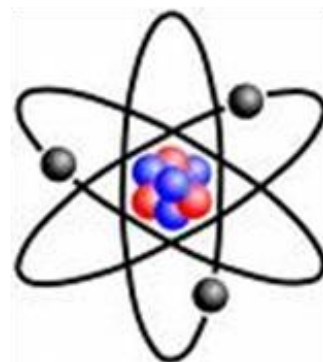


ISSN: 2167-9851

RATS



RESEARCH AND TECHNICAL STUDIES

Research and Technical Studies

Specialty Group Postprints

From the 50th Annual AIC Meeting

May 13-18, 2022

Volume 10

2022



american
institute for
conservation

**Preserving Cultural
Heritage**

American Institute for Conservation

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Research and Technical Studies Specialty Group Postprints

Abstracts, Extended Abstracts, and PowerPoint™ presentations from the 49th Annual Meetings of the American Institute for Conservation

RATS 2022 Annual Meeting Program Committee

Jane Klinger (Program Chair), Katherine Schilling and Federica Pozzi

Compiler

Molly McGath

Volume 10

2022



american
institute for
conservation

**Preserving Cultural
Heritage**

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American Institute for Conservation

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www.culturalheritage.org

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Research and Technical Studies Specialty Group Presentations:

Graphs, Jargon, and Science: The Creation of the Research and Technical Studies Specialty Group

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Original Abstract

Sitting around a table at the Getty Conservation Institute in late 1987, Eric Hansen, Chandra Reedy, and Mary Striegel were lamenting the less-than-optimal integration of conservation science in the day-to-day conservation activities that took place in studios around the country. What were the root causes for this disconnect? Was science not important to treatment or were other factors at play? From these ruminations arose the seed of an idea. What about a specialty group with the American Institute for Conservation that worked to find the shared pool of knowledge that would advance the role of science in conservation? Thus, the idea of the Research and Technical Studies Specialty Group was born.

This presentation will focus on the early beginnings of the specialty group and discuss everything from its tongue in cheek RATS logo to the serious mission of forging common ground and of increasing communications between conservators and conservation scientists. Why were there no RATS sessions in the early years? What was the RATS paper award? When did they host their first specialty group session? How did the group change over the years? Has the RATS group accomplished its mission? What are the new directions needed to lead science and technology in the field of art conservation? We look forward to sharing the stories and history of the group.

Annotated Presentation



This paper gives an overview of the birth of the Research and Technical Studies specialty group, fondly known as RATS. We talk about why the group was formed, the process that we went through to get the group started, and the original goals of RATS. We end with a discussion about what directions RATS might want to go towards in the future, as some of those original goals may have changed over time, and the AIC and the field of conservation science has also changed over time. We invite discussion about possible future directions and activities for RATS so that it can continue to have a useful impact on conservation, conservation science, and technical studies.

The Discussion



- Eric Hansen
- Chandra Reedy
- Mary Striegel



While sitting around a table at the Getty Conservation Institute in late 1987, Eric Hansen, Chandra Reedy, and Mary Striegel were lamenting what appeared to be less-than-optimal integration of conservation science into the day-to-day conservation activities that took place in studios around the country. This conversation later expanded to include conservators Phoebe Dent Weil, Paula Volent, and others. Discussions focused on trying to identify the root causes for this seeming-disconnect. Was science not central to most treatment decisions, or were other factors at play?

The Problem

- Lack of communication between conservators and scientists at AIC
- The best treatments required multidisciplinary approach
- How do we integrate conservation science into the day-to-day conservation activities?

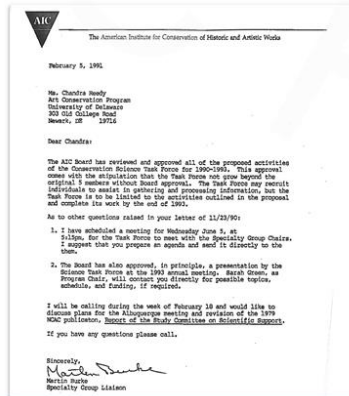
● Phoebe Dent Weil



One problem appeared to be miscommunication or lack of communication between conservators and scientists. These discussions were related to similar ones taking place at this time in the United Kingdom; in 1988 a meeting was held in the UK to brainstorm future directions in conservation science, and a report had been published that expressed some of the same concerns being raised here in the United States. An idea began to take shape: What if there were a specialty group within the American Institute for Conservation that was dedicated to increasing and improving these communications, at the annual meeting and beyond? Could such a group find a shared pool of knowledge that would advance the role of science across all conservation specialties? Thus, the idea of the Research and Technical Studies specialty group was born.

The AIC Task Force on Conservation Science, 1989-1993

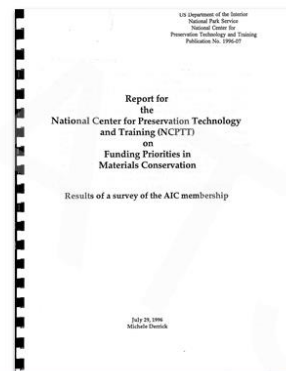
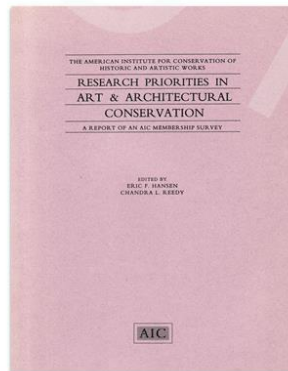
- Request to AIC Board to form a specialty group
- Approval of a Task Force to study the issue



However, the initial proposal to the AIC Board in 1988 for establishing a new specialty group was denied. Instead, the Board suggested more research was needed to determine if a specialty group focused around conservation science would be useful, and they felt that a Task Force was the best vehicle to carry out this research. As a result, in 1989, Hansen, Striegel, Reedy, and Dent Weil were appointed by the Board to a Conservation Science Task Force, initially for a one-year period. The Task Force charges were to investigate methods to promote interaction between conservation scientists and conservators, study the need for a new conservation science specialty group, and research potential activities of such a group. An underlying goal was to find ways of improving collaboration between conservators and conservation scientists in the planning, performance, and analysis of technical studies or research. Initial information-gathering activities included informal polling of AIC members (through the specialty group chairs) and distribution of a formal questionnaire to the entire membership through the AIC newsletter. The Task Force presented a report on their results at the 1990 AIC Annual Meeting. This session was very well attended, with a packed room and quite lively discussion. This initial information-gathering indicated that there was support for a new specialty group, but what the exact function and scope of that group should be was still not clear. The AIC Board was therefore asked to continue the Task Force, expanding it to include additional conservators and scientists.

Initial information-gathering

- Formal questionnaire
- Research Priorities in Art & Architectural Conservation
- Prototype Research Resource Directory



The Board agreed to extend the Task Force on Conservation Science for the period of 1990-1993. However, they stipulated that it could not grow beyond five members, although it was allowed to recruit others to assist in gathering and processing information. It was charged with continuing to investigate methods of promoting interactions between conservation scientists and conservators. The goals were to find ways to upgrade research in the field, both in the use of science by conservators and in enhanced conservation-relevance in the work performed by scientists. The Task Force was limited to the activities approved by the Board, which included continued informal polling of conservators and conservation scientists and the addition of formal questionnaires distributed in collaboration with all specialty groups. Some of the products included a survey of the entire AIC membership (published by the AIC in 1994 as *Research Priorities in Art & Architectural Conservation*, edited by Eric F. Hansen and Chandra L. Reedy), and creation of a *Conservation Research Resource Directory* by Mary Striegel.

End of the Task Force and beginning of the Research and Technical Studies specialty group

● James Stroud



● George Wheeler



● Julie Reilly



When the term of the Task Force on Conservation Science ended, the AIC Board approved establishment of a new specialty group, Research and Technical Studies (RATS) as of the 1993 Annual Meeting in Denver. Since the purpose of RATS was to show that conservation science was integrated with, and relevant to, conservation practice, leadership was originally shared by a Scientific Co-Chair and a Conservator Co-Chair. The formation of RATS was not without community dissent; in particular, some conservation scientists felt that science should be integrated into all specialties and that the formation of RATS might result in increased separation. Because of this concern RATS programming at AIC annual meetings was initially quite limited. The new RATS specialty group was not intended to compete with or draw away from other specialty group activities; instead, RATS was to work with other specialty groups to create projects, training, programs, and events.

Evolution of the RATS specialty group

- Change in bylaws and structure to be uniform with other Specialty Groups
- First RATS logo and pin, designed by Tom Sain



In 1996-1997 the AIC Board moved to standardize the structure, officers, and bylaws of each specialty group. Ultimately, the structure of the RATS leadership became uniform with other groups, so there was a single Chair, a Program Chair, a Secretary Treasurer, and a Chair Emeritus. However, RATS continued to alternate between a scientist and a conservator in leadership positions. During this early period the first RATS log was designed and used for RATS pins that were distributed to all members.

RATS Receptions



RATS programming also changed over time. In the first few years after its inception the AIC annual meeting participation focused primarily on an evening business meeting and reception. These early ones were known to be lavish with plentiful food and beverages, which helped attendance and camaraderie. The purpose was to facilitate conversations where conservators and conservation scientists could talk to each other and share ideas about their work. How could science influence conservation? In which ways could research be made more relevant to conservation practice?

RATS Sponsored Papers

Paintings

A Paintings Research and Technical Studies Joint Program on Saturday, 8:30 am-12:00 noon. This half day session features presentations by invited speakers on the use of analytical techniques for examination of paintings. Emphasis will be on practical applications within painting conservation.

The following papers will be sponsored:

Examination and Analysis of Paint and Varnish Using Optical, Infrared, and Electron Microscopy by James Martin.

Analysis of Organic Materials in Works of Art Using Instrumental Chromatographic Techniques by Christopher Maines.

Thin-layer Chromatography: Techniques for the Analysis of Varnishes, Resins, and Binders by Mary F. Striegel.

X-ray Diffraction of Pigments by Richard Newman.


A very wonderful Performance: The Paintings of John Singleton Copley in America by Lydia Vogts.

Textiles

Textile Pseudomorphs for a Seventeenth-century New England Native American Burial Site by Cathy J. Cobo and Margaret Ordóñez will be sponsored. The paper will be presented by Ms. Cobo on Saturday at 2:00 pm in the Textiles session.

Cathy Cobo will present the results of physical and chemical studies of pseudomorphs, mineralized textile formations, found at a seventeenth-century Narragansett Indian burial site in Rhode Island. The elemental analysis of the pseudomorphs were used to associate the mineralized textiles with metal artifacts responsible for their preservation. This study serves as a basis for further research on the mineralization of buried textiles. A review of literature, including previous studies on the subject, provides a background for more in-depth investigations, and questions raised are intended to serve as a starting point. This paper was recommended for RATS sponsorship by the Textiles group. The RATS group feels this paper shows the steps involved in developing sound technical research – execution of an in-depth literature review; development of an hypothesis; documentation of observations and acquisition of data; statement of results; evaluation of hypothesis; and formulation of new questions.

RATS Sponsored Papers



RATS sponsorship of technical papers within the AIC specialty groups is designed to encourage and promote the presentation of quality scientific studies relevant to the needs of each specialty. RATS Officers worked closely with each specialty program chair to develop the concept and select sponsored papers. We look forward to continued sponsorship in the future!

Members who are interested in becoming involved with the program should contact the RATS Program Chair, Mary F. Striegel.

Due to concerns that scientific papers presented at the annual meeting would cluster in a RATS session and do the opposite of integrating science and technology into conservation, in 1996 the RATS leadership decided to work with other specialty group chairs to select sponsored science papers in each of the other specialty group sessions, with the intent of promoting the presentation of quality technical papers that addressed the needs of each specialty. In 1996 sponsored papers were awarded in each specialty group. Though labor intensive, the RATS sponsored papers continued for three years.

Special General Session

1997 25th Annual AIC Meeting

“Concepts, Literature, and
Technology Transfer from
Industry to Conservation”

Some topics included:

- microbial production of cellulose
- electrophoresis in the identification of proteins
- and uses of literature, electronic publications, and the internet in the transfer of technology



Also in 1996, the first ‘joint’ session between RATS and another specialty group (Paintings) was held at the annual meeting. At the 1997 Annual Meeting, RATS organized an update session for the General Session, focusing on technology transfer from industry to conservation, which was very well attended.

Evolution of the RATS specialty group

- First full session
- Continued Joint Sessions
- New Initiatives




But by 2004, the RATS group presented its own full program, similar in program design to all of the other specialty groups, on the topic of lighting – one of interest to both conservation

scientists and conservators. The RATS group started as a venue to improve communication between scientists and conservators, and to interact with other specialty groups. At the beginning, RATS offered a reception and one or two papers at an evening event, which was followed by a business meeting. These receptions were jovial and sometimes irreverent gatherings. Still, some scientists saw the group as a place for scientific papers. They wanted a home within the AIC organization. By 2004, the RATS group was holding a full session with papers in a structure identical to all other specialty groups. While joint sessions with other specialty groups, and now AIC networks, continue to be organized for annual meetings, over the years more emphasis on conventional programming appeared than was originally intended. Some new initiatives that bring together scientists and conservators have been spearheaded by RATS, such as the Imaging Working Group (a RATS subgroup). But other initiatives that incorporate RATS members do not specifically involve the RATS specialty group, such as the Materials Selection and Specification Working Group, and Held in Trust. Does the RATS group still have an important role to play within the AIC, and what should that role be?

Have We Accomplished the Goal?

- Interviews with RATS leaders
 - Lynn Brostoff
 - Jason Church
 - Corie Rogge
 - Karen Trentelman
 - Federica Pozzi



Creating a place for scientists and conservators to interact and understand each other's perspectives is no small feat. Scientists want rigorous questioning and review of their work. They expect critical thinking about the work they do. Conservators want meaningful results that improve the quality of their work. Conservation scientists often prefer to vet their research at scientific conferences. There are currently ample opportunities for that at a wide variety of scientific meetings outside of the AIC. Thus, many conservation scientists are not members of AIC and the RATS group and don't prioritize attending the annual meeting. In early March, we conducted a series of informal interviews with some of the current and past RATS officers to gather their perspectives and suggestions for the future of RATS.



They agreed that RATS offers a valuable service to the AIC through joint sessions with other specialty groups. When RATS officers worked closely with the other groups to form a cohesive session on a specific topic, they could infuse science and technical studies into conservation in a natural and logical way. Joint sessions have also offered the ability to bring national and international experts to the AIC meetings that might not otherwise attend. For example, in 2012, RATS sponsored joint sessions with two specialty groups. The joint session between RATS and the Book and Paper specialty group focused on deacidification of books and included five papers from national and international experts including Anna Friedman, Conservator, National Archives and Records Administration (NARA), who presented her work on *Evaluating Deacidification after 20 Years of Natural Aging*. The joint session between RATS and the Objects specialty group covered more general topics including Some Unusual, Hidden, Surprising, or Forgotten Sources of (Possible) Sulfur Contamination in Museums and Historic Structures by Paul Benson (Nelson Atkins Museum) and A Comparative Study of Protective Coatings for Marble Sculpture in the Museum Setting by Laura Kubick (Smithsonian American Art Museum).

Promote International Speakers



Those past officers who were interviewed felt it was important to promote international speakers and well-recognized scientists who might not otherwise come to the AIC meeting. They lauded RATS for offering funding to sponsor speakers at a time when Kress funding for international speakers has diminished. Jason Church noted the standing room only crowd for a presentation on laser cleaning by John Asmus. Lynn Brostoff and Karen Trentelman both mentioned the success of bringing Dr. Baglioni and Dr. Bernardi from Europe to the 2012 RATS session. Baglioni spoke about the development of polymer coating removal nanosystems for finely controlled cleaning of cultural heritage. Bernardi presented new inorganic consolidants for the restoration market.

Build a sense of community



Past officers also suggested that the RATS group could continue to try to build a sense of community between conservation scientists and conservators through RATS receptions, perhaps done jointly with another specialty group, to allow scientists and conservators to learn informally about each other's work.

Is a separate session needed?



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Virtual Meeting
May 21 – September 2, 2020

Volume 8
2020



While some like the idea of a separate RATS session, others felt that RATS does not need to be like all the other specialty groups with a dedicated session but could achieve its goals through evening receptions and joint sessions.

Continuing technical education

- Workshops
- Webinars
- Combining the two
- Periodic online lectures
- Online lecture series



Other activities suggested for an evolving group include continuing education with an online webinar component coupled with hands-on experiences at the annual meeting, and a periodic online lecture series. Annual meeting workshops seem to be popular, and well

attended; augmenting them with pre-annual meeting online synchronous or asynchronous learning could make more efficient use of the in-person time available at a pre-session or post-session workshop. A series of related online lectures could allow topics to be delved into in-depth and would permit participation from members in far-flung locations. All of these educational experiences could be designed to fit into the new, upcoming continuing education requirements for maintaining professional levels of membership in the AIC. Perhaps making them free to RATS members would encourage participation in the group.



With the twentieth anniversary of RATS approaching, this would be an opportune time to reconsider how today's RATS could best serve the AIC membership to better integrate science and conservation practice for the future. We look forward to your hearing your ideas about how RATS can better serve you as an AIC member as we move into the future.

Current Trends in Scientific Instrumentation for Conservation Practices and Research: Lessons from an International Survey

Aïda Menouer¹, Léonie Hénaut²

¹PhD candidate, University of Turin, Tech4Culture PhD Programme

²Center for the Sociology of Organizations, CNRS and SciencesPo

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Annotated Presentation

Reflecting on the Past, Imagining the Future
Los Angeles 2022 #AICat50

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Tech Culture
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Current International Trends in Using Scientific Instrumentation for Conservation Practice and Research

Aïda MENOUEUR
Conservator-restorer in private practice, Algeria
PhD Candidate University of Turin, Italy.
Fellow of the Tech4Culture Programme
PhD Research topic: Selection of Accessible Technologies and Scientific Instrumentation for the Creation of a Conservation Center in Emerging Countries

CO-AUTHOR: Léonie HÉNAUT
Associate Professor at the French National Center for Scientific Research (CNRS)
Center for the Sociology of Organizations, SciencesPo Paris.
Honorary Fellow at the Department of Sociology University of Wisconsin-Madison

Specialty Session: Research & Technical Studies
Date: Sunday, May 15, 2022 / Time: 02:30 - 03:00

Good afternoon, I am Aïda Menouer. My presentation is based on an international survey on the use of scientific instrumentation for conservation that I have conducted as part of my PhD dissertation. Before I start, I would like to acknowledge the contribution of my co-author, Léonie Hénaut, who is a sociologist. She helped me with the analysis.

