instances, a 3% error, took the prediction over the reported damage (strain or risk) threshold.

22 - Mechanical analysis of restoration protocols using Digital Image Correlation: application to textile and paintings

Joséphine Delengaigne[1], Marie-Laure Gascon[2], Julien Colmars3, Sandie Le Conte[4]

[1]Textile Conservator graduated from Institut National du Patrimoine in 2024, 93300 Aubervilliers, France, [2]Painting Conservator graduated from Institut National du Patrimoine in 2024, 93300 Aubervilliers, France, [2]Senior Lecturer, Contact and Structural Mechanics Laboratory, INSA Lyon, CNRS, LaMCoS, UMR5259, 69621 Villeurbanne, France. , [3]Research Engineer, head of the research laboratory at the Institut National du Patrimoine, 93300 Aubervilliers, France.

Strip lining intervention on the Deploration of Christ, a 16th-century painting, or mesh consolidation on a cyclist's jersey has a common point: the modification of the mechanical state of the object after the conservation process. How to evaluate the consequence of these interventions on the mechanical equilibrium of the cultural heritage objects? Which restoration technique will modify as little as possible the mechanical behavior of the object? To answer these questions Digital Image Correlation (DIC) has been used to address conservation issues.

Joséphine Delengaigne was in charge - for her final dissertation at the Institut National du Patrimoine - of studying and restoring a cyclist's jersey worn during the 1935 Tour de France by cyclist Julien Moineau, which is kept at the Musée National du Sport in Nice. Made from wool jersey, the jersey's mechanical stability was a major problem. An infestation of keratophagous insects in 2020 had caused a large number of lacunas. In order to select the best restoration protocol, we carried out an analysis of the mechanical behavior of mesh consolidation techniques using DIC. Indeed, the consolidation of knitted fabrics has never been approached from a mechanical point of view. The comparison of strain maps led us to select the "best" restoration technique among four that were possible, based on a mechanical point of view.

Marie-Laure Gascon - also for her final dissertation - studied and restored a work depicting the Deploration of Christ, a 16th-century painting on canvas in the Palais des Beaux-Arts in Lille. It is an early copy of a work by Bartolomeo Suardi, known as Bramantino, held at the National Art Museum of Romania in Bucharest. As part of the restoration treatments, it was decided to remove the canvas from the stretcher frame. Re-attaching the work on the stretcher frame therefore required the use of strip-lining. Thus, different strip-lining textiles usually used for stretching were compared using DIC. The experimental setup consists of a canvas on which these different textiles were installed and stretched.

So, DIC has demonstrated its use for the conservation process providing answers relatively easy to understand.

23 - Evaluation of a tear mending by digital image correlation (3D-DIC) and analysis of the impact of its restoration on the flatness of the work

Marie-Noëlle Laurent-Miri[1], Nicolas Wilkie-Chancellier[2], Sandie Le Conte[3]
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When we restore a tear on an easel painting, the method is often based on empirical knowledge, and the question of the flatness of the original support, the mechanical properties of the painting, and stress distribution around the tear is rarely studied. In this perspective, our research aims to analyze the mechanical phenomena involved and the behavior over time of a tear depending on the restoration treatment carried out.

The study set up jointly by the Satie laboratory of the CY Cergy Paris University and the Institut National du Patrimoine laboratory - Restoration Department, aims to study different tear consolidation systems on an easel painting. In the past in France, glue-paste lining appeared to be the best solution for preserving the flatness of a tear, but in recent years there has been a fundamental change, with the emphasis on preserving the integrity of the work and increasing application of the principle of minimal intervention. This raises the question of rigidity as a solution to the problem of flatness, and how to reconcile stability and stress reduction with maintaining the flatness and tension of the painting.

The first step of this study involved designing the most suitable samples and the different consolidation systems representative of current practices. The second step was the development of the measurement technique. To measure the stress and strain around the restored tear, 3D digital image correlation (3D-DIC) was used. This contactless technique is particularly suited for measuring in-plane and out-of-plane displacements.