In this talk, I will first present the motivations behind such a survey; second, the methodology; third, the most important findings from the statistical analyses.

1.

Motivations

STARTING
POINT

DIFFERENT WORK CONTEXTS, UNBALANCED RESOURCES, VARIETY OF EQUIPMENT

Algerian painting **conservator** (Graduated in 2014) Trained in France and Canada
Experience in international **cooperation projects** for Cultural Heritage

Aïda MENOUEUR

Current International Trends in Using Scientific
Instrumentation for Conservation Practice and Research

Specialty Session: Research & Technical Studies

Léonie HÉNAUT

Let me first explain how I came to the realization that I wanted to study scientific instrumentation for conservation and its variations across the globe. Well, I am an Algerian painting conservator, I have been trained in France (I joined one of the elite Master programs in conservation at Sorbonne University) and in Canada (I was an intern at the Centre de Conservation du Québec). During my studies and early career, I have been exposed to very different work contexts, unbalanced resources, and a variety of equipment – from the smallest conservation private practice studio I had in Algeria, with scarce technological resources, to the most ambitious research centers, with international cooperation projects and high-tech equipment. Witnessing such variation was intriguing or even disturbing to me. Was there any minimum equipment required to do conservation practice and research? How do conservators and conservation researchers get their work done?

1.

Motivations

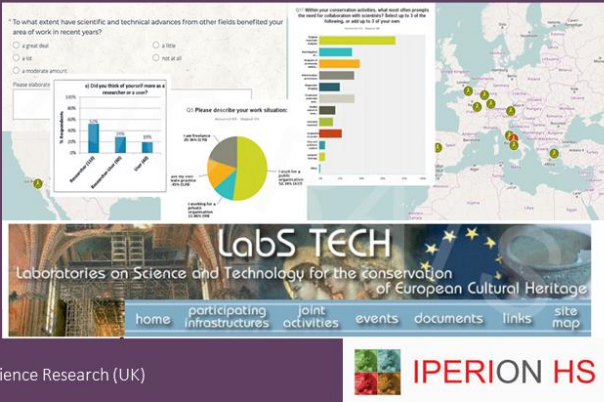
PRIOR > CURRENT
RESEARCH

PAST SURVEYS FOCUSED ON HERITAGE SCIENCE IMPACT

2012 : Mind the Gap
Rigour and Relevance in Heritage Science Research (UK)

2013 : ICCROM Forum on Conservation Science
Conservators' access and use of scientific information and service
Trends in conservation science research undertaken in key organizations

2001 : LabS-TECH (EU) Precursor of current IPERION HS consortium
Questionnaire about the availability of scientific facility in conservation institutions



Current International Trends in Using Scientific
Instrumentation for Conservation Practice and Research
Specialty Session: Research & Technical Studies

Past surveys mainly focused on studying the impact of scientific research on conservation practice. I refer here to two initiatives: in 2012, the “Mind the Gap” project aimed at assessing the rigor and relevance of heritage science collaborative research in the UK; in 2013, an ICCROM forum has been devoted to the global issues encountered in conservation science. To our knowledge, the only survey which aimed at describing and assessing scientific instrumentation in conservation practice has been conducted in 2001, in the context of the European Collaborative Project Labs-Tech that was the precursor of the current project IPERION HS. This 2001 survey targeted 114 institutions located in 26 countries, most of them in the Global North.

27

1.

Motivations

PRIOR > CURRENT RESEARCH

CURRENT SURVEY FOCUS

1- INCLUDE EMERGING COUNTRIES
To get a better picture of the global distribution of scientific instrumentation

2- INVESTIGATE SPECIFIC DYNAMICS OF COLLABORATION
To explore variations in the degree and types of availability

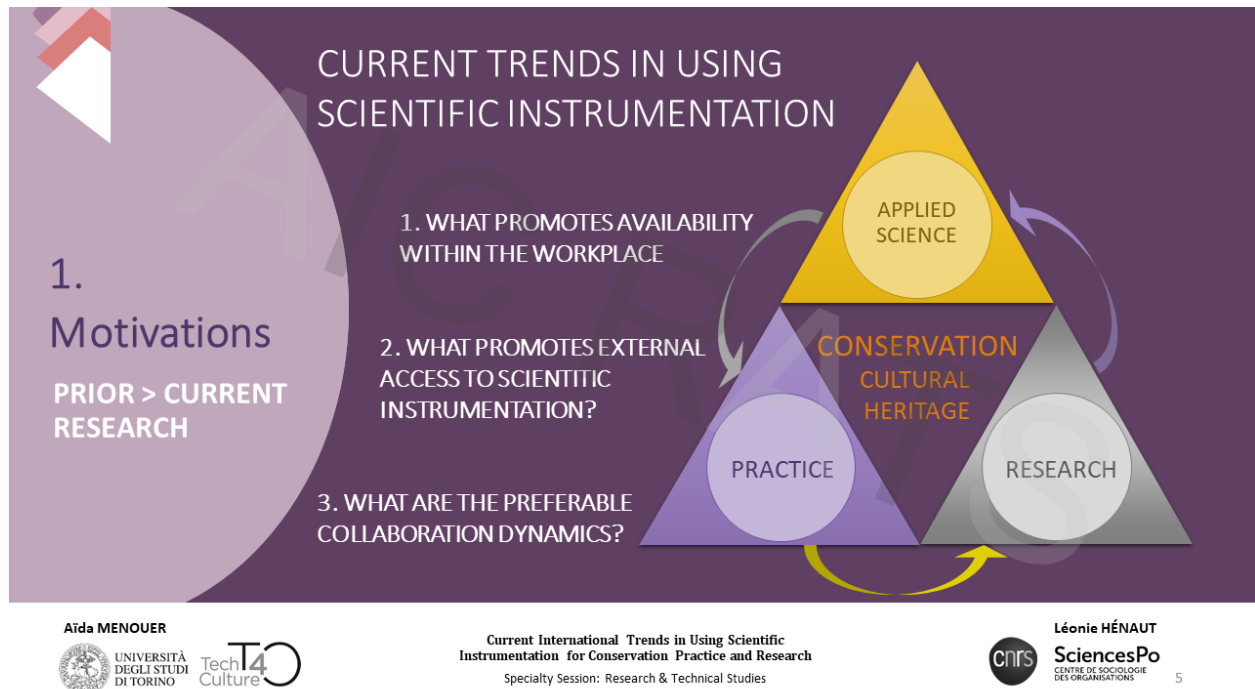


Current International Trends in Using Scientific
Instrumentation for Conservation Practice and Research
Specialty Session: Research & Technical Studies



In our study, we propose to go further in the understanding of conservation practice and research facilities by extending prior research in two directions:

- First, we propose to include emerging countries to get a better picture of the global distribution of scientific instrumentation, beyond the usual focus on Northern and highly developed countries.
- Second, we propose to go beyond a descriptive inventory of scientific instrumentation to include the study of the variations in their availability, and therefore understand to what extent these variations are associated with particular collaboration dynamics.

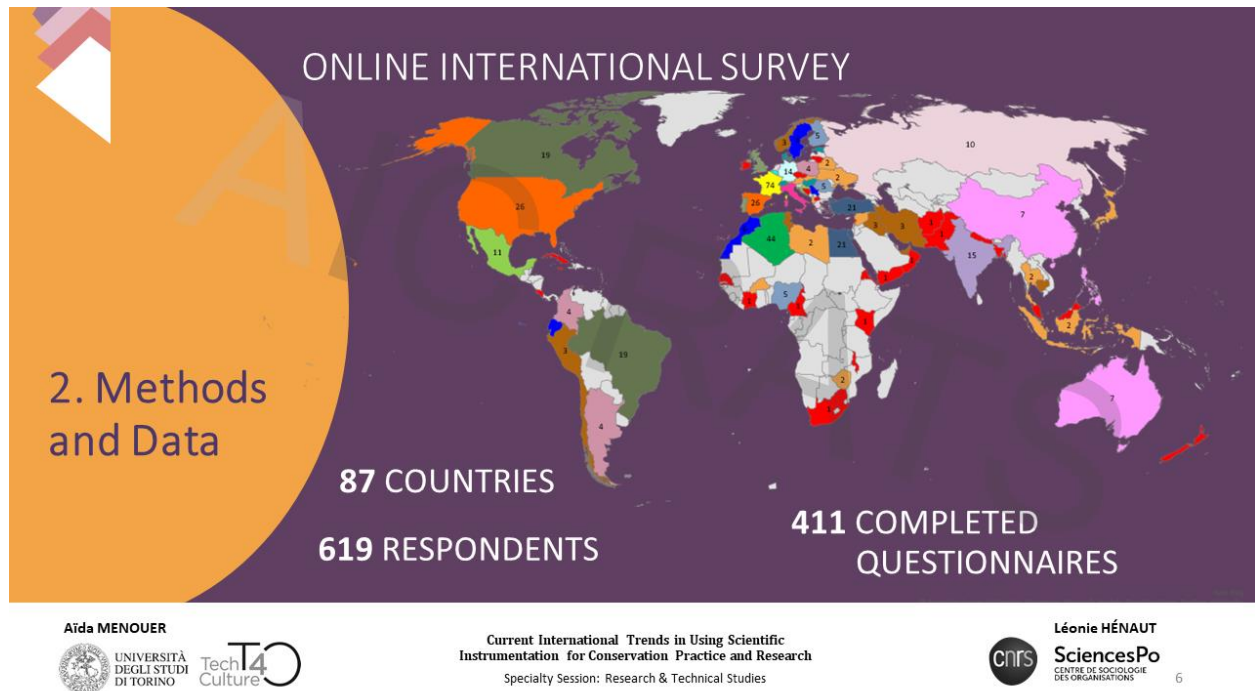


We approach conservation as a network of activities, instrumentation, professionals and workplaces that are at the crossroads of conservation practice (in which actors solve practical conservation issue), research (in which actors produce knowledge), and applied science (in which actors use research findings to support practitioners' interventions).

In this project, we are investigating the interactions between these three spheres of activity, through the examination of the instrumentation used in conservation workplaces.

More precisely, we are going to address three questions:

- What promotes the availability of scientific instrumentation within conservation workplaces?
- What facilitates the access of scientific instrumentation outside the conservation workplace, in other facilities?
- What are the most desirable collaboration dynamics between conservation workplaces in terms of scientific instrumentation accessibility?



Through an international online survey in 2021, I managed to collect contributions from 619 respondents (or 619 conservation workplaces) located in 87 countries, of which 411 completed questionnaires in a way that was satisfying for the purpose of the statistical study. Obviously, one has to keep in mind that any survey would provide only a snapshot of the reality we would like to study.



POPULATION AND SURVEY DISSEMINATION

2. Methods and Data

TARGETED POPULATION
All professionals who may be concerned with scientific and technological applications in their practice for the conservation of cultural property.

SNOWBALL SAMPLING
March – November 2021

2775 EMAILS SENT
64 ASSOCIATIONS
40 SOCIAL MEDIA POSTS
242 INDIVIDUAL MESSAGES

7 LANGUAGES
Arabic, English, French, Italian, Russian, Spanish, Turkish

Call for participation!
NEEDS IN CONSERVATION EQUIPMENT AND INSTRUMENTATION
International survey

If you are a professional working in the field of Cultural Heritage Preservation, you may be concerned with scientific and technological applications in your practice.

MAKE YOUR OWN EXPERIENCE COUNT BY TAKING OUR SURVEY !

Available in Arabic, English, French, Italian, Russian, Spanish, Turkish.

Aida MENOUEUR
Heritage Conservator (Algeria)
Researcher at The University of Turin-TechCulture Program (Italy)
aida.menouer@unito.it

UNIVERSITÀ DEGLI STUDI DI TORINO Tech4Culture

Current International Trends in Using Scientific Instrumentation for Conservation Practice and Research
Specialty Session: Research & Technical Studies

cnrs Léonie HÉNAUT
SciencesPo
CENTRE DE SOCIOLOGIE DES ORGANISATIONS

The surveyed population was defined as follow: the professionals who may be concerned with scientific and technological applications in their practice for the conservation of cultural property, which ranged from conservators, conservation scientists, heritage architects or engineers, curators or field archaeologists, to any other potential “user” of conservation equipment and scientific instrumentation.

Snowball sampling method was used for three months, from March to November 2021.

Online questionnaire was translated and disseminated in seven languages, with:

- 2775 two thousand seven hundred seventy-five emails were sent;
- 64 sixty-four associations reached;
- 40 forty social media posts published;
- and 242 two hundred forty-two messages were distributed on Facebook and LinkedIn.

Unfortunately, the American Survey Software used Alchemer® which had a negative and unexpected impact when applied to USA Sanctioned countries such as Cuba, Democratic Republic of Korea, Iran, Sudan, and Syria. This effect was mitigated by sending PDF-fillable forms to participants from these countries and responses have been collected from Syria, Iran and Cuba.

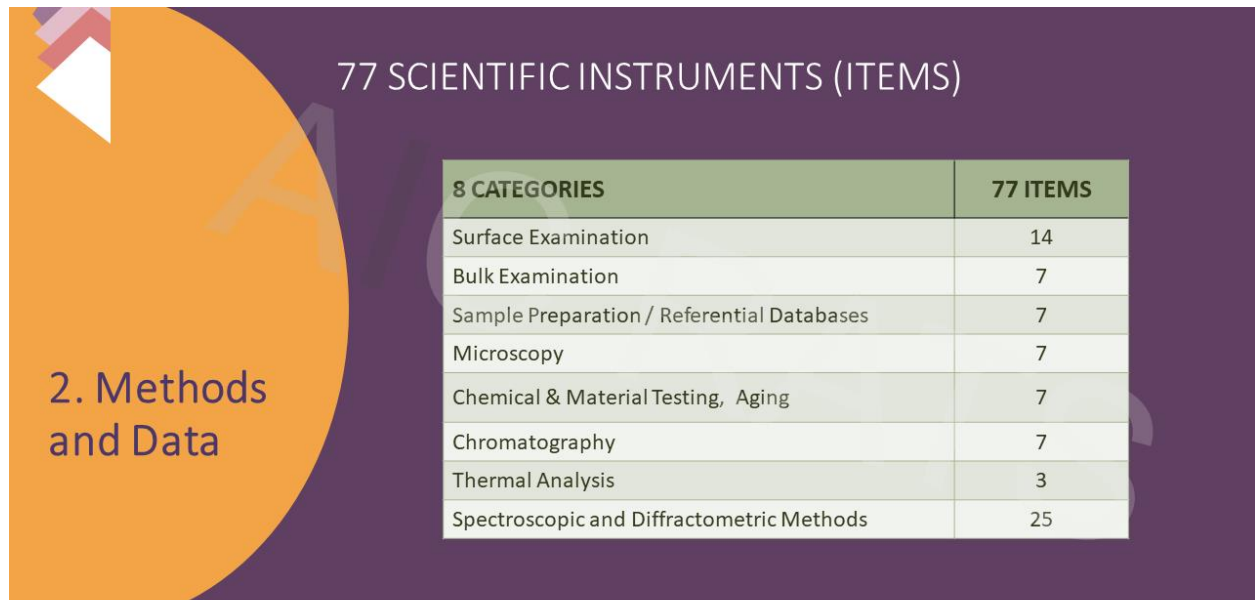
2. Methods and Data

QUESTIONNAIRE DESIGN

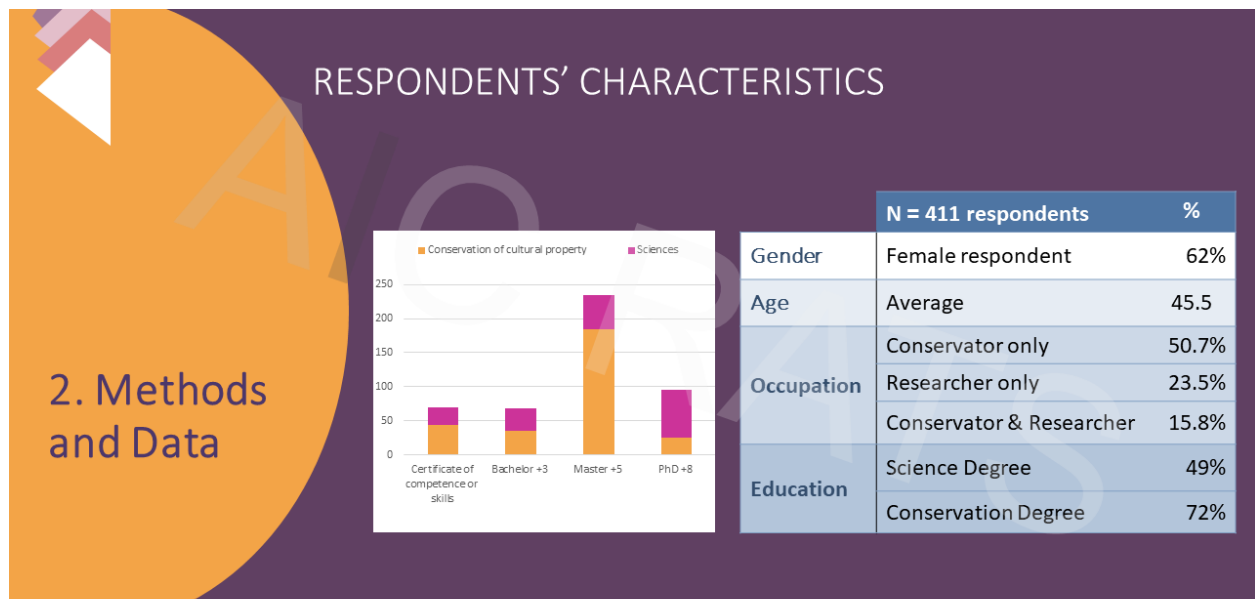
25 min AVERAGE DURATION
33 QUESTIONS
5 SECTIONS

	"Welcome" page
1	Workplace Information
2	Type of Activity
3	USE OF SCIENTIFIC INSTRUMENTATION and Conservation Equipment
4	Opinions
5	Respondent's Professional Profile
	Consent form
	"Thank you" page

On average, respondents took 25 minutes to answer the questionnaire, which unfolds in five sections and totals 33 questions. While the first two sections are related to the workplace characteristics and the type of activities performed in the workplace, the last two are related to the respondents' profiles and their opinions. The third section represents the core of the questionnaire, as it includes a fairly exhaustive long list of 133 conservation equipment and scientific instrumentation. For each of them, respondents had to answer the following questions: is this equipment accessible in your workplace? (Yes/No). If not, do you access this equipment outside your workplace in another facility? (Yes/No).

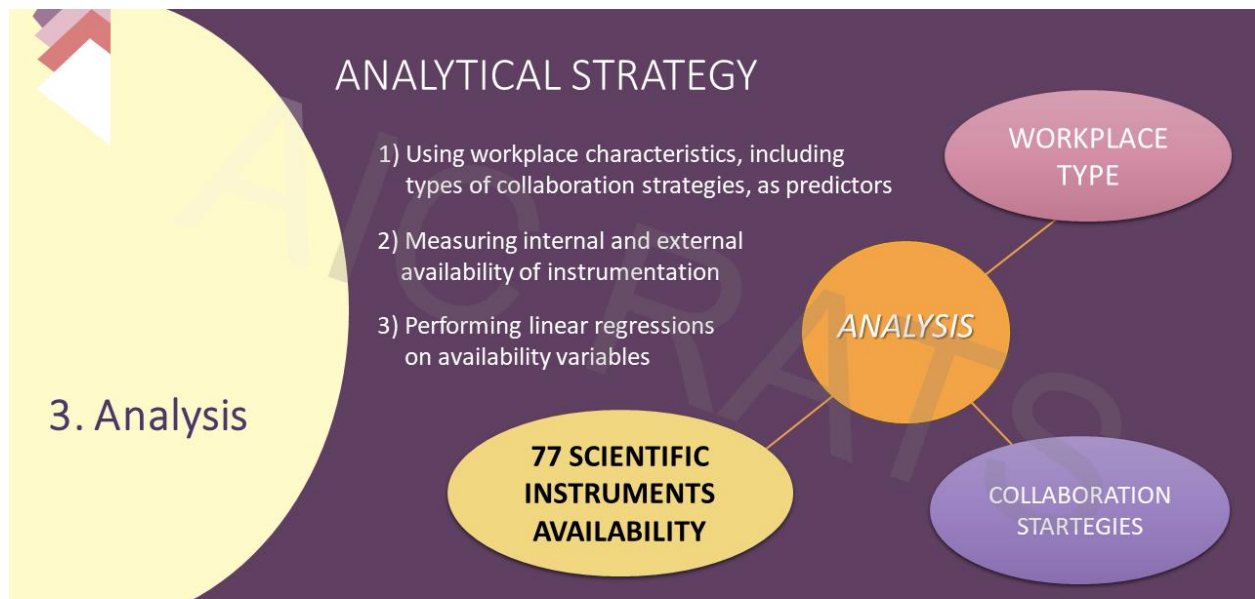


Our analysis here focuses on 77 instruments, which are scientific instruments used in conservation research. They are grouped into 8 categories. Here, the second column shows the number of items in each category.



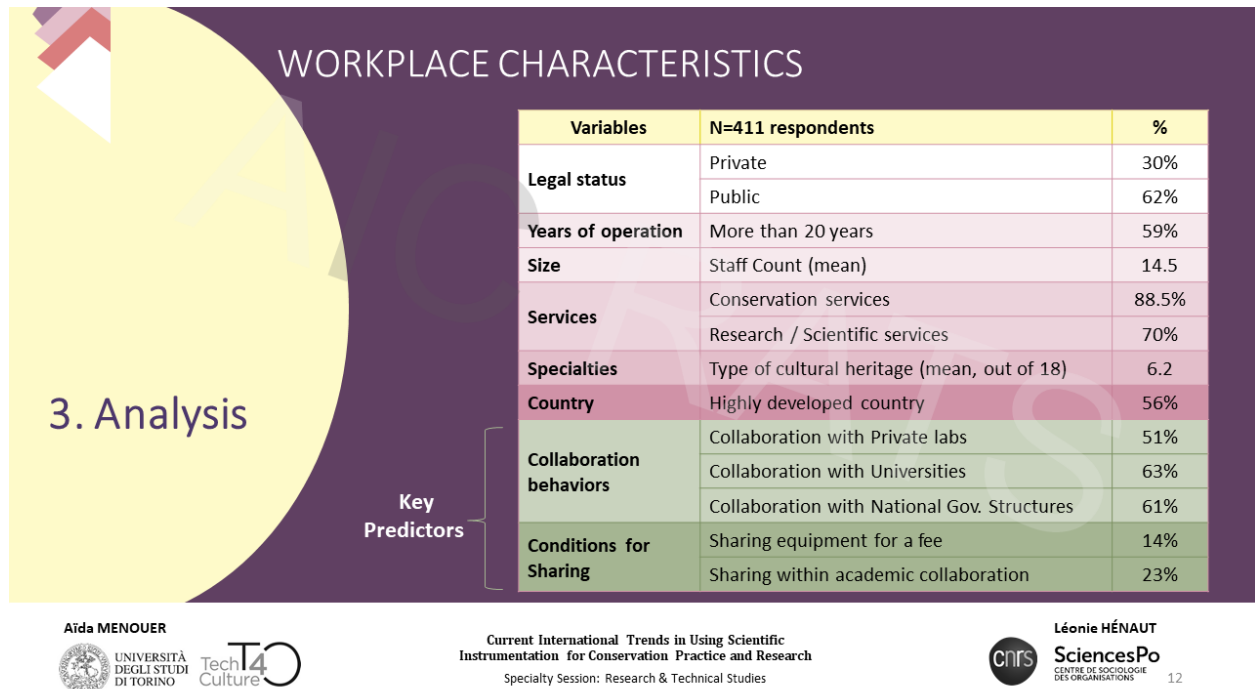
Before we go on with the analysis, let me present the respondents' characteristics. Survey respondents (N=411) are mostly female (62%), with an average age of 45.5 years; 50.7% are conservators only, 23.5% are researchers and 15.8% declared having both occupations. 49% of

respondents hold science degrees (typically, a Master degree or a PhD) while 72% hold conservation degrees (typically, a Master degree).



The analysis now focuses on the inter-relational dynamics of the following elements: workplace type, collaboration strategies, and the availability of scientific instruments.

- In the rest of the talk, I will first describe respondents' workplace characteristics, including types of collaboration strategies. These will serve as predictors in my analysis.
- Second, I will show how we measured internal and external availability of 77 instrumentation, which will be our dependent variables.
- Last, I will present our results from linear regressions performed on availability variables.



Our respondents are located in workplaces with different features: they are private in 30% of cases, and public in 62%; 59% of the workplaces surveyed have been in operation for more than 20 years; their size, measured by the staff count, totals an average of 14.5 people. In 88.5% of the cases the types of services relate to conservation activities (e.g. preventive conservation, direct interventions on object and monuments...), while 70% are Research/Scientific Services (e.g. Analysis of composing or of alteration materials, engineering surveys...) On average, workplaces take care of six different types of cultural heritage (books, rock art, textiles, paintings, etc.) Another control variable is binary and depends on whether the workplace is located in a highly developed country or not. In our sample, 56% of respondents work in country viewed as highly developed according to the ICOM-CC 2019 classification.

We approach collaboration strategies using five predictors which are not exclusive (respondents can deploy multiple collaboration strategies at the same time): collaboration with private laboratories, collaboration with universities, collaboration with national government structure, sharing equipment in exchange for a fee, and sharing equipment within the context of an academic collaboration.

3. Analysis

INTERNAL VS EXTERNAL AVAILABILITY

1.1 Examination – Measurement & Morphology

1.1.1 Surface examination

Enter a frequency if Yes or External was chosen, Enter a frequency of Never if No was chosen

	Availability *		
	YES	NO	External Service
Photography Digital Cameras (Black & White, Color, High Definition /Macro, ...)	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>
Reflected, Raking or Transmitted visible light observation	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ultraviolet light (UV) (Visible Fluorescence)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reflected Ultraviolet (UVR) (Modified full spectrum digital camera)	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
Infrared (IR) light (Modified full spectrum digital camera)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Infrared (IR) reflectography	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
False color UV- IR imaging (Modified full spectrum digital camera)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

AVAILABILITY STATUS

Available in Workplace (YES)
Not available in Workplace (NO)
Accessible through (EXTERNAL SERVICE)

INTERNAL AVAILABILITY

EXTERNAL AVAILABILITY

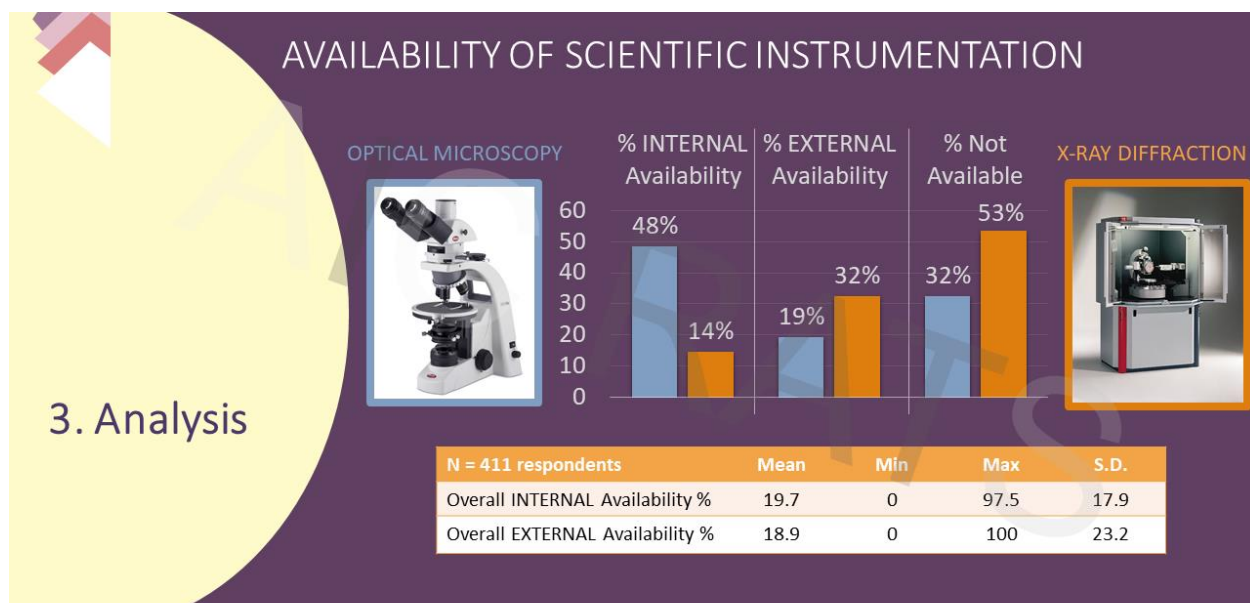
Aïda MENOUEUR



Current International Trends in Using Scientific
Instrumentation for Conservation Practice and Research
Specialty Session: Research & Technical Studies



As we said earlier, for each of the 77 items, our 411 respondents were asked what kind of access they had to this scientific instrumentation. We therefore can distinguish three availability statuses: internal availability characterizes scientific instruments which are available within the respondent's workplace; external availability describes instruments which are accessible outside the workplace at another facility; an instrument is not available when it cannot be accessed by the respondent at all.



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Based on the answers to these questions, we calculated the rates of internal, external, or no availability for all 77 items. These rates vary greatly. For example, let's consider two items in our list which exhibit different patterns of availability, the microscope with transmitted and polarized light (see blue bars on the left) and the X-ray diffraction XRD (see orange bars on the right). The microscope is a highly accessible instrument, mainly available through internal access: 48% of our respondents claimed that they can access it in their workplace while 18% claimed that they had external access to it, and 32% had no access at all.

In contrast, 14% have internal access to X-ray Diffraction XRD, and therefore, this second instrument is far less internally available than the previous one, but still relatively available compared to other instruments in the list, and its availability is more likely to be external availability.

Next, we calculated these same rates for each item, each category of items, and finally for the whole set of 77 items, or the overall availability rate. The table below shows that, on average, respondents have internal access to 19.7% of the 77 instruments (this is the average overall internal availability rate), and external access to 18.9% of the 77 instruments (this is the average overall external availability rate).

Yet, these rates vary greatly, as shown in the table. Some respondents said that they had access to zero equipment, while others said they had access to all of them.

These variations between respondents are our object of study. We suspect that internal and external availabilities are correlated with workplace characteristics. Hence, we ask: what types of workplaces would manifest higher rates of overall internal availability and where could overall external availability preferably occur?

Our hypothesis is that this variation between internal and external availability is contingent upon the relationships that workplaces may have with other organizations, especially private laboratories and universities. This hypothesis was tested using linear regressions.

CORRELATES
OF EQUIPMENT
AVAILABILITY

3. Analysis

OLS Regression (ordinary least squares)	Dependent variable INTERNAL availability	Dependent variable EXTERNAL availability
Intercept	2.623	5.966
Collaboration with private labs	.327	5.028***
Collaboration with universities	-.314	2.204*
Collaboration with National Gov.	-.042	1.914
Sharing equipment for money	1.949	-3.975
Sharing within academic collab.	9.367***	.633
Workplace of private legal status	-1.815	8.334**
More than 20 years	.914	-.008
Size by Staff Count (mean)	.154**	.118
Conservation services	-4.646*	-.380
Research / Scientific services	9.078***	-1.408
Highly developed country	6.225***	-1.388
R ²	.347	.144

* p<.05, ** p<.01, *** p<.001 (two-tailed tests)

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We performed OLS Ordinary Least Squares standard linear regression on our two dependent variables: (overall) internal availability and (overall) external availability.

The coefficients associated with statistical models are displayed in the table (Note 1).

Looking first at the predictors for internal availability in the second column (framed in pink), the results show that a higher percentage of internal availability is positively and significantly associated with sharing equipment in the context of academic collaboration, net of other workplace characteristics.

Additionally, the regression analysis shows that higher rates of internal availability are associated with workplaces performing research and scientific services, not performing conservation services (which you see here as a negative), as well as being a well-resourced structure (large size and highly developed country).

In contrast, the predictors for external availability in the third column (framed in purple) exhibit quite different results. As the numbers show, a higher rate of external availability is positively and significantly associated with collaboration with private laboratories, collaboration with universities and the workplace being a private structure.

Note 1: The numbers in the regression table are the coefficients, not the significance values
* p<.05, ** p<.01, *** p<.001 (two-tailed tests)

Correlations are significant when p is inferior to $<.05$ et super significant when p is inferior to $<.001$ and we use asterisks to indicate it.

4. Conclusions

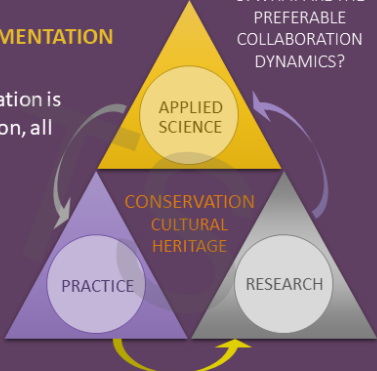
TAKE-HOME POINTS

- 1. INTERNAL AVAILABILITY IS HIGHER IN RESEARCH-ORIENTED AND PRIVILEGED WORKPLACES**
- 2. ACADEMIC COLLABORATION PROMOTES INSTRUMENTATION AVAILABILITY**
Sharing equipment as part of an academic collaboration is associated with high rates of internal instrumentation, all other workplace factors considered.
- 3. ROLE OF PRIVATE ACTORS**
External access to instrumentation is predominantly found in collaborations between private workplaces and private labs.

1. WHAT PROMOTES AVAILABILITY WITHIN THE WORKPLACE?

2. WHAT PROMOTES EXTERNAL ACCESSING OF SCIENTIFIC INSTRUMENTATION?

3. WHAT ARE THE PREFERABLE COLLABORATION DYNAMICS?



When circling back to our research questions, we have learned that:

- 1) Internal availability is higher in research-oriented and privileged workplaces.
- 2) Academic collaboration promotes instrumentation availability. And, more specifically, the sharing of equipment as part of an academic collaboration is associated with high rates of internal instrumentation, all other workplace factors considered.
- 3) External access to instrumentation is found in the context of collaborative relationships between private workplaces and private labs.

4. Conclusions



FIRST RESEARCH MOTIVATIONS

Feedback from the field about the **most distributed equipment** according to **workplace type and user's profiles**
Identify **efficient patterns** for equipment sharing

CAN A MORE SUSTAINABLE SOLUTION FOR
ACCESS TO SCIENTIFIC INSTRUMENTATION BE COLLABORATION
AND SHARING WITH PRIVATE LABS AND UNIVERSITIES?

FURTHER RESEARCH WILL SEEK TO IDENTIFY OTHER DYNAMICS IN THE USE OF
SCIENTIFIC INSTRUMENTATION AND CONSERVATION EQUIPMENT.

Coming back to the initial motivations for this research, in emerging contexts, as opposed to highly developed countries that can afford costly scientific equipment, we would argue that a more sustainable approach would be to access scientific instrumentation through collaboration and sharing with private labs and universities.

Please consider that we are still working on the data, exploiting various other leads from the rich and nuanced survey questionnaire. Further research will address the frequency of use of scientific Instrumentation, in comparison with other conservation equipment that were mentioned by participants. In addition, opinions and personal views about respondents' own practice are also valuable sources for further understanding the dynamics in the use of conservation equipment.

ACKNOWLEDGMENT

Many thanks

To the **Samuel H. Kress Foundation** and **Foundation for Advancement in Conservation** for their support in making this communication in person possible.

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Thank you for your attention!

Sharing Technical Art History: Past, Present, and Moving Forward

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Extended Abstract

In the theme of the AIC conference *Reflecting the Past and Imagining the Future*, we consider Technical Art History and its collaborative nature by revisiting its past and pondering its future. While Technical Art History is a new-ish field with designated programs within Universities, technical art history (with a little t-a-h) encompasses a way of looking that is much older. According to Marco Cardinali, the term “technical art history” was introduced for the first time in 1998 by David Bomford, and he defined it as a “wide-ranging evocation of the making of art and the means by which we throw light on that process [that] goes far beyond the physical materials of works of art into questions of artists’ methods and intentions.”¹ But of course, long before this specific term was coined, people were looking at art and considering its materiality and process.

The present field of Technical Art History can trace its origins to several areas of study over the centuries. The first includes the study and documentation of artist workshop practices, often authored by practicing artists, in the form of manuscript treatises from mostly from Asia and Europe. These treatises, some dated back at least to the 13th century, were the first consideration and documentation of how art was made and the context that surrounded it. The second, though certainly not entirely separate from the first, is academic Art History and connoisseurship. Practicing artists were generally considered earliest scholars of art/art historians (Vasari, Alberti, etc.), but as art was lifted from a craft to a liberal art subject over the 18th century, academic art historians and connoisseurs came to the fore.² 18th century German art historians criticized Vasari’s approach to art history, and instead emphasized the opinions of the learned beholder over the artist. A shift in art historical thought was proposed: to move from studying texts about art to examining actual objects from antiquity themselves. In the frenzy of 18th and 19th-century archeological excavations of Egypt, Greece, and Italy, European scholars often took material samples on site and sent them to post-Scientific Revolution-trained chemists for analysis to understand the artistic materials; this was the beginning of the scientific study of art.