It will enable the measurement of deflection at the tear and the different consolidation systems to develop tools for understanding stress fields and the mechanical behavior of the tear and its restoration, and to establish predictive models of its behavior over time.

24 - Epidemiology of decay: environmental and mechanical study of historic tapestries on open display

Constantina Vlachou-Mogire[1]
[1]Historic Royal Palaces

Historic tapestry collections have been considered among the most significant forms of art from the 15th to 18th century in Europe. When on open display, tapestries are exposed to environmental fluctuations which cause cycles of moisture intake that can lead to damage. This paper explores the 'epidemiology' of decay within a collection of historic tapestries, focusing specifically on those on open display.

Historic Royal Palaces (HRP) is the custodian of Hampton Court Palace in London, UK, and its important tapestry collection, developed primarily by Cardinal Wolsey (1475-1530) and Henry VIII (1509-1547)[1]. Over the last fifteen years, HRP has studied the impact of environmental risks on tapestry collections through two collaborative doctorate projects and an in-house long term research programme [2]. The outputs of these projects inform suitable preventive and interventive conservation strategies for these nationally significant large-scale textiles.

Methods deployed included a network of sensors measuring real-time changes in temperature and relative humidity while laser or IBM tri-axial sensors measured the displacement/strain tapestries experience during environmental fluctuations. To study this further an 18th century tapestry was subjected to controlled environmental cycles simulating typical fluctuations experienced in display conditions. Both IBM sensors and digital image correlation (DIC) were deployed during this experimental work to measure the tapestry's strain response to these environmental changes.

Characterization of the mechanical properties of fibres and woven structures in historic tapestry fragments achieved using tensile testing and DIC. These methods enabled the measurement of tensile strength and strain distribution, providing a comprehensive understanding of the tapestries' mechanical performance. Furthermore, dedicated experimental work explored the impact of the tapestries' own weight on the mechanical damage.

FEM computational modelling has also been deployed to simulate physical and mechanical properties for predictive modelling applications including the assessment of tapestry conservation interventions.

Future work will focus on the development of non invasive analytical methods e.g. hyperspectral imaging to map the condition of tapestries and correlate this information to strain exposure.

References

[1] These tapestries are part of the Royal Collection www.rct.uk
[2] Collaborative doctoral research projects: "Investigation into Structural Analysis and Associated Conservation Support Strategy in the Display of Large Historic Tapestries and Textiles" AHRC/EPSRC Science and Heritage collaborative doctoral award University of Manchester and HRP Palaces (2008 - 2012), "Monitoring Strain in Historic Tapestries" EPSRC SEAHA doctorate award, UCL Engineering, HRP and IBM Research (2016-2021). The Tudor Tapestries Environmental Protection project is a long-term research project funded by HRP.

25 - Vibration and conservation: a new system to reduce in situ the low frequency vibrations

Le Conte sandie[1], Forma Loic[2, 3], Boutin Henri[2], Jossic Marguerite[4], Wilkie-Chancellier Nicolas[3]
[1]Institut National du Patrimoine, France, [2]Ircam - Sorbonne Université, France, [3]CYU, France, [4]Philharmonie de Paris

Vibrations of cultural objects due to different sources (transport, exhibitions, construction works) have recently been raising more and more interest from the heritage community. Consequently, the development of anti-vibration protection systems has become a major issue. However, most of the proposed solutions suffer from a lack of adaptability, practicality and effectiveness. To overcome these limits, a working group has been created, composed of academic researchers and museum professionals to identify the needs expressed by museum staff and define the specifications for a solution compatible with the heritage environment.. This communication investigates the possibility to design a vibration control system based on the active control technique, whose purpose is to reduce the disturbance vibration by creating an opposite vibration. This approach, which allows to control vibrations without contact to the object, is particularly suitable for heritage objects protected by cultural ethics rules. To test its feasibility, an experimental demonstration bench has been developed, including a reproduction of a museum shelf and an active control device, composed of sensors and an electro-dynamic actuator. The shelf is set in vibration by realistic source signals, the frequency bandwidth and the amplitude of which have been previously identified during a previous measurement campaign, in different museums and different contexts (transport, visitors' walk, fashion parade, or musical events in the museum). These measurements have been done with a light equipment potentially used by the museum professional themselves.