¹ Cardinali, Marco. Technical Art History and the First Conference on the Scientific Analysis of Works of Art (Rome, 1930). *History of Humanities*. 2 (2017). 221-243.

² Brown, Jonathan. *Kings & Connoisseurs : Collecting Art in Seventeenth-century Europe* / Jonathan Brown. New Haven: Princeton: Yale UP; Princeton UP, 1995. Print.

It became clear that the scientific study of artist materials was not only important for academic reasons, but also because much of the artwork in both private and public collections was in poor condition due to age, lack of climate control, bad previous restorations, and modern industrial gasses. The art restorers of the 18th and 19th centuries did not have answers for some of these issues. There was an obvious need to study, codify and develop conservation methods and understand preservation tactics, which ultimately led to the formation of the first scientific laboratories for art. The first museum conservation labs were created in Europe and North America (and one in India) in the late 19th and early 20th centuries, with the intention of studying artist materials and conservation methodologies. Newly invented imaging techniques, such as X-radiography, proved to be useful in examining artist techniques, and by extension, art connoisseurship and authentication.

As the conservation labs and their associated training programs were created with analytical and imaging equipment, the technical study of art became intertwined with the new conservation field. New analytical research was published for and shared with international audiences. For example, the first international conference on conservation and technical study was held in Rome in 1930. The Fogg Art Museum began publishing *Technical Studies in the Field of the Fine Arts* in 1932. Art historians, chemists, and conservators together published the *Manual on the Conservation of Paintings* in 1939 (French) and 1940 (English), and listed all of the tools available for technical analysis including X-rays, ultra-violet rays, infra-red rays, microscopy and microchemical examination, among others.

While technical study became inextricably linked with conservation, it fell largely out of favor with the greater Art History field, especially in academia, starting in the 1960s as scholars moved Art Historical discussions towards critical theory. The Archaeology and Anthropology fields did continue to study objects with a material lens under the term Material Culture studies. In the last two decades, Technical Art History, as material-based study of art objects has come to be called, has been established as its own field within a few Universities internationally and is once again gaining ground outside the museum lab and conservation field.

In the next chapters of the Technical Art History field, the editors of the new, online, open-access *Materia: Journal of Technical Art History* envision a future that will address issues of representation, equity, and accessibility. Material-based study of art and cultural heritage objects will incorporate a post-colonial lens that recognizes past and present research interpretation bias and no longer privileges white, European and European-diaspora art over all others. Technical study of underrepresented artists will be prioritized in the field's research; especially because these artists often could not create or inspire the same wealth of textual evidence as established Old Masters, close examination and material study is crucially important to understand the making and meaning of their artwork.

As it stands today, much of technical study research is published behind print or digital paywalls, making access difficult for those who can't afford publication subscriptions, and publication fees often make authorship unattainable for those working outside a wealthy institution. In the future, access to research and publication for all scholars will have to be prioritized to create equity in the field.

As mediums of artistic expression expand into digital art, the Technical Art History field will grow to include the study of these as well. Online publications will be a useful venue for writing about digital and digitized art, including video, audio, web-based art, blockchain/NFT art, etc. Technical Art History will work alongside Digital Art History and Digital Humanities to leverage the best digital tools to showcase and archive research and to make that research accessible to those with visual impairments and various disabilities. Accessible, online tools will also allow scholars to self-publish in a sustainable, archivable way and depend less upon institutional gatekeepers to determine what is worthy of publication.

Optimizing Oddy! Streamlining the Implementation of the Metropolitan Museum of Art Oddy Testing Protocol in a Multi-User Work Environment: Tips and Troubleshooting

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Original Abstract

In conjunction with new construction and major renovations of several exhibit halls at the American Museum of Natural History (AMNH), AMNH conservators adopted the Oddy testing protocol recently developed by the Metropolitan Museum of Art (MMA). The MMA protocol addresses sources of potential error in the Oddy test through its highly detailed specification of hardware to be used, and well-defined procedures for washing hardware, preparing samples and metal coupons, assembling the test, and interpreting and documenting results. With its improved reliability, however, comes a more time-consuming workflow.

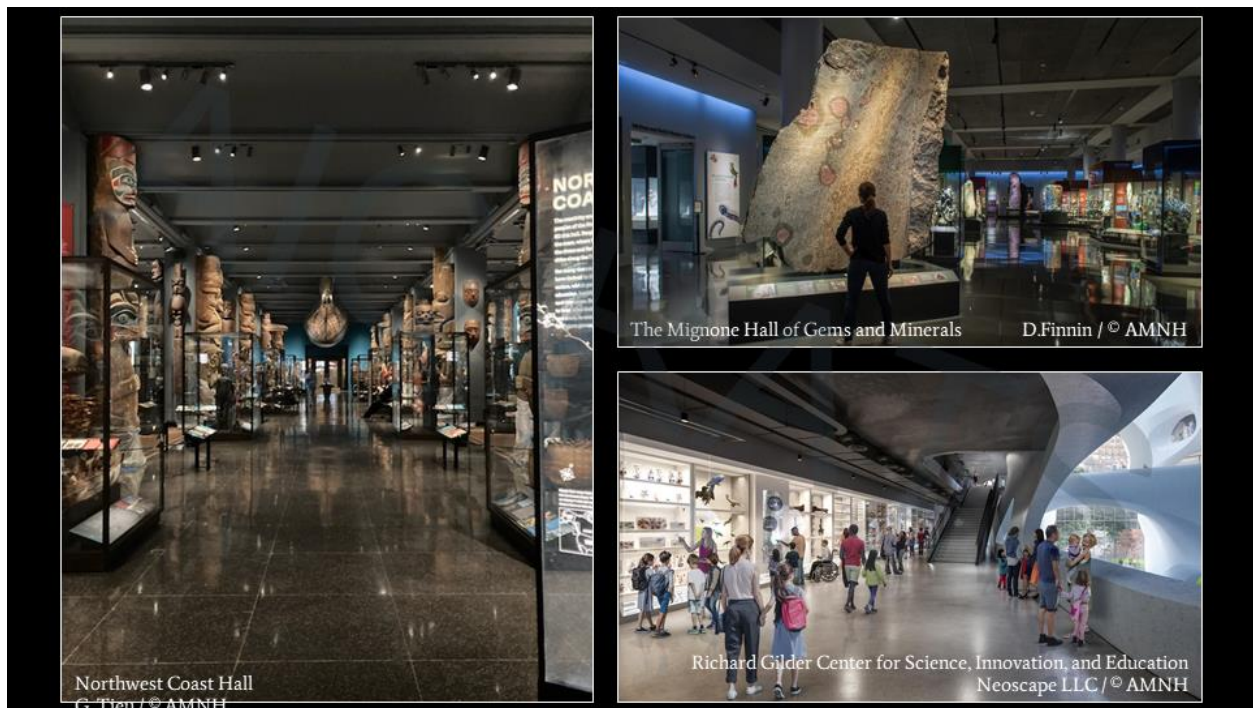
While testing over 450 materials using the MMA protocol, AMNH conservators sought and found opportunities to streamline its implementation in a multi-user environment without straying from its standard guidelines: simple time-saving tips for organizing equipment and lab space; expediting the glassware cleaning process; making repetitive or delicate tasks easier by selecting the right tool for the job; tracking the reuse of components that have the potential to absorb contaminants from past tests; and preparing metal coupons more easily while avoiding pitfalls that complicate the evaluation of results. They also successfully troubleshooted unexpected challenges with jars that became very difficult to open after testing, and an unidentified source of contamination within the test setup.

Lessons learned at the AMNH may help others to reduce time spent preparing the Oddy test, further standardize workflows, and troubleshoot problems encountered in testing.

Annotated Presentation



This paper is a presentation of lessons learned while applying the Metropolitan Museum of Art's (MMA) Oddy testing protocol to recent projects at the American Museum of Natural History (AMNH). It includes tips and insights gained over the course of 3 ½ years and over 450 Oddy tests conducted in association with the renovation and construction of three permanent exhibit halls at the AMNH.



With these installations expected to remain on view for decades, materials testing was critical to ensuring the safety of the diverse collections exhibited. Our testing was primarily focused on case construction materials, coatings, and sealants, but also included graphics and mount-making materials.

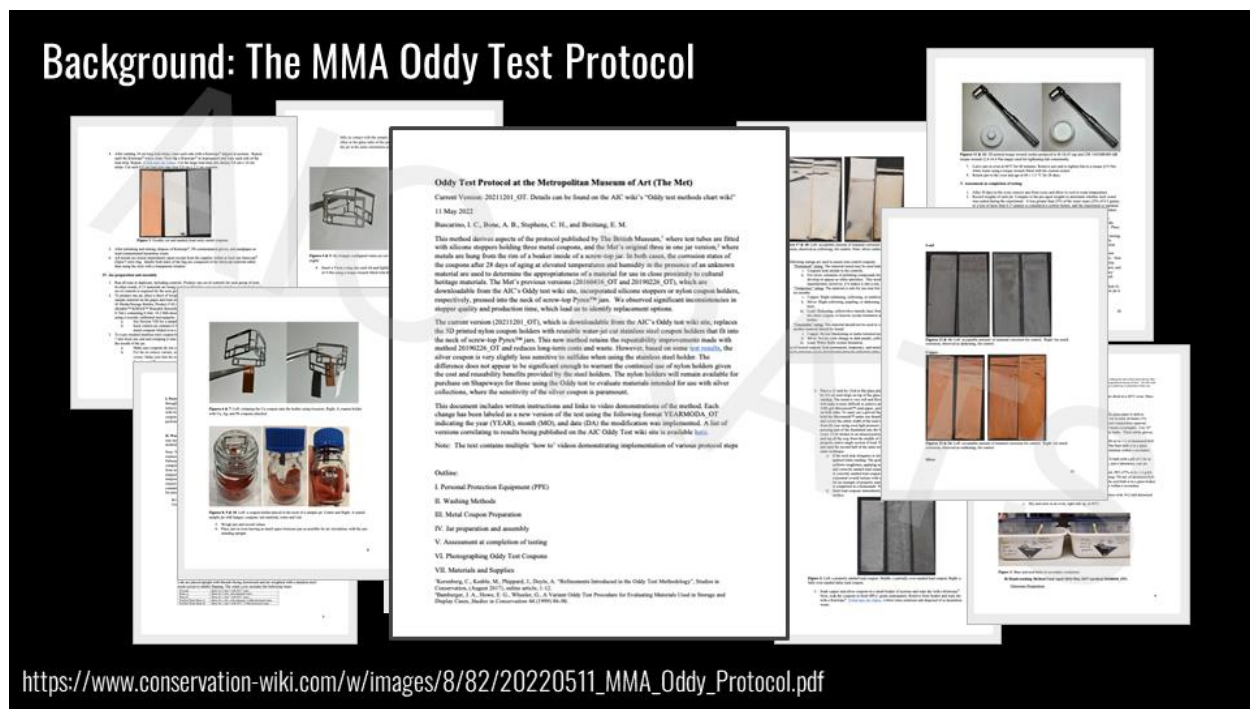
Background: The Oddy Test

Variability in Test Outcomes

- Procedural variations between testers
- Subjectivity in the interpretation of results
- Lack of standards for written and photo-documentation
- Maintaining a consistent test environment/limiting water loss
- Minimizing the influence of materials used in the test setup
- Ensuring consistency in the manufacture and preparation of test components
- Achieving a uniform exposure of coupons within the test volume

Andrew Oddy's original 1973 benchtop accelerated aging test has undergone numerous modifications over the intervening years. In fact, an unpublished 2014 survey by Elena Torok and Joelle Wickens (*Reevaluating the Oddy Test: An Examination of the Diversity in Protocols Used for Material Testing in the United States*, presented at the Winterthur Museum, Garden, and Library in Wilmington, DE in 2015) documented over 20 distinct procedural variants at that time. Their survey also reaffirmed common frustrations with the variability of results, which derive from procedural differences between testers and subjectivity in the interpretation of outcomes, as well as the difficulty of ensuring an absolutely consistent experimental setup free of contaminants.

Background: The MMA Oddy Test Protocol



Recent updates to the MMA Oddy testing protocol tackle many of those challenges. It's an exacting guideline, specifying each part and product to be used, and how it should be prepared. It establishes a rubric for the interpretation of corrosion phenomena, and includes guidance for the visual and written documentation of results. It also incorporates a number of adjustments to the test setup itself that are intended to improve consistency. For more details, you can find the most recent version on the AIC Wiki.

For these reasons, the AMNH adopted the MMA's protocol for our materials testing program. We were very fortunate to have training from Eric Breitung and his staff in the Preventive Conservation Science Laboratory, and we have benefited enormously from an ongoing dialogue around testing and troubleshooting.

Tips, Tricks and Insights

- Staying organized
- Easi(er) Setup and Breakdown
- Time Management
- Troubleshooting



Oddy testing at the American Museum of Natural History

Meeting the needs of these projects required applying this protocol to a high volume of materials. We had to stay organized, work efficiently, and manage the cost of consumables. Samples came in sporadically, so tests on different schedules shared the same lab oven. Once at the museum, samples for each project were tested by different people, so training and communication were important to our all executing the setup the same way. Our testing was conducted in a shared lab used for specimen preparation, so we had to manage equipment to limit contamination risk. And even then, sometimes things unexpectedly went wrong that were not addressed by the protocol itself.

With these challenges in mind, we have organized the tips herein into four general groupings: Tips for staying organized, making setup and breakdown easier, time management, and troubleshooting. Some of these insights may seem very basic, while others perhaps less so. We hope that you will find some value in the lessons learned from our experiences.

Staying Organized

We will start with simple ways that we kept our Oddy testing workspace organized, beginning with tools.

Staying Organized: Keeping Track of Tools



Tool set designated for coupon preparation from each metal:

- Scissors
- Ruler
- Needle Tool
- Scalpel
- Blunt forceps
- Rounded forceps
- Pointed forceps

The MMA protocol specifies that separate scissors are to be used with each type of metal; however, we found it easier to keep track of dedicated scissors, while also equipping multiple people to prepare coupons side by side, and avoiding transfer of residues from sample materials to the coupons, if we designated a full set of tools for each metal, detailed here.

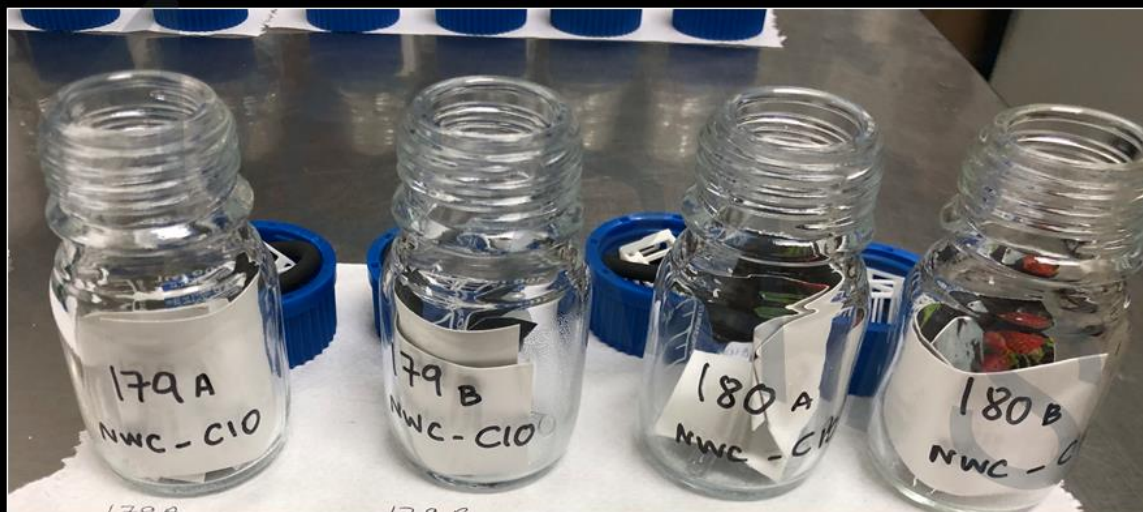
Staying Organized: Keeping Track of Tools



Baskets containing segregated Utility, Pb, Ag, and Cu tool sets

We also designated a fourth set of tools for preparing and handling sample materials. Each set is segregated and stored in a separate basket.

Staying Organized: Unique IDs for Samples and Test Batches

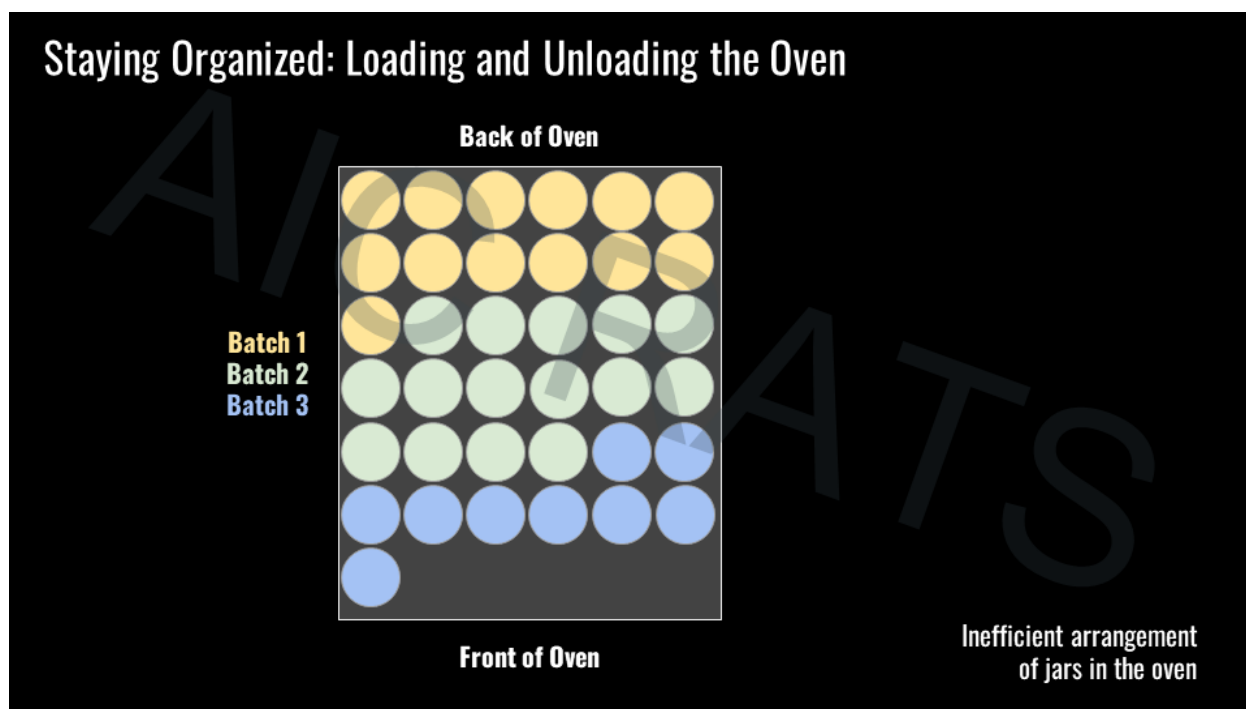


Labeled Oddy test jars

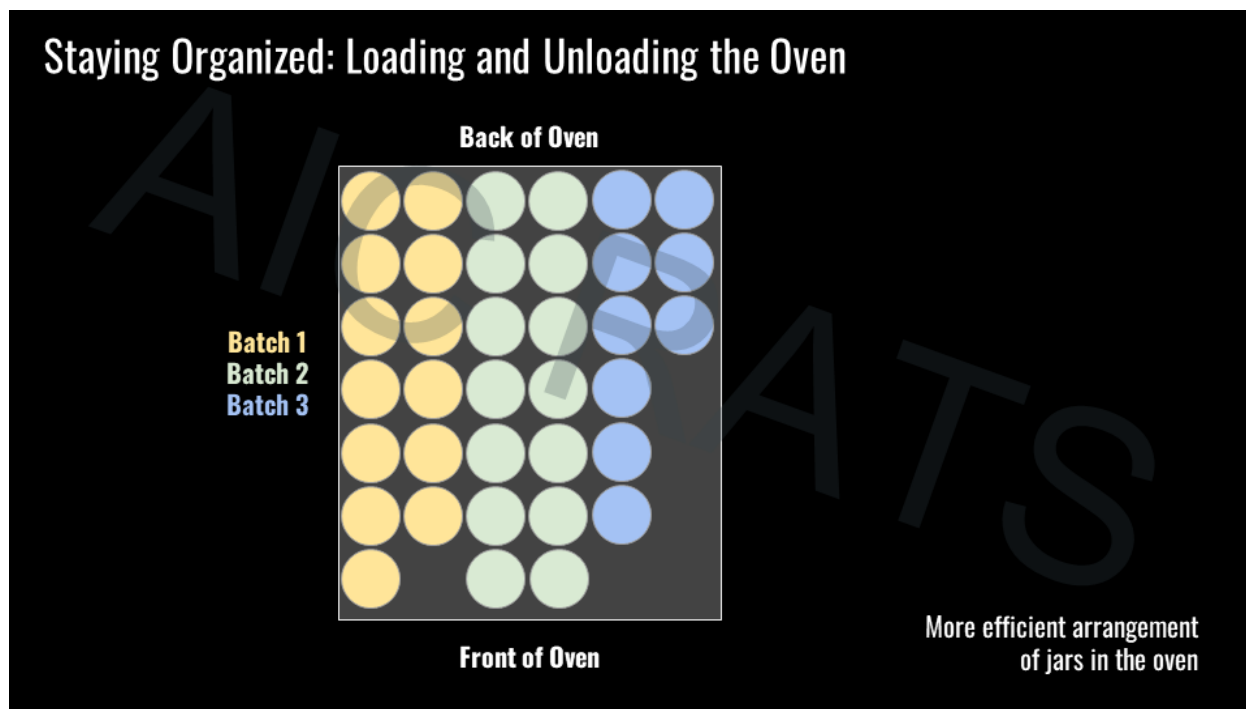
Sample Number - Replicate Identifier (A/B) - Project ID (NWC = Northwest Coast Hall) - Batch Identifier (C10)

Per the MMA protocol, samples are tested in replicate alongside a pair of Control jars containing no sample material. With proposed materials being supplied to us sporadically, we often had to start one batch of tests, followed by another, sometimes as soon as the following day. To keep track of batch groupings, we assigned each sample and each batch a unique ID number in a simple FileMaker Pro database based on the one used at the MMA.

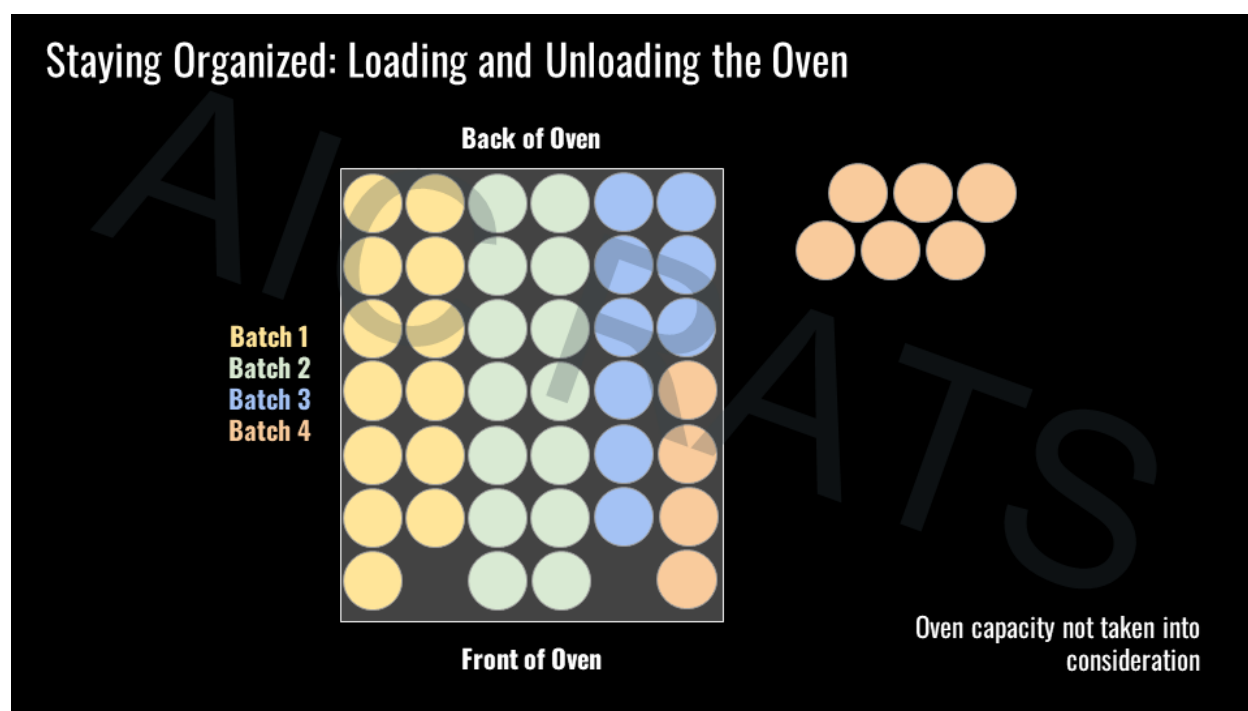
Each test jar was labeled with the Sample Number (179 or 180 in the image above), an A or B replicate designation, an abbreviated Project ID code (NWC for Northwest Coast), and the batch number (C10 for the tenth set of Controls we have used in our tests). After 28 days in the oven, using our database, we could pull up the list of samples in each batch to be quickly identified and removed from the oven.



When we first found ourselves working with multiple test batches simultaneously, we were loading the oven as pictured, with each group of jars packed one in front of the other, from the back to the front of the oven. We soon discovered that this makes unloading the oven difficult, since the first batch in is the first batch out.



We realized that we could more quickly locate all of the jars in a batch by filling the oven as pictured, packing batches next to one another.



We also learned that it was important to know the capacity of our oven to avoid finding ourselves with a newly prepared batch of samples that was too large to fit.

Staying Organized: Keeping your Coupons Straight



Gabrielle Tieu and Julia Sybalsky handle coupons as Devon Lee records observations during a group assessment

Many of our Oddy test batches were quite large, and we sometimes needed to assess the results from as many as 30 jars, or 90 coupons, at one time. Coupons were examined with illumination at close range. This process went most smoothly with one person handling the A coupons, a second person handling the B replicate coupons, and a third person recording fast paced observations and outcomes, much like a court stenographer. All parties participated in the assessment of coupons, and a final result required consensus.

Staying Organized: Keeping your Coupons Straight



Control coupons differentiated by marking with metal A and B punches



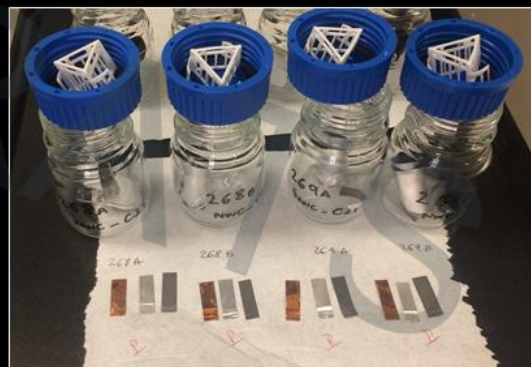
Dog-eared Control A coupons in a petri dish

At the time of assessment, we differentiated A and B Control coupons with metal punches, and placed them in separate petri dishes to make for easy movement around the assessment area. Small dog ears on the Control coupons further distinguished them from the sample coupons and made them easier to handle with tweezers.

Staying Organized: An Orderly Coupon Assessment



Disassembled Oddy tests arranged on a lunch tray with coupons awaiting assessment



Ratings (in red) marked alongside disassembled Oddy tests

To keep the coupons together with their respective IDs and jar components while moving them in and out of the assessment area, we found it helpful to repurpose lunch trays. Kimwipes or paper towels lining the trays kept coupons clean and provided a ready place to jot down results on the fly.

Staying Organized: Tracking the Reuse of Components



After assessment, ratings are used to add tally marks to "T" lids, and all are sorted into buckets P and T:1 through T:4



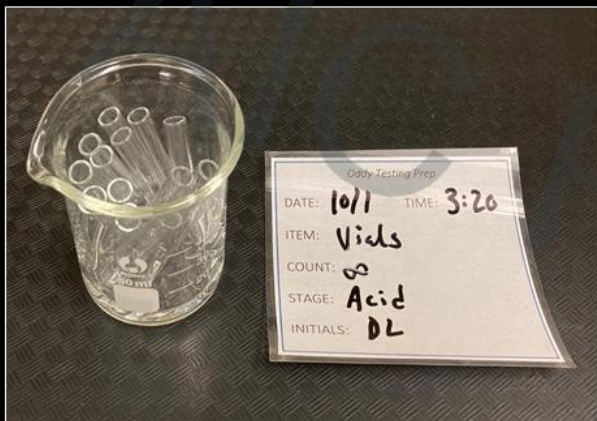
A and B replicate jars respectively assembled with P and T:1 components prior to a new round of testing

It is not clear whether reused lids, O-rings, and sintered nylon coupon hangers retain compounds evolved during testing, but it is reasonable to assume that they can, at least in some circumstances. In an effort to balance this concern with cost-management and sustainability, the MMA protocol includes a system for their reasonable reuse that we have slightly adapted.

Per the MMA protocol, those components from tests ranked Permanent are washed and returned to the general supply; components from tests given Unsuitable ratings are discarded outright; and a "four strikes, you're out" system is applied to lids from tests ranked Temporary. The MMA protocol specifies that O-rings and nylon coupon hangers given Temporary ratings are discarded, but in the interest of sustainability and cost effectiveness, we expanded the strike system to include these components. A tally mark is added to reused lids after each Temporary rating, and upon receiving a fourth strike, the lid and its accompanying O-ring and nylon coupon hanger are discarded. We used labeled buckets or beakers to segregate the groups during washing and storage.

For procedural consistency, components with tally marks were only used for the B replicate assemblies, and the reuse status of each assembly component was noted in each sample's entry in FileMaker Pro. In the future, a careful analysis of our data could be conducted to look for any correlation between reuse and differing outcomes in A and B replicates. In practice, however, we very rarely saw such differences.

Staying Organized: Sharing the Washing Load



Tracking card detailing the item count, current washing stage, and start date/time for a beaker of vials soaking in acid



Tracking cards detailing the item count and start date/time for glass jars soaking in acid (left) and base (right) baths

After assessment, test assemblies were broken down for cleaning. Without a special lab dishwasher, this is a multi-day process that involves multiple soaking and rinsing steps. We consistently had one load of glassware soaking, another drying, and still another waiting in the wings to be cleaned. With multiple people independently moving things along through each step of the washing process, it was helpful to use laminated, waterproof (i.e. reusable) cards to keep track of the status of each tub, beaker, or tray of parts.

Easi(er) Setup and Breakdown

The next section will present some tips for making test setup and breakdown easier.

Easi(er) Setup and Breakdown: One Thing at a Time



Cut copper and silver coupons



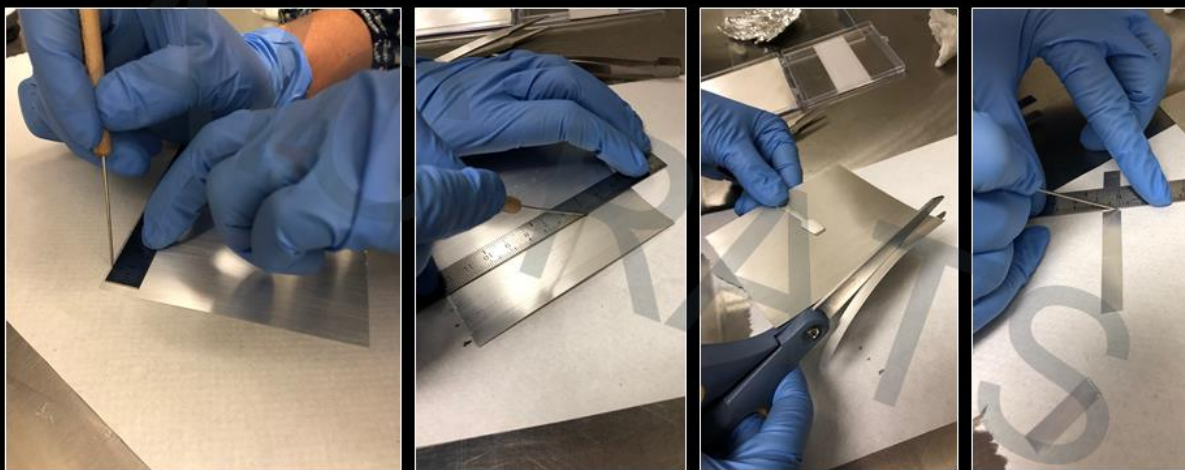
Solvent cleaning silver coupons



A batch of tests (top) and folded metal coupons (bottom) ready for assembly, inspection, and closure

When setting up a new batch of tests, we liked to use large watch glasses to contain loose coupons until it was time to attach them to the hangers. After all of the coupon hangers were assembled, the jars were inspected one by one to make sure all the parts were in place, and then closed up and placed in the oven.

Easi(er) Setup and Breakdown: Careful Cutting Simplifies Assessment



Marking silver foil with a needle tool before cutting coupons with scissors; coupon length is parallel to striations

We used a needle tool to mark the metal foil sheets for cutting coupons, and learned the hard way that it's important not to leave needle marks or tiny holes in the foil that do not align exactly with the scissor-cut lines. These surface irregularities can corrode preferentially in testing, complicating assessment.

This image shows us cutting silver coupons. Silver foil sheets are available with mirror and striated finishes; we preferred to consistently use one or the other, and we never mingled coupons cut from the two finish types within the same batch, because distinguishing subtle differences between coupons is made even more difficult when *also* comparing striated and mirror-finished silver. In the same vein, when using striated silver, we chose to consistently orient the long edge of the coupon parallel with the striations.

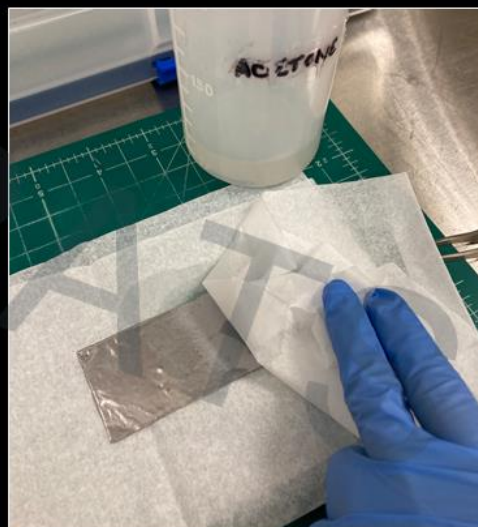
Easi(er) Setup and Breakdown: Handling your Heavy Metal



Equipment and supplies for preparation of lead coupons



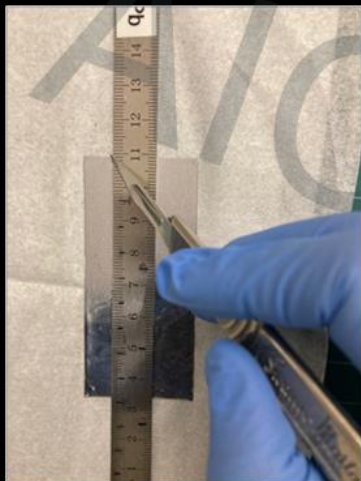
Strip of lead foil during sanding



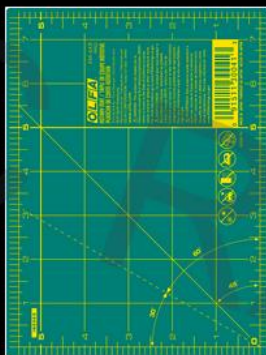
Flooding lead foil with acetone from a squirt bottle.

Preparing the lead foil has special challenges. The MMA protocol specifies that while the copper and silver coupons are simply cleaned with HPLC grade acetone and isopropanol, the lead is sanded with 3200 grit micromesh and cleaned with the same solvents immediately prior to assembling the tests. It can be challenging to get consistent results with lead coupon preparation, even by the same hand: the lead is soft and easily scarred, and sanding too hard or for too long may burnish the surface. To make this step easier, the MMA protocol suggests sanding intermediate-sized strips rather than single coupons that are hard to hold onto, or a whole 10 x 10 cm sheet that will produce more coupons than you will generally use at once. We found it easiest to cut and sand strips 2-3 cm wide; additionally, holding the lead strip with a Kimwipe over a gloved finger while sanding can avoid scratching or marking the fragile surface. To efficiently remove lead particulates from the surface and minimize contact by wiping, we used a squirt bottle to flood the strip with acetone, which easily lifted the particulates.