The shelf vibration is controlled using the Filtered X Least Mean Square algorithm, proven solution in feedforward active control.

Results point out that the control device is able to reduce the amplitude of harmonic, and broadband, primary sources. Furthermore, the system is robust to both amplitude and frequency content changes.

The next step, after this proof of concept will be to develop an industrial beta version.

26 - AGATO: An Online Decision Support Tool to Assist Museum Professionals with Preventive Conservation of Historic Mixed-Media Objects

Marjolijn Debulpaep[1], Elke Otten[1]
[1]Royal Institute for Cultural Heritage (KIK-IRPA)

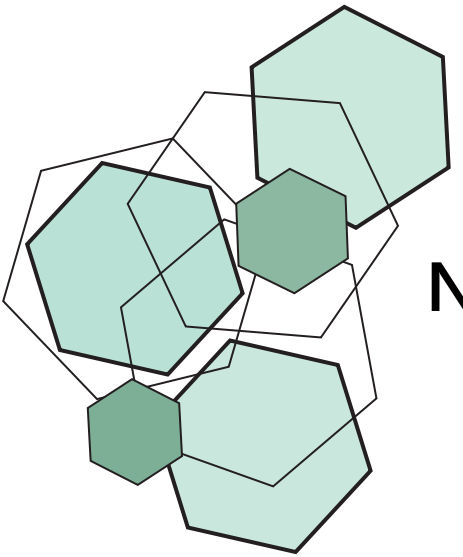
At the end of 2022, AGATO was launched as a conclusion of the ARTGARDEN research project focused on historical mixed-media objects, such as the Enclosed Gardens of Mechelen. https://agato.kikirpa.be/home

This online tool enables to analyze an art object and its interaction with its immediate preservation environment. Indeed, the state of conservation of the object materials as well as climate and other factors play a role in the possible future degradation of an artwork. The tool indicates the risks evolving from the current display or storage conditions and the preventive measures which could be deployed to avoid future damage. The input process encourages users to consider the value of the different materials in the artwork and the various ways material degradation can lead to value loss. In AGATO an attempt has been made to perform risk analysis at the scale of an object or even of individual materials. To date, the tool incorporates insights from 300 bibliographic references on material degradation, also making them available to users.

AGATO is designed for museum professionals and cultural heritage caretakers responsible for preserving objects or collections and making preventive conservation decisions, such as managing museum environments, transporting art objects, while addressing risks from the ten agents of deterioration.

Although this abstract about an online decision support tool may seem slightly outside the symposium's primary objectives, AGATO was developed using extensive evidence-based research, particularly concerning historical materials and their mechanical properties. It intentionally serves as a channel to disseminate knowledge on preventive conservation linked to research on the physical damage of different materials, and can therefore be seen as an extension of this symposium’s topic.

The oral presentation will demonstrate the tool's functionality interactively and online. Additionally, we will elaborate on the challenges involved in developing such a tool. We aim to provide (and receive) valuable feedback for future release of research findings to a broad audience of heritage caretakers, which we encourage to be the ultimate goal of research efforts.



TUESDAY, NOVEMBER 12

POSTERS

P-1 - Developing a strategy for environmental management for a sensitive painting with soft paint in the National Museum of Norway's collection. A cross-disciplinary collaboration.

Ida Antonia Tank Bronken[1]
[1]The National Museum, Norway

The phenomenon of soft and dripping paint in 20th Century collections has been under investigation by the author for over a decade (Bronken 2022; 2023).[1] The known examples of soft and dripping paint can be found both in European and North American artist's oeuvre at irregular intervals. The mechanical properties of soft paint have been researched in two campaigns at the Getty Conservation Institute where a novel adaption of the testing protocol solved issues on how to indent into soft materials to identify their characteristics (Fujisawa et al. 2022; Bronken et al. unpublished).[2]

It was already known from an initial examination that the targeted paints in the investigated artworks were soft. The nano-indenter is enclosed in a climatic control chamber. This allowed for the investigation of how the paints' mechanical properties respond to changes in the relative humidity. Still, it was surprising to find that some of the samples were softer than anticipated when examined with the nano-indenter, particularly at the upper region of Relative Humidity (RH) range chosen for the museum.

From this investigation- a few things could be concluded:
- There is no point within the range of 40-60% RH where the soft paints would become solid.
- Paintings with soft and dripping paint react to fluctuations in RH in such a way that this needs to be integrated into a collection management strategy.

Therefore, the research needs to be disseminated and discussed with curators, art handlers and storage officers. This is planned for the summer and autumn of 2024. This presentation aims to document critically the process of the development of a specific strategy for one individual object - while making considerations about the work's function within a larger collection. By discussing the process and the various considerations brought to the table the aim is to reach a realistic and pragmatic strategy from a weighing of expenses, security, audience reactions, curatorial judgment and the condition of the work. How can the scientific information come across more optimally for other fields of expertise within the museum?

References

[1] French connections (uva.nl) and Our Titles > Soft Paint and the Care of Paintings (archetype.co.uk)
[2] Nanoindentation of softening modern oil paints - ScienceDirect

P-2 - A Study to Assess the Efficiency of some Gap Filling Materials for Ancient Ceramic Tiles

Al-Shaima Abdel-Rahman[1]
[1]School of Antiquities Restoration - Department of Restoration - Faculty of Archeology - Cairo University

This research studies some materials that fill the gaps in old ceramic tiles. In addition to evaluating them in terms of their efficiency even over long periods and in the event of exposure to various weather fluctuations, the complete loss of missing parts of ceramic tiles is one of the most important stages in the treatment and maintenance stages. Because it is a type of preservation of pottery and ceramic antiquities that have been collected or lost from damage and breakage. Complementary material must meet a set of basic conditions, including that it has a stable chemical composition, is composable, is susceptible to additives and colorings, is compatible with different environmental conditions, and has an appropriate density. The tiles were examined and analyzed using digital optical microscopy (USB), X-ray diffraction (XRD) analysis, and scanning electron microscope (SEM-EDX). It was necessary to choose complementary materials that were tried and studied to identify and measure their various physical and mechanical properties, such as (porosity - density - water absorption - pressure resistance - and shrinkage) before applying them to reach the best mixtures that can be manufactured and used in the process of completing ceramic tiles.

Choosing treatment hypotheses (completion modules) for ceramic tiles in the experimental aspect:

- Group (A2): (A1), - where two types of gypsum were chosen and the bond was standardized with Adibond 65 adhesive to compare the effect of the treated gypsum and the effect of Diofex + water + Adibond 65 adhesive + fiberglass.

- Group (- (B2 (B1):- where modern porcelain powder mortar was standardized with a different solvent (Paralloy B72 - Paralloid 44) to compare the effect of using Paralloid B72 and the effect of Paralloid B44 on changing the different properties of the mortar dissolved in 40% acetone + fiberglass.

Group (C2) ((C1): - The mortar (C1) was chosen, which has the same composition and proportions of materials as the mortar (C2), with the difference in the binding material, which is epoxy, such as Poxy 150+ hardener, to compare the use of allaldite 1306 and the effect of epoxy 150 on changing the values of different properties. For Montaigne (C2) (C1). + modern porcelain powder + fiberglass.

P-3 - Displaying historical tapestries on slanted supports, what advantages and disadvantages?

Mohamed DALLEL[1], Faustine Massera [1], Rana Ali[2]
[1]CRC-LRMH, [2]CY Cergy Paris University

The conservation of tapestries, delicate and valuable textile artworks, presents unique challenges due to their sensitivity to both hanging conditions and environmental factors. In recent decades, displaying tapestries on slanted supports has become more common, particularly in Europe and offers several benefits in terms of stabilising effect, reducing deformations and better distribution of stress. However, dust accumulation according to this configuration seems to be more significant than in usual vertical display, which is particularly problematic for conservation considerations.