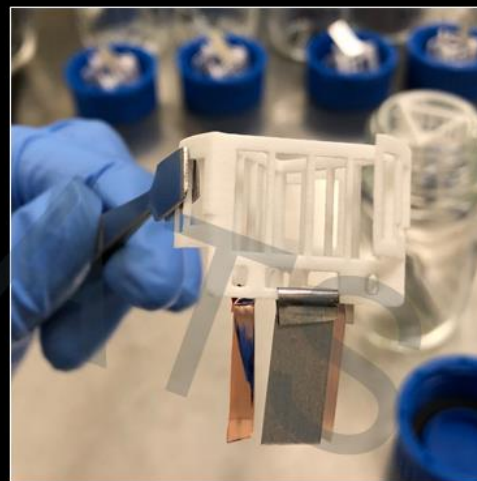
Easi(er) Setup and Breakdown: Handling your Heavy Metal



Cutting an intermediate strip of lead into strips the width of a single coupon



Cutting mat (top) and rounded tweezers (bottom)



Metal coupons attached to coupon holder

Due to its malleability, lead is more easily cut with a scalpel than with scissors; we used a small, dedicated cutting mat for this purpose. Though lead coupons are soft and easily folded around the coupon hanger, they are quite fragile and fussy to manipulate. Once a lead coupon has been affixed to the coupon hanger, any further handling of the hanger risks bending or dislodging the coupon. For this reason, we preferred to attach the lead coupons after the copper and silver coupons had already been affixed to the coupon hanger.

Easi(er) Setup and Breakdown: Handling your Heavy Metal



Gloves, KimWipes, and micromesh packaged as hazardous waste



Gloves (top), packaged for recycling (bottom)



Terracycle nitrile glove collection box for recycling

Our Oddy testing program generates a significant amount of nitrile glove waste. Gloves used while preparing lead have to be treated as hazardous waste, alongside the Kimwipes and micromesh involved in the process. We collect those materials in clearly labeled Ziploc bags for proper disposal. The other gloves used for coupon and sample preparation, however, can be saved separately for recycling.

Easi(er) Setup and Breakdown: Loosening Tight Lids



Jar pliers (left) and strap wrench (right)



Using two pairs of jar pliers to open a jar



Using two pairs of jar pliers and two pairs of hands to open a jar. Success!

When tests are removed after 28 days in the oven, the lids often require some effort to open; in some cases, quite a lot of effort; occasionally, herculean effort, bordering on the impossible. We believe that inconsistencies in lid manufacture have contributed to our struggles. The silver lining is that we have had very few issues with water loss in our tests!

But there are some tools that have helped us to open these difficult jars more safely. Two pairs of jar pliers can be used to grasp the lid and the jar. The MMA sometimes uses an inexpensive strap wrench, which is very effective. In lieu of these tools (or in the rare cases when they are unsuccessful), we have resorted to wrapping the jar in duct tape, adhesive-side-out, and assigning one brave person to hold the jar still while another twists the lid open.

Easi(er) Setup and Breakdown: Faster Flattening of Bent Coupons



Glass canning weights (left), and their use flattening copper coupons before assembling the test (right)

Once the test has been disassembled, the coupons need to be removed from the hangers and flattened for assessment. Glass canning weights work very well for this step; they are inexpensive, heavy, smooth, and can be easily cleaned of corrosion products deposited by spalling coupons.

Time Management

The tradeoff for a meticulous protocol is that it takes time to execute each step correctly and consistently. When you have hundreds of samples to test on short timelines, you also need to be efficient. There are some shortcuts that have allowed us to streamline the process.

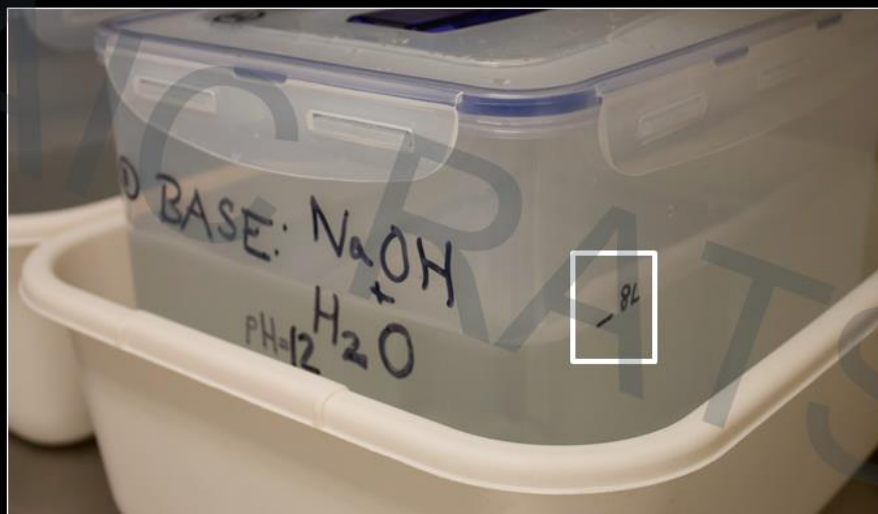
Time Management: Cutting Corners, Cutting Coupons



Ruler for cutting Cu coupons, marked at 2.5 cm (coupon length) and 0.8 cm (coupon width) increments

For example, marking our tools with measurement increments expedited cutting metal coupons.

Time Management: Modify for More Manageable Mixing



Base bath with level for total volume (8L) marked

Similarly, marking containers used in washing glassware allowed us to quickly mix detergent, acid, and base solutions. Washing was, in our experience, the greatest time cost in the process, so any small time savers were most welcome.

Time Management: Maximizing Space in Soaking Containers



Top-down view of the ideal “head-to-toe” jar arrangement in an acid or base soaking container



Jars packed into acid and base soaking containers

With a finite supply of glassware in our lab, we needed to wash our jars and vials and prepare them for reuse as quickly as possible.

We determined that we could most efficiently move jars through our acid and base baths by packing them in layers, “head to toe,” if you will, as pictured here. Using this arrangement, we could fit as many as 29 jars in our 8-liter container of solution, which really sped up the multi-day washing cycle. The best orientation of jars will depend on the dimensions of the container; taller containers might allow jars to stand upright, rather than lying on their sides.

Time Management: Taming Tiny Vials



100-mL beaker packed with glass vials while washing (left).

Pipetting deionized water into glass vials while setting up new tests (right).

The glass vials used in the Oddy test are too small to be similarly cleaned by immersion. Washing them involves pipetting multiple cleaning solutions and water rinses in and out of each vial individually, multiple times.

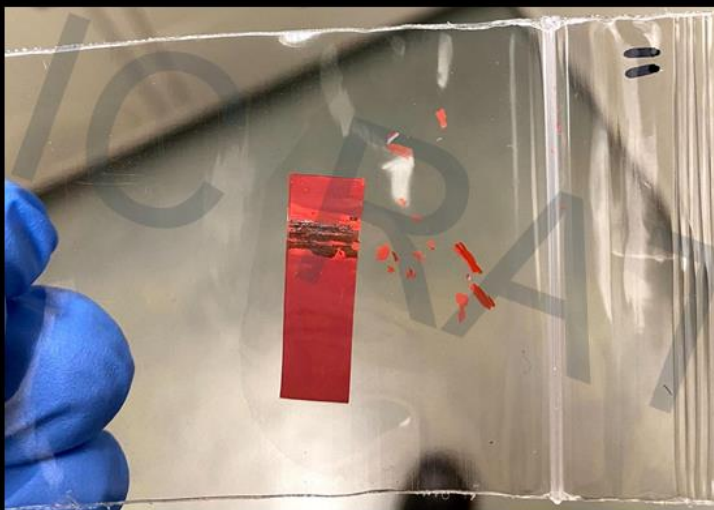
It is easier to pipette solution into the vials if they are packed tightly in a beaker because they prevent each other from moving around. Alayna Bone, who conducts Oddy testing at the MMA, shared a trick for emptying the vials as an alternative to pipetting water and detergent solution out of each individual vial: gripping a small handful of vials in a gloved fist and giving them one firm shake over the sink immediately breaks the surface tension and releases all of the liquid. Acid and base must still be pipetted out of the vials back into their respective baths or a waste container, but for water and detergent solution, this simple tip has easily saved us hours.

The beaker is also helpful when preparing new tests; if you learn the capacity of your beaker, you can quickly see whether your supply of clean vials is sufficient for the number of jars required for your next batch. A 100-mL beaker, for example, will fit 40 vials.



Comprehensive though it is, the Metropolitan Museum of Art's protocol, like any Oddy test protocol, is not invulnerable to the impact of external factors. Occasionally things unexpectedly went wrong that were not addressed by the protocol, and we were required to develop solutions to manage them. We will conclude this paper with one such complication: a significant lab contamination event.

Troubleshooting: Isolating a Lab Contaminant



Heavy red corrosion product formation on a copper Control coupon

After baking a batch of samples, we began disassembling the jars and preparing the coupons for assessment. We noticed that all of the copper coupons in the batch, including both Controls, were abnormally corroded.

A different batch of samples, prepared by a different conservator, was halfway through the baking period in the oven, and a quick glance into those jars revealed the same unusual corrosion on all of those copper coupons. Immediately, we could assume that this issue was not due to one person's error in preparing the tests and instead began to suspect that we had a contaminant in our Oddy test assembly.

Troubleshooting: Isolating a Lab Contaminant

Round 1: Testing Lab Supply of Copper / DI Water / Glass Jars				
	Cu	DI Water	Glass Jar	Result
New Supply Test	New	New	New	Corroded
Lab Supply Test	Lab Supply	Lab Supply	Lab Supply	Corroded
Water Test	New	Lab Supply	New	Corroded
Glass Jar Test	New	New	Lab Supply	Corroded
Copper Test	Lab Supply	New	New	Corroded

Both of the batches at issue used jars from the same clean storage shelf and were prepared using the same sheet of copper foil; we considered that the jars might have become contaminated, or that there could be impurities in the copper. Or perhaps our copper coupons were being affected by contaminants in the deionized water used in each jar.

Based on this initial thinking, we prepared 5 test jars in an effort to identify any one of those components (copper, water, or jars) as the source of contamination. The first test used components from our standard lab supply. A second test contained all newly sourced components. And each of the final three tests included one component from lab supply in combination with new components. Silver and lead appeared unaffected by the contaminant, so in the interest of conserving materials, these investigative tests contained only copper coupons.

After only 5 days in the oven, the copper coupons in all five jars had developed extremely thick red corrosion.

Troubleshooting: Isolating a Lab Contaminant

Round 2: Testing Lab Supply of Solvents / Air			
	Solvents	Air	Result
New Supply Test	New	New	Corroded
Lab Supply Test	Lab Supply	Lab Supply	Corroded
Solvent Test	New	Lab Supply	Corroded
Air Test	Lab Supply	New	Corroded

We ran a second round of tests, this time comparing copper coupons prepared using newly acquired solvents with those prepared using solvents from the lab supply.

Since we conduct our Oddy testing in a shared lab also used for osteological specimen preparation, we considered it possible that the ambient atmosphere in the lab itself might have been affected, perhaps by vapors emitted from a massive drum of formaldehyde stored nearby. Consequently, this second round of tests also compared jars sealed with air from the Oddy testing lab to others sealed with air from a different part of the Museum.

After one week, the result in this second test was the same: all of the copper coupons were entirely coated in a thick, matte, red corrosion product.

Troubleshooting: Isolating a Lab Contaminant

Round 3: Testing Lab Supply of Coupon Hangers / O-rings / Lids				
	Coupon Hangers	O-rings	Lids	Result
O-Ring and Lid Test	New, Stainless Steel (MMA)	Lab Supply	Lab Supply	OK
New Supply Test	New, Nylon (AMNH)	New	New	OK

At this point, we had 70 sample materials waiting to be tested, and we had eliminated the glassware, copper, deionized water, solvents, and the very air itself as the culprit, so the only way forward was to test the non-glass test assembly components: the lids, O-rings, and sintered nylon coupon hangers. In the first and second rounds of investigative tests, we had reused lid components that had earned Permanent ratings in previous tests, been cleaned following the plastics washing protocol, and then been stored in our cabinet in large glass beakers covered with aluminum foil. We reached out to Eric Breitung at the MMA for guidance. He suggested that we run a test using one of the MMA's stainless steel coupon hangers. At the same time, we had just fortuitously received a shipment of brand-new lid components.

We conducted a third round of tests with differences only in the lid components. One jar contained a reused lid and O-ring from our lab supply cabinet, paired with a stainless steel coupon hanger from the MMA. The second jar contained all brand-new and freshly washed lid components that had never seen the inside of our lab.

After one week, the copper coupons in both jars were pristine. These results suggested that our supply of sintered nylon coupon hangers were the smoking gun and had absorbed a harmful compound that must have evolved inside the storage cabinet.

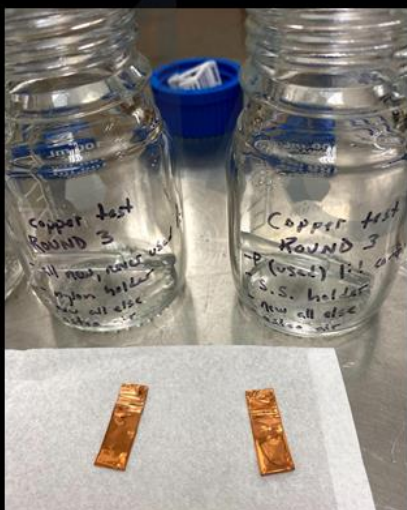
We ran a fourth and final round of tests to confirm this suspicion.

Troubleshooting: Isolating a Lab Contaminant

Round 4: Testing Lab Supply of Coupon Hangers				
	Coupon Hangers	O-rings	Lids	Result
Coupon Hanger Test	Lab Supply	Lab Supply	Lab Supply	Corroded
Coupon Hanger Test (Replicate)	Lab Supply	Lab Supply	Lab Supply	Corroded
O-ring and Lid Test 1	New, Nylon (MMA)	Lab Supply	Lab Supply	OK
O-ring and Lid Test 1 (Replicate)	New, Nylon (MMA)	Lab Supply	Lab Supply	OK
O-ring and Lid Test 2	New, Stainless Steel (MMA)	Lab Supply	Lab Supply	OK

This final round of tests used combinations of new and old nylon coupon hangers, lids, and O-rings. Results affirmed our assessment that the nylon coupon hangers were the only contaminated component in our lab supply. One of our nylon coupon hangers was analyzed at the MMA using GCMS, and hydrochloric acid was detected in the sample. Though we never conclusively identified the source of contamination, we suspect that the nylon coupon hangers might have absorbed vapors from a small bottle of hydrochloric acid that was improperly stored at the back of the storage cabinet. We discarded our old supply of nylon coupon hangers and our testing program was able to proceed without further disruption.

Troubleshooting: Isolating a Lab Contaminant



Pristine copper coupons from investigative testing using **new** nylon coupon hangers



Heavily corroded copper coupons from investigative testing of various assembly components, using **lab supply** of nylon coupon hangers

Our experience suggests that the nylon coupon hanger may be the component of the Oddy test assembly that is most vulnerable to absorption of harmful compounds. Since this event occurred, updates to the MMA protocol now specify the use of stainless steel coupon hangers rather than the nylon. However, in the event of a suspected contamination, those still using nylon coupon hangers should consider this the first place to look.



In this presentation we have shared with you: several simple, pragmatic adaptations to maximize efficiency within an exacting protocol, especially accounting for the involvement of multiple users assisting with the procedure; we have detailed our efforts at integrating cost management and a few provisions for sustainability; and we have walked you through our experience of troubleshooting and identifying a contaminant that acted as a spanner in the works.

Our process and learning have benefitted from numerous collaborations, both within the AMNH and with our colleagues at the MMA, and we give our thanks to all those who have helped us by generously sharing their expertise and problem-solving insights. Whether you use the protocol developed by the Metropolitan Museum of Art or another institution, we hope that some of what we have shared here will be helpful to you in optimizing your own Oddy testing practice.

Imaging Illuminated Manuscripts with Multi Light Reflectance and the use in Conservation. Past and Future

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Original Abstract

Art technical research on illuminated manuscripts has a long and broadly elaborated history. Visual inspection always stood central, but in more recent times an arsenal of additional analytic micro and macro technologies have been added to the spectrum of research methods. As such, manuscripts are the crossroad of information and during advanced conservation research, historical context, materiality, content and technology are coming together. In the field of heritage science applied to manuscript and conservation studies, scholars and conservators deploy methodologies from the humanities and exact sciences to increase the understanding of heritage artefacts through the use of advanced technology and infrastructure. This evolution was initiated when digital involvement entered the conservation lab and beside advanced hands-on skills, treatments before and after conservation have to be more and more supported by detailed documentation.

One of the methods is a Multi Light Reflectance (MLR) imaging technology, a method to inspect and analyze the topography and spectral surface characteristics of paper, parchment and miniatures. The microdome module of the Portable Light Dome (PLD) system has been specially designed for the imaging manuscripts, i.e. facilitating stable and safe positioning of the acquisition device hovering above a manuscript opened up and laying in a book cradle, inside the binding. By combining MLR imaging with Multispectral (MS) imaging, this PLD system presents itself as a calibrated integrated tool that delivers the benefits of these both technologies.

In the presentation the focus is laid on three case studies revealing practical functionalities of the PLD system for the documentation and study of manuscripts during conservation (Illuminated Book of Hours, Flanders, 15th century (KU Leuven Libraries, Ms 283); Rijmbijbel, 13th century (KBR 15001); Illuminated Bible, Naples, 1340 (KU Leuven, Maurits Sabbe Library, Ms 1). The methods are interactive relightings & visualizations, measuring topography, analyzing, characterizing and identifying materials.

The implementation of the Pixel+ Viewer will give conservators and scholars the possibility to access the dynamic images of the studied and conserved object on an interactive way (<https://www.heritage-visualisation.org/pixelplusviewer.html>). The pixel+ viewer is an open source tool to visually analyze the surface of artefacts. It goes beyond traditional photography

as it allows the user to virtually interact with the surface of the object by manipulating the light and enhance specific characteristics of the surface.