This research project aims to explore the combined effects of slanted display on the structural integrity of tapestries and on the dust accumulation on the surface, as well as to develop effective conservation strategies to optimize these effects.

The study is structured around three main objectives:

1. **Mechanical effects of slanted displays:** extensive investigations were conducted to understand how inclined display affects the stress and the strain of tapestries over time. A modeling framework capable of predicting the mechanical behavior of tapestries was developed ; we studied a two-branch viscoelastic-plastic rheological model of generalized Maxwell type. We opted for orthotropic Hooke's laws, the Hill plasticity criterion, and associated plastic flow. Concerning the delayed response (viscoelasticity), creep tests conducted, using digital image correlation, showed good agreement with the power law of Norton-Hoff type. The mechanical model coupled with finite element resolution validated the experimentally obtained results and then simulated tapestries in various configurations. The mechanical gain was quantified as a function of the inclination angle and areas of interest could be highlighted.
2. **Dust accumulation and textile/fiber degradation:** mechanisms by which dust accumulates on tapestries were analyzed. The goal was to determine the kinetics of this accumulation causing the degradation of artefacts, in particular the amount of the dust deposited and the particle size distribution depending on different inclination angles ranging from 0° (horizontal) to 90° (vertical). Glass slides were subjected to dust exposure, and the accumulation was measured using optical microscopy using an original protocol especially developed for this purpose.
3. **Conservation strategies:** based on the findings from the first two parts, we will present recommendations for displaying tapestries to minimize the extent of stresses and deformations, without exposing the tapestries to significant accumulation of dust which should be avoided.

These results will provide practical recommendations for museums and cultural institutions, helping to extend the lifespan and preserve the aesthetics of historical tapestries.

P-4 - Dynamic Mechanical Analysis (DMA) and its role in assessment of state of preservation of collagen -containing cultural heritage objects

Marianne Odlyha[1], Charis Theodorakopoulos[2], Gary Foster[3], John Duncan [4], Angelica Bartoletti[5], Laurent Bozec[6]

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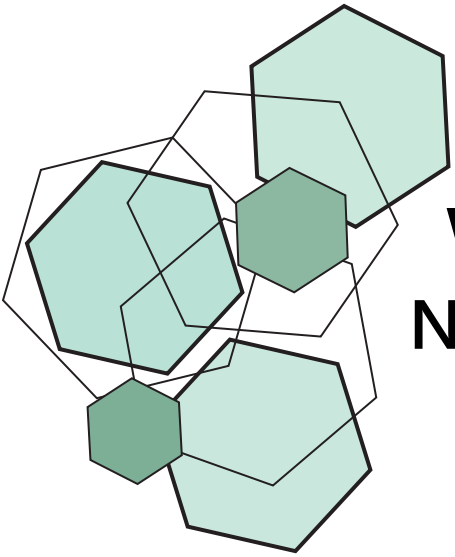
Our work has focused on using DMA to measure response of collagen containing materials (parchment and leather) to moisture. The aim has been to establish guidelines in terms of environmental conditions (RH and T) for their safe preservation. Parchment (accelerated aged and historical from several European archives) was first studied by DMA in the EU project MAP (Microanalysis of Parchment) and IDAP project (Improved Damage Assessment of Parchment) . This led to development of damage assessment categories. Measurements were made either using a temperature ramp (-100°C to 250°C) or by exposure to programmed increase in RH (20-80%) at 1%RH/min, and currently complemented with neutron radiography. From DMA-RH the rate of displacement was found to have some correlation with extent of intact D-banding in AFM (Atomic Force Microscopy) images of collagen in these parchment samples. The lower the displacement rate the more damaged the sample and the lower level of intact D-banding. DMA-RH was then used to evaluate effect of novel nano-based materials used in their conservation treatment (Nanoforart project). Results for treated samples showed minimum change in displacement rate and minimum change in modulus of treated samples after aging, in comparison to the untreated sample, where a significant increase in modulus was observed. DMA-RH was also used to test effects of their exposure to volatile organic acids (MEMORI project) and data contributed to the English Heritage decision support model. From thermal DMA data, one set of criteria used to assess damage was based on the behaviour of the low temperature relaxation peak. This peak, which has been observed in collagen and other hydrated proteins, has been widely studied , particularly by dielectric techniques. It is generally accepted that the process is related to water in the hydration shell of the protein and current literature has highlighted that changes in this peak are associated with extent of hydration processes. There are differences in moisture sorption between historical parchment and modern parchment shown by our DMA data due to differences in extent of collagen denaturation. The structural change will affect its ability to interact with water molecules and how they are accommodated in the structure, and will be affected by proportion of collagen and gelatine . This lies at the basis of our damage assessment and is supported by AFM which showed alterations in collagen D-banding as well as localised areas of gelatinization and loss of ordered structure.

P-5 - New Insights into the Mechanical Properties of Metal Soaps Using Nanoindentation

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Metal soaps present several problems in the care and conservation of historic and modern painted surfaces. The formation and growth of metal soaps have been associated with several different forms of deterioration, including cracking, delamination, and the formation of holes on the surfaces of paintings. Scientific studies on metal soaps have largely focused on their chemical characterization and the mechanisms driving their formation while research on the mechanical properties of metal soaps, however, has been rather limited. Owing to the small size of metal soap particles within oil paintings, traditional methods of mechanical measurements such as tensile testing and dynamic mechanical analysis cannot be used to study these materials. A relatively novel method of mechanical analysis in the study of cultural heritage materials is nanoindentation. This presentation concerns the mechanical analysis of metal soap samples prepared in 2013 by Alysia Sawicka from the Courtauld Institute of Art. These artificially induced soaps served as a model for metal soaps in oil paintings, with tests designed to learn about the viscoelastic behaviour of materials and properties such as storage modulus (stiffness), tan δ (viscous response) and hardness. Through nanoindentation, areas of different hardnesses were discovered within a single soap mass. These areas largely align with those of differential lead concentrations as seen with SEM/EDS, as well as areas of varying colour from optical microscopy of the sample. The preliminary results of the investigation suggest that there is a relation between storage modulus and the elemental composition and appearance of the metal soap. On the basis of visual, chemical, and mechanical analyses, we hypothesize that two phases of the metal soap were present in the sample: a softer amorphous phase and a harder crystalline phase. The presented findings will constitute the first published results of the mechanical properties of metal soaps, and we expect these results to inform current understanding of the mechanism through which metal soaps can contribute to the physical degradation of oil paintings.



WEDNESDAY, NOVEMBER 13

POSTERS

P-6 - Condition Assessment Scanner (CAS): a fast, high precision scanner to assess and monitor the topography of paintings

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The assessment and monitoring of paintings' appearance and condition is paramount to their care and preservation, whether in advance or return of a loan, in preparation for an exhibition or conservation treatment or in the scope of a collection survey. This assessment is generally carried out by conservators and is a painstaking activity that would benefit from a more quantitative and automated approach.

Previous studies showed that surface color and topography can be captured, documented, and possibly monitored using 2D and 3D imaging systems such as high-resolution photography, reflectance imaging spectroscopy, photogrammetry, laser scanning or 3D digital microscopy. Distinguishing aspects between these techniques are accuracy, resolution, scalability but also speed and mechanization, two essential and challenging constraints for routine inspection of objects in a museum. To address this challenge, the Van Gogh Museum has partnered with ASML, an innovation leader in the semiconductor industry, to develop a fast, high precision scanner to assess and monitor the topography and color of paintings.

This presentation will focus on the design of the condition assessment scanner (CAS) and on the selection, implementation, and performance of the topography probe. The Keyence XT-024 — a probe that uses pattern projection lighting — was selected for fast and high-accuracy height measurement complemented with 2D color inspection. Post-processing algorithms were developed to register and stitch images, and AI-based algorithms are being developed and trained to detect, classify, and monitor cracks, in particular those with lifting edges and thus at higher risk of delamination. These methods are being validated using naturally and artificially aged test paintings and will be refined further with scans of paintings by Van Gogh and his contemporaries. In addition, a visualization platform has been developed to handle and visualize the gigapixel 2D and 3D images and to allow conservators to interactively explore and further enrich their condition assessments with annotations. Data management strategies are being devised to store and easily retrieve the data and relevant information.