In situ hyperspectral imaging of monumental oil paintings: practical approaches within an interdisciplinary context

Jan Dariusz Cutajar^{1*}, Federico Grillini, Agnese Babini, Jon Yngve Hardeberg, Tine Frøysaker

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Original Abstract

In this contribution, the authors' collaborative work – between conservators, conservation scientists and imaging scientists – targeted the evaluation of hyperspectral imaging for the in situ documentation of previous cleaning treatments of the monumental University of Oslo (UiO) Aula unvarnished oil paintings on canvas by Edvard Munch (1909-1916). The project forms part of the pan-European CHANGE-ITN consortium which is implementing the integration of imaging technologies in conservation practice, by an interdisciplinary team of heritage and imaging researchers-in-training.

The imaging campaign in its own right presented several challenges, which required creative and adaptive thinking to resolve. This was especially since costly, specialized equipment for large-scale scanning (such as that used by the Rijksmuseum on Rembrandt's *Nightwatch*) was not available at either collaborating institution. The vast scale of the paintings required targeted solutions to work on scaffolding as closely as possible under standardized acquisition conditions, whereas the limited access to the paintings dictated laboratory preparations to account for the unpredicted conditions in the UiO Aula so as to maximize on the scarce time available for scanning.

This paper therefore presents the practical approaches adopted by the team that allowed for resource-sharing, cooperation on site and the ensuing focused interpretation of results. In particular, the talk presents the joint discussions from a conservation perspective between team members that gave rise to the protocols adopted for technical aspects such as corrections for distortion and for non-uniform lighting conditions. Adaptations for operation of the hyperspectral cameras used (Norsk Elektro Optikk HySpexTM VNIR1800 and SWIR384 cameras) on scaffolding are shared, together with a proposed workflow for similar operations that can be used and modified in other acquisition campaigns for monumental paintings, there where costly equipment such as robotic arms are not available to the heritage researcher.

Overall, by presenting unpublished details of the first ever hyperspectral acquisition campaign in the Aula, the paper aims to contribute to filling the paucity of accessible literature for the conservation audience on practical working guidelines for the imaging of monumental paintings on site. This work will thus propose a collaborative-based guidance for improved non-

contact identification of preparatory and pigmented material mixtures used in large-scale unvarnished oil paintings on canvas with exposed grounds. Ideally, this will serve to furnish a practical hyperspectral imaging toolkit, as part of the lead author's doctoral project, for adoption into conservation practice for the care and study by conservators of these and other related monumental unvarnished oil paintings.

Annotated Presentation



In situ hyperspectral imaging on monumental oil paintings: practical approaches within an interdisciplinary context

Jan Dariusz Cutajar (MA, MSc)

MSCA Doctoral Research Fellow
Conservation Studies, University of Oslo

with **Federico Grillini, Agnese Babini, Jon Yngve Hardeberg, Tine Frøysaker**

This presentation talks about how in situ hyperspectral imaging of a monumental oil painting in central Oslo has been undertaken by the undersigned research team during February 2021, within the framework of the CHANGE-ITN project (www.change-itn.eu). Specifically, these slides focus on methodological workflows which can be adapted for similar projects on monumental-scaled artworks, there where low-cost options are required and time is of essence. It therefore should be kept in mind that these guidelines are not exclusive, and that there are other options and other pieces of equipment that can be used in these scenarios.



Agenda

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- 1 **COLLABORATION** Meet the team and see how we worked together on the project
- 2 **HSI FOR MUNCH'S AULA** Hyperspectral imaging, monumental paintings, and all the challenges
- 3 **PRACTICAL APPROACHES** Discussions on adapted methods and the workflows used in the Aula
- 4 **PROCESSING DATA TOGETHER** Collaborative outcomes and interpretations of results
- 5 **CONCLUSIONS** Summary, publications and next steps

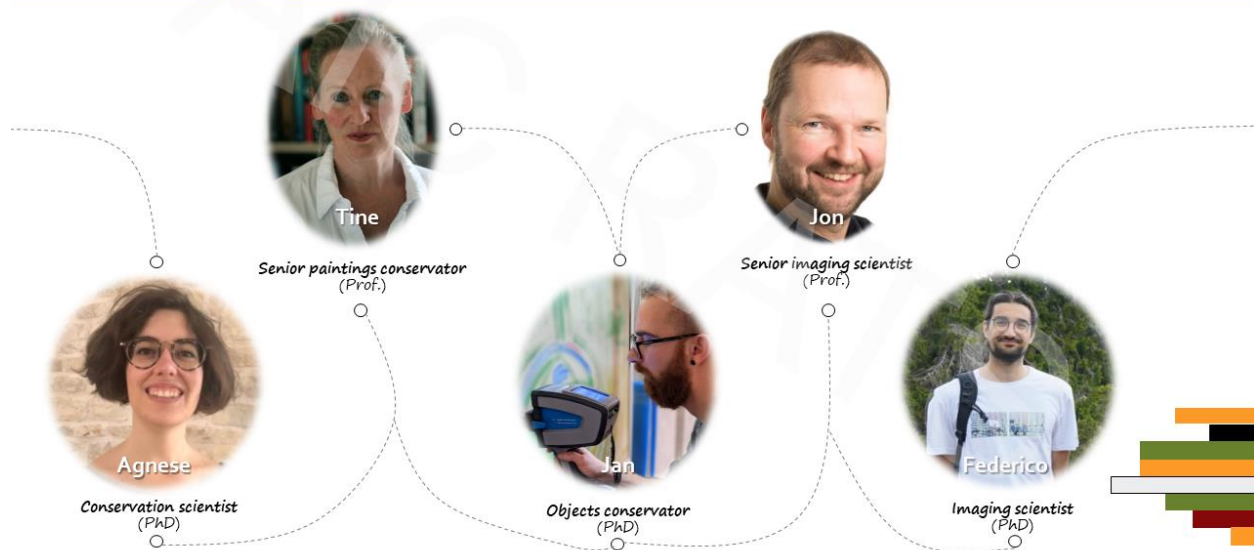


The presentation is split into five sections as outlined above. This project was successful thanks to a high degree of interdisciplinary collaboration at all moments, and therefore it is apt to introduce the participating team first. The next section brings readers up to scratch on hyperspectral imaging (henceforth referred to as HSI), and introduces the context of Edvard Munch's (1863-1944) monumental Aula paintings (1909-1916) in Oslo, and the challenges associated with conserving and imaging them. The third and major section of this presentation presents and discusses the adapted workflows used in the imaging campaign in the Aula. No HSI acquisition is complete without a post-processing phase, and this is what the fourth section talks about, with a taste of results generated and interpreted collaboratively. The final section ties all the previous ones together by providing a summary, and indicating forthcoming publications related to this project.



Collaboration

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SECTION 1

Here is the interdisciplinary team that coordinated and carried out this work. Tine is a senior paintings conservator at the Conservation Studies department at the University of Oslo. She is the direct supervisor of this project, and as such has been key in providing access to the Aula paintings and overseeing the research process. Jon is a senior imaging scientist at the department of Computer Studies at NTNU Gjøvik and has generously allowed access to all the HSI equipment that has been used. The team would not have been complete without Agnese and Federico, a conservation scientist and an imaging scientist respectively, with whom I, an objects conservator, collaborated heavily, especially *in situ*. Hours of conversation took place between all of us in order to develop a common language with which to work effectively and consistently, at all stages of the project. Each person's specialization permitted the resolution of particular challenges, and allowed for rich on-the-job training exchanges.

Should you wish to contact any of us, here are our email addresses:

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Agnese – agnese.babini@ntnu.no

Federico – federico.grillini@ntnu.no



Collaboration in the CHANGE consortium

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Search for: "CHANGE-ITN video EU"



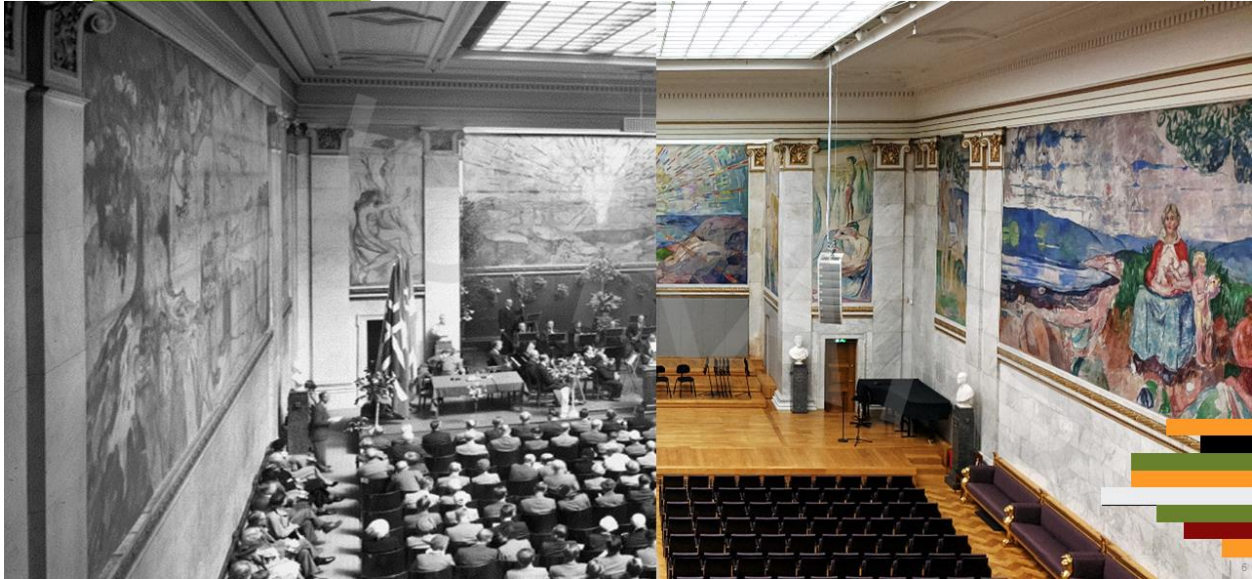
14 PhD researchers from across all disciplines around Europe

The collaboration discussed here did not stop at project-level. Indeed, it expanded at a pan-European level, as this research study forms part of a larger project entitled CHANGE (Cultural Heritage Analysis for New Generations). Without the discussions and back-and-forth with our CHANGE colleagues, life would have certainly been much harder. You can learn more about this project by following any of the social media handles listed above. You are also invited to watch the YouTube related to this project, by searching for "CHANGE-ITN video EU" online.



SECTION 2

This is the University of Oslo Aula (built in 1911), found at heart of Oslo and also in the hearts of many Norwegians. It is a listed heritage site which has seen the Nobel Peace prize awarded for many a decade, and is the site of constant musical and cultural events. It is also the site where Edvard Munch's eleven monumental unvarnished oil paintings on canvas hang, the only *in situ* monumental collection of his paintings which still hangs in its original context. The paintings were made between 1909 to 1916, and were first displayed more than over a hundred years ago.



Ever since their first display, these unvarnished paintings immediately started collecting soiling upon their surfaces, such that only after their first decade of hanging, they were already in requirement of conservation, and this within Munch's own lifetime. On the left, you can see a shot from the 1950s displaying very notable soiling grid marks on the painting known as *Historien*. These grid marks form as a result of so-called "cold bridges" upon which dirt preferentially settles. As a result of their being unvarnished in a frequently used room found at the center of a then-polluted city, these paintings were cleaned at least seven times within the past seventy years! This is considerable as one would usually predict a painting would need cleaning once every half a century, and a result the materials on these paintings have become ever more fragile than they originally were.



Given that the Aula paintings comprise more than 200 m² of painted surface, this project has limited itself to focusing primarily one of the paintings found at the back left corner of the room. The painting, here displayed above, is entitled *Kjemi* in Norwegian, or *Chemistry* in English (1914-1916, Woll no. 1227). All images and discussions in this presentation are related to this painting, unless otherwise stated.



HSI for Munch's Aula

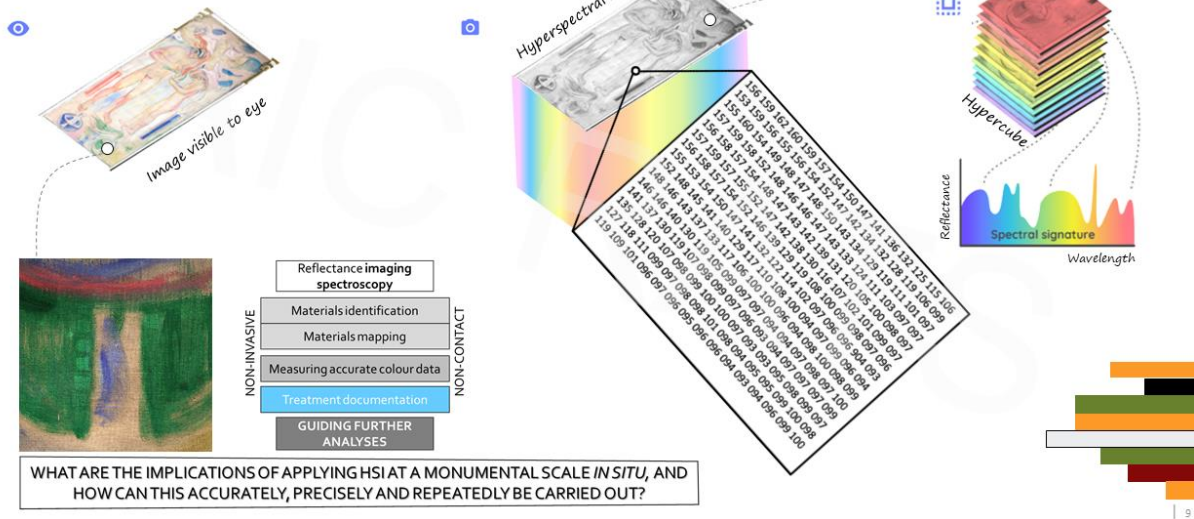
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The research questions shown here are related to my doctoral studies and will allow us to contextualize further this discussion in the space of the Aula. The research team led by Tine (Munch Aula Paintings Projects, MAP) has been addressing the issue of finding the best means to treat the unvarnished oil paints and exposed grounds for several years now. Any future treatment that would take place would be carried out across a massive area, and therefore it will be necessary to document any such cleaning campaign as accurately and reliably as possible. This is where HSI comes into the question, and its advantages as a non-contact, non-invasive analytical technique could come into play. But what are the implications of using HSI at a monumental scale *in situ* and how can conservators and conservation scientists accurately, precisely and repeatedly carry this out?

HSI for Munch's Aula

HSI & PROJECT AIMS

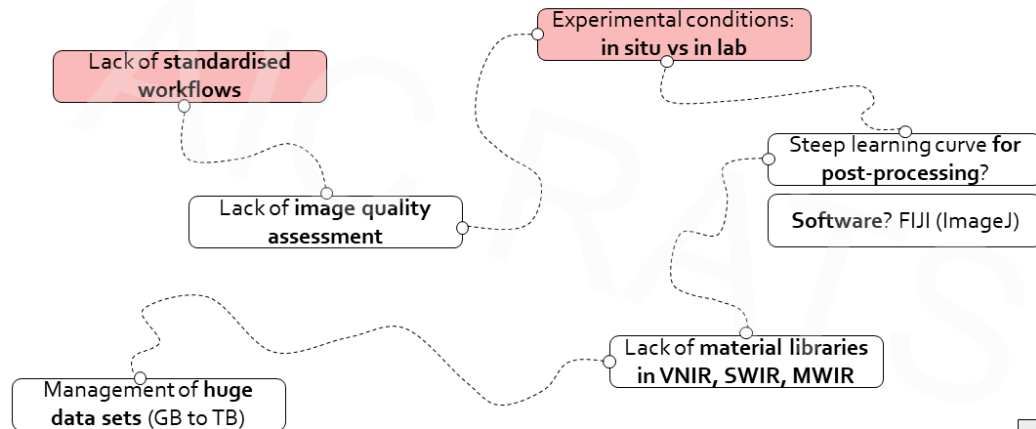


Talking of HSI, what is it exactly? Contrary to what our eyes allow us to see (shown on the top left), hyperspectral images can span large sections of the electromagnetic spectrum and can range from just short of the UV all the way down through the visible and different sections of the infrared region. One can think of a hyperspectral image as a continuous stack of greyscale images, each one captured at a different wavelength (see to the top right). The power of these images lies in that for every pixel on the image, not only do we have spatial information, but also spectral information that is characteristic to a material.

Another way of thinking of hyperspectral images is as a 3D matrix of values (see center right), which we can manipulate statistically to draw further understanding from our image. This will become relevant towards the end of this presentation.

One should always be aware as to why in particular HSI is being used. In this case – in addition to the usual aims of reflectance imaging spectroscopy (bottom left), a synonymous term for HSI – the aim was to use HSI in order to capture any surface changes that had resulted from a set of cleaning tests carried out on *Kjemi* (bottom far left) during 2008 as part of the MAP project.

MORE CHALLENGES

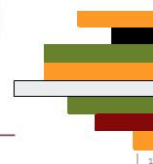


It is important to note that although HSI offers exciting avenues into materials research for conservation purposes, it in itself is fraught with a number of challenges. These are highlighted on this slide. In particular for our interest, it is good to note at the time of presenting, the literature does not yet offer any encompassing standardized workflows for HSI scanning of artworks (and certainly not for works at a monumental scale): all guidelines and recommendations are applicable to controlled laboratory contexts, and none for *in situ* scanning of heritage surfaces. Works like this and others in the community are working towards this goal (for example, there is an IEEE technical committee that should be publishing a standard in the next few years).

Another point is the steep learning curve involved with post-processing, post-processing software and script coding. To overcome this, this talk proposes the use of an open-source freeware called FIJI (Fiji Is Just ImageJ) – the use of this software will be touched upon shortly.