The CAS is expected to provide a more accurate and substantiated assessment of physical changes in paintings caused by transportation and environmental conditions and ultimately guide preventive measures to minimize further change. We also anticipate that the data produced will contribute to a better understanding of the mechanical properties of the paintings materials and help validate or further develop existing models and predictions based on mock-ups.

P-7 - The degradation of Vincent van Gogh's Prussian blue oil paints investigated through the mechanical properties of paint reconstructions

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Several degradation phenomena have been observed in very dark blue, almost black paint strokes in Vincent van Gogh's oil paintings. The phenomena are mostly of a mechanical nature, including different types of cracking, delamination and paint loss and appear to be specific to the dark blue strokes. The paint has also been found to be solvent sensitive, its blue colour bleeding from cracks upon contact with solvent. Chemical analysis of several samples taken from these areas has been used to confirm that the paint is an almost pure Prussian blue oil paint, mixed with very little or no lead white or zinc white.

The cause behind the formation of these phenomena and why they appear to be specific to this dark blue paint is not yet understood and requires further investigation of the mechanical and chemical properties of Prussian blue oil paints. To be able to study changes in the properties of this paint over time, Prussian blue oil paint reconstructions were prepared and artificially aged. This also allows for the exploration and development of suitable mechanical testing methods for small paint samples, as would be taken from a historical painting.

In order to investigate and optimise a nanoindentation methodology applied to artificially aged Prussian blue paints, paint outs were prepared consisting of Prussian blue and linseed oil. After becoming dry to the touch, they were artificially aged at 60 °C and 80% relative humidity for 0, 2 or 4 weeks. A Bruker Nanoindenter (TI 980) was used to perform nanoindentation and nanowear measurements on the top of both polished and unpolished samples cut from these paint outs. Measurements were also performed on a naturally aged Prussian blue oil paint sample from Winsor & Newton, painted out in 1964. This enables comparison of the nanomechanical response of artificially aged reconstructions and historical paint samples.

An increase in stiffness and hardness upon ageing of the Prussian blue reconstructions was found, as well as a loss of elastic recovery, indicating a higher chance of fracture for the aged paint films. Furthermore, the nanowear measurements on polished and unpolished samples of the same paint outs allowed for visualisation of a difference in material removal (wear rates) between the top layer and bulk of the paint samples .

P-8 - EVALUATION OF STARCH AND CELLULOSE BASED CONSOLIDATION MATERIALS ON THE MECHANICAL PROPERTIES OF PAPYRUS

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In this study, polysaccharides, namely, potato starch, ethyl hydroxyethyl cellulose and cellulose nanocrystals (CNC), were used as consolidation materials for papyrus. The starch solution was applied on papyrus strips by two different methods: by brush and by an ultrasonic humidifier, the latter being a new approach for the application of consolidation materials. The consolidated papyrus was subjected to a thermal ageing study and several measurements were conducted to evaluate the efficiency of the selected consolidation materials and of the two different application methods of starch. The mechanical properties of the consolidated papyrus strips were evaluated by measuring the tensile strength and elongation. FT-IR spectroscopy and scanning electron microscopy of the papyrus strips were performed before and after thermal ageing. The study showed that CNC and ethyl hydroxyethyl cellulose improved the mechanical properties of the tested strips. Applying potato starch using the ultrasonic humidifier improved the mechanical properties of the consolidated strips more significantly than its application by brush.

P-9 - Morphological and structural description of historical textile samples and canvas painting supports

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Quantified data on the structure and morphology of canvas supports are uncommon and rare compared to the information available in textile research. The lack of data complicates predictive studies and limits the understanding of their structures that would be useful for conservation science and practice. This is due to the difficulty of sampling historical artifacts, but also to measurement techniques requiring large amounts of uncontaminated material. Twist and crimp are of paramount importance to the textile industry in understanding the properties and performance of a textile. Because they describe how the fibers were twisted and organized to form the textile, standard measurement methods are based on mechanically reversing the deformations back to the initial unorganized state. This is not possible for historical yarns, which are often fragile or impregnated with foreign materials.

Novel methods were used to measure twist, crimp, and yarn width on 22 historical and 4 modern textiles, along with thickness, weight, pH, and thread count. The study provided recurring features that allow identifying warp and weft directions with good approximation when a selvedge is not available. The warp yarns have a higher thread count than the weft yarns in 20 of the 26 specimens, and values are equal in the remaining 6. When measuring yarn width with a statistical approach, warp yarns are wider in 80% of the cases. The amount of twist in a yarn is directly correlated with its width, and the wider yarns always have a lower number of twists per meter, thus implying a higher twist in the weft yarns. Crimp is instead correlated with the manufacturing of the textile, and the 92% prevalence of the crimp value in the warp direction seems to be due to the fact that the weft yarn inserted between the warps causes them to bend over during the shedding process, acquiring a crimped shape that becomes permanent because of the friction. The difference in crimp is so wide that, on the base of the acquired information, naked eye observation of crimp is often enough to discern warp from weft. All other features require the more detailed observation made possible by the use of the described novel methods.

Correlations apply to both hand-woven and industrial textiles, and were established in a heterogeneous sample set. The information collected so far may lead to more general statements if confirmed by the ongoing work on a wider group of samples.

P-10 - Environmental conditions monitoring using wireless sensors for the conservation of museum exhibits: The case of the Tsitsanis Museum in Trikala, Greece

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Musical instrument artifacts in museums play a vital role in preserving and showcasing cultural heritage. These instruments are valuable for their craftsmanship and historical significance, as well as their ability to convey the musical traditions and artistic expressions of past cultures and civilizations. The conservation of these historic artifacts involves a multifaceted approach to ensure their longevity and maintain their historical and cultural significance.

Environmental control is a key aspect of this conservation process. Temperature and humidity imbalances caused by heating, air conditioning, ventilation systems, air exchange with the outdoors, building structures, and high visitor traffic pose significant risks. Maintaining stable temperature and humidity levels is crucial to prevent the deterioration of materials such as wood, metal, and leather. Museums must adopt innovative, non-invasive, and cost-effective technologies that enable continuous, real-time monitoring of environmental parameters to minimize negative impacts and ensure effective damage control of musical instruments.

Traditional environmental monitoring in museums involves manual measurement and recording by trained personnel, which is time-consuming, labor-intensive, and prone to errors. Wireless Sensor and Actuator Networks (WSANs) offer an innovative solution for museum environmental monitoring and control. These small, portable devices can be discreetly placed in exhibition spaces, including hard-to-reach areas, to provide real-time data on environmental conditions. The primary benefit of WSANs is their ability to deliver continuous, real-time data, allowing museum professionals to identify trends and make informed decisions about exhibit placement and environmental control. Integrating WSANs into the Internet of Things (IoT) enables prompt automated responses to sudden changes, such as adjusting HVAC systems or dehumidifiers in response to temperature or humidity changes, preventing potential damage to exhibits. Long-term data collection helps identify patterns, informing strategic decisions to protect exhibits from persistent environmental threats. Incorporating a mobile application into the process ensures data is available to smartphones, allowing monitoring by interested parties anytime, anywhere.

However, implementing wireless sensor systems poses challenges, including high initial and maintenance costs, a learning curve for staff unfamiliar with the technology, and potential data overload. Effective data management strategies are essential to ensure the information collected is useful and actionable.

In conclusion, environmental conditions monitoring using WSANs integrated into the IoT is a promising solution for the conservation of musical instruments in museums. By investing in this technology, museums can ensure their collections are preserved for future generations and contribute to a more sustainable future by transforming traditional museums into smart ones