Push-broom cameras

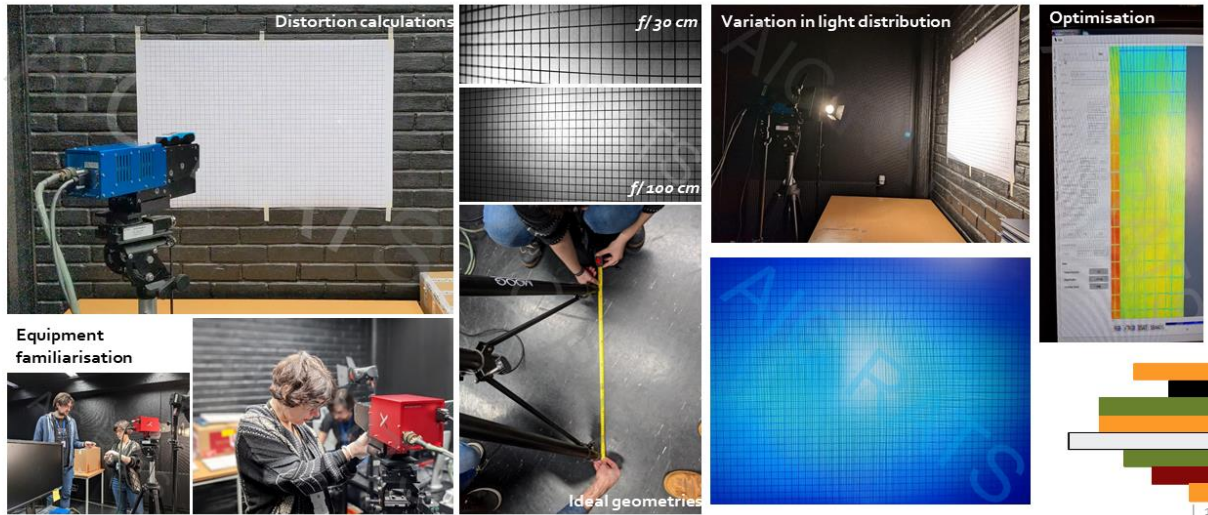
	HySpex VNIR-1800	HySpex SWIR-348
Spectral range	400 - 1000 nm	930 - 2500 nm
Number of bands	186	288
Pixel resolution @30cm	~ 50 μ m	~ 220 μ m



SECTION 3

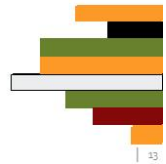
Within this project, the HSI cameras you see here were used, generously provided the NTNU Colourlab. During the Aula campaign that took place in February 2021, this HySpex® visible-to-near-infrared (VNIR) and shortwave-infrared (SWIR) camera were utilized for data capture. The most important thing to take note of here is that between the both of them, these cameras allowed for images to be taken between 400 to 2500 nm. Due to their physical properties highlighted above, the images from the cameras could not be fused together, but this is something which our colleague Federico is working on for his doctoral research. Another thing to point out is that mid-infrared (MIR) cameras were not used in this campaign, and therefore the direct signal of soiling upon the painting surface could not be detected, but only its indirect presence. This is since the chemical signature of soiling tends to fall within the MIR range (2 500 to 15 000 nm). Further studies into this are being carried out by the undersigned research team.

LAB PREPARATIONS



Access to the Aula was granted for a short and limited time period only, and therefore laboratory preparations prior to the campaign were key to developing an effective and efficient workflow. These trial HSI scans at the NTNU Colourlab in Gjøvik also allowed Agnese, Federico and myself to familiarize ourselves thoroughly with the cameras (bottom left) as we dismantled them and put them together, building a common vocabulary of reference. Whilst in the lab, we also calculated the effect of optical distortion for each lens as the angle of view was changing using a rotating tripod, allowing us to predict the maximum angular interval that defined how wide our regions of interest (ROIs) could have been (top left and center). The ideal geometries for the halogen lamps used to provide lighting were also estimated, based upon the best quality signal and integration time (i.e. “exposure time”) for each camera and lens (bottom center). In relation to this, the variation in light distribution was also studied, and the parameters of capture optimized according to our findings (right). All of this information was to be of great use during capture on site, as well as during post-processing.

IN THE LAB: SETUP

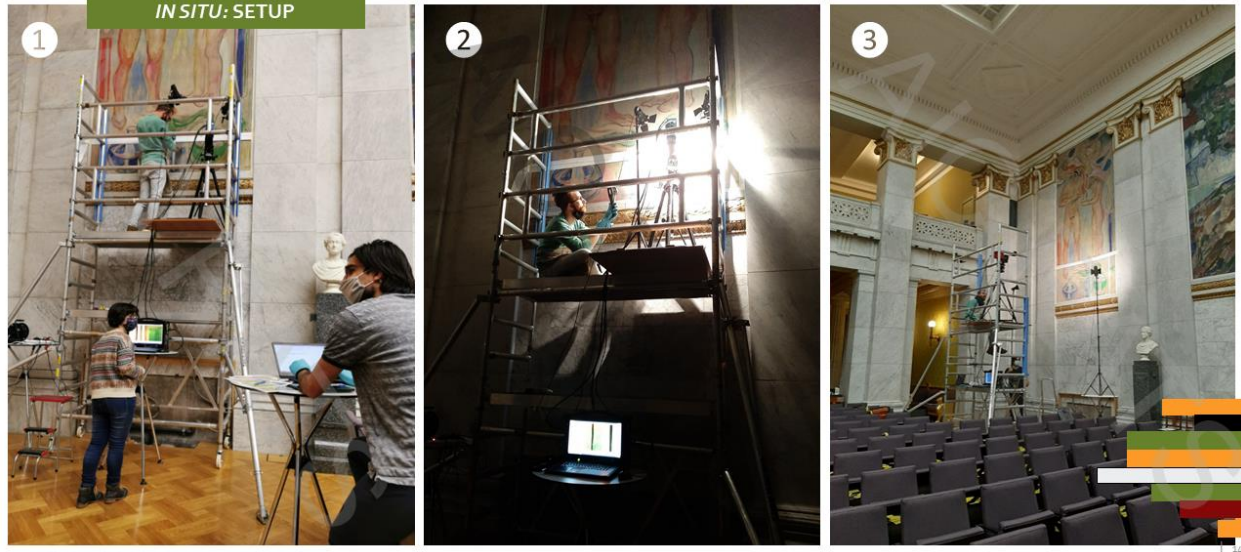


Before going on to describe our setup *in situ* within the Aula, here is an example of a HSI setup within the laboratory*. Lighting and camera geometries are strictly controlled and quantifiable, with the sample in question (some paint mock-ups related to this study) being translated across the field of view of both cameras simultaneously. The setup is stable with all components fixed in position.

*This setup was designed by Federico for his doctoral research. The pros of this system are that it is fast, efficient and both cameras have very similar lighting geometries. To keep in mind are two points: the high thermal output of the lights, and some slight shadows that might be captured as a result of the specific lighting geometry.

Practical approaches

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The reality of the situation in the Aula, however, was quite different from that in the lab. First and foremost, we were working from a scaffolding; lighting conditions were much harder to regulate, and all the advantages of a fixed lab setup could not be drawn upon.

The subsequent slides address how we adapted to this non-ideal situation, and will talk about, following the numerals on the slide: (1) scaffolding arrangements and communication, (2) temperature monitoring and lighting, and (3) light distribution.

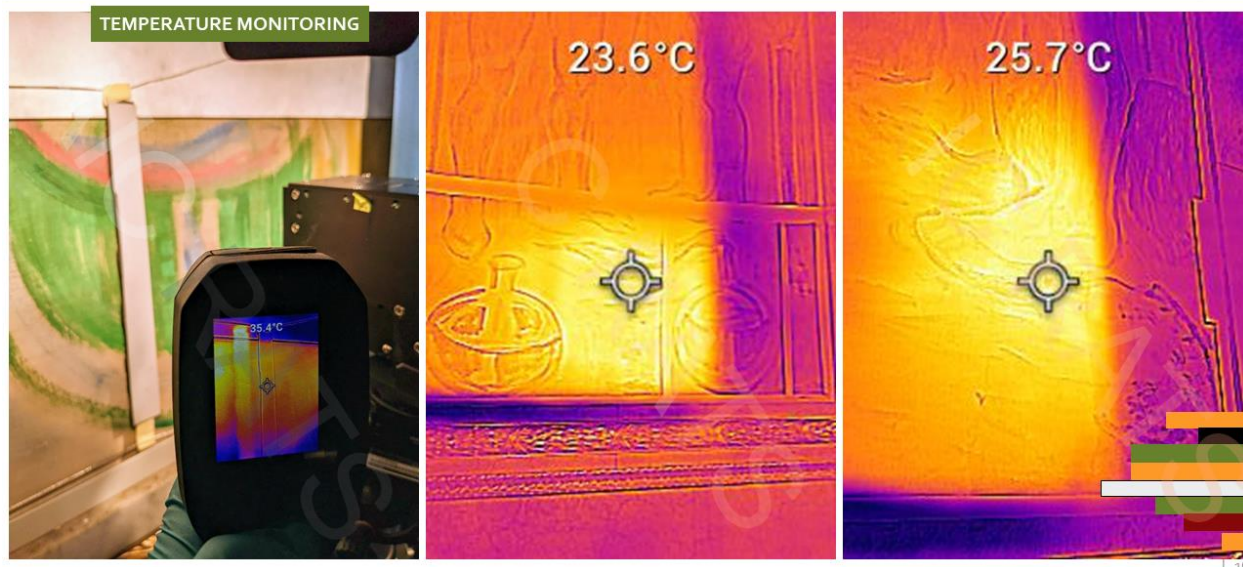


(1) scaffolding arrangements and communication

Here is the scaffolding setup used within the Aula. The scaffolding reached a height of 6.0 m, the legal height at which a scaffolding can be used without any special permits. Although it was supported by diagonal stabilizers as shown in the image, vibrations were still well-felt with the smallest of movements, which had an impact on the noise registered during HSI capture. The bottom hang of the paintings began at 3.5 m, and the paintings went up by another 4.5 m. This meant that with this scaffolding (which was readily available for use at Conservation Studies, UiO) only the bottom half of the painting could be safely accessed.

The scaffolding was divided into two levels for logistical organization. The bottom half was purposed as a “PC station” to house the cameras’ stations for operation. This allowed the most comfortable wire connections to be made, which was important to consider given the limited space for movement on the upper level when in vicinity to the painting. The latter upper level was turned into the “camera station”. It soon became evident that moving the camera tripod by its legs each time was cumbersome, fastidious work that also involved certain risk. For this reason an upturned table was used to serve as a sliding platform, and minimize changes to the geometry of the setup.

The focus on getting to know each other and our equipment during our lab preparations paid off very well whilst working on the scaffolding, as this allowed us to communicate very clearly and efficiently in a scenario where caution, risk mitigation and health and safety were of importance.



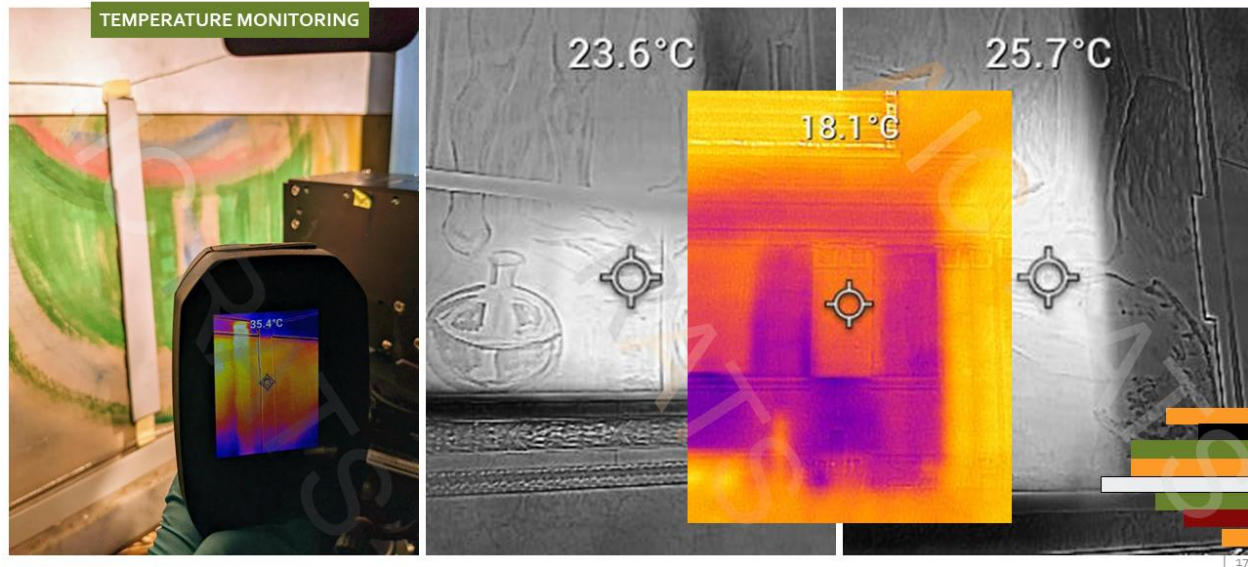
(2) temperature monitoring and lighting

When it comes to HSI scans, it is important to keep in mind lighting conditions, but likewise it is also crucial to keep in mind the potential detrimental effects of said lighting on the artworks. Given that the Aula was shut for public events during the pandemic and therefore lights in the room were not used at maximum capacity, the luxhours of light received by the paintings during the acquisitions were deemed to be acceptable. The halogen lamps that were used also generated a considerable amount of heat via infrared (IR) radiation, and therefore the surface temperature of the paintings was always monitored during scans. The temperature was not allowed to rise above 30°C, which is safely below the glass transition temperatures for many polymers (generally between 45-80°C) found on oil paintings. This is shown in the above IR thermographs*.

*Please note, the thermograph on the left indicates a temperature above 30°C, but this was registered for the reference standard surface, and not the painted surface.

Practical approaches

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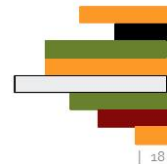


Notably, the room temperature was approximately 18°C, as shown above, and the surface temperature of the painting was on average 23°C. As such the surfaces were measured to have experienced a mean thermal change of 4.2°C over an acquisition of roughly 20 minutes.

Practical approaches

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LIGHTING GEOMETRIES



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To continue on the theme of lighting, in the center of the slide you can see the ideal setup and lighting geometries that were devised based on our laboratory preparations. However, from the first initial trial scans up on the scaffolding, it became clear that this arrangement was slightly idealistic for in situ work in the Aula.

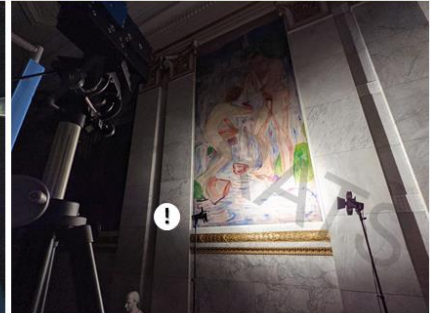
Practical approaches

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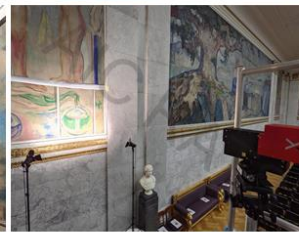
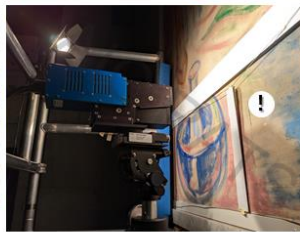
LIGHTING GEOMETRIES



Lighting setup for $f/0.3$ and 1 m



Lighting setup for $f/3\text{ m}$



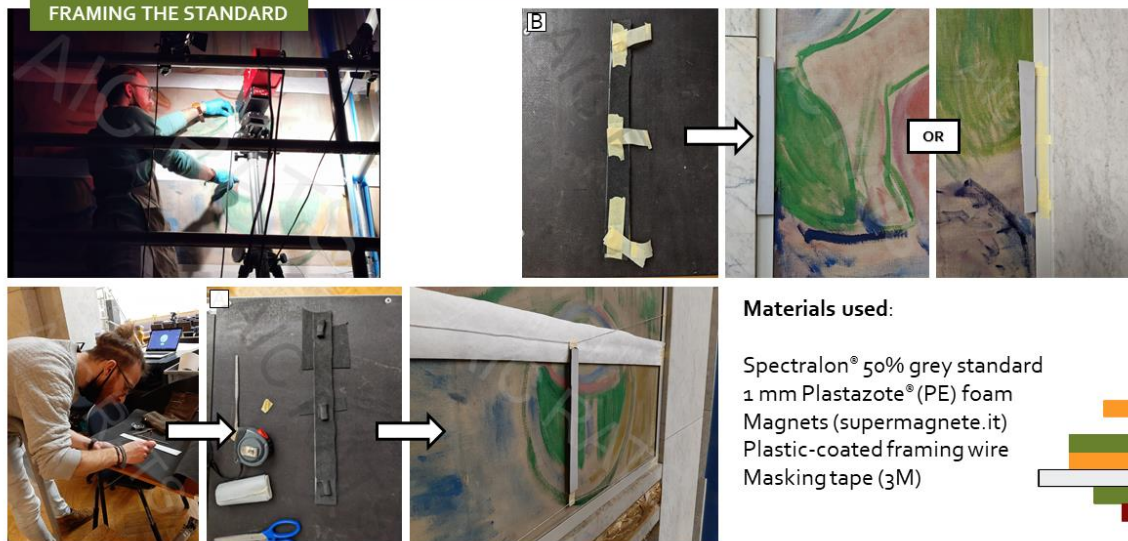
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Instead, different lighting arrangements were needed to obtain the best spectral signals and lighting distributions during scans. Some of these arrangements are shown above, with the halogen lamps on tripods on the scaffoldings, attached to the scaffolding itself, or - in the case of the scans taken from a focal distance of 3.0 m - with the lights extended at the topmost of the tripods whilst standing on the ground. These lighting conditions were less than ideal, and although they introduced a known source of error in the acquisitions, the required results did not necessitate “laboratory-perfect” outputs. The key point to bear in mind in these situations is to maintain best practice as is feasible and practicable, in a transparent and recordable manner so as to permit repeatability and reproducibility of measurements, and ensure faithful interpretations of data in the future.

This leads us on to the next points on standardizing light distribution and spectral distribution from the light sources.

Practical approaches

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(3) light distribution

It is of utmost importance to always include a white or grey standard reference in the field-of-view of any HSI acquisition. This is since the standard is necessary to perform post-processing corrections of the datacube, without which it would be rather complex to interpret the information collected (in technical jargon, this process is called *normalization**). During these acquisitions, a 50% grey standard Spectralon® reference was used.

In the case of the monumental Aula paintings, keeping the standard in view was easier said than done as there were no proper means of attaching the standard to the painting surface. Attempts to hold the standard (top left) proved to be unviable due to potential movements by the operator which would introduce noise into the acquisitions. For this reason, an improvised method was developed on site (see (A) bottom left) as shown above using the listed materials. A Tyvek™ (non-woven spun polyester fiber) sheet was stretched across the painting (and attached to the frame using masking tape) to protect the surface that was not being scanned. Across this, a plastic-coated framing wire was also stretched across and secured to the frame, so as to allow the Spectralon® to be hung in-between two levels of wire to fit into the required frame of capture. The Spectralon® itself was modified at the verso to protect the paintings surface using Plastazote® affixed with magnets (also covered in Plastazote®).

In some cases, it was also possible to use the frame itself to attach the standard and these methods can be seen above (see (B) top right).

*A small note on technical terms: *normalization* is a form of spectral calibration which requires a standard material of known reflectance. Flat-fielding, another term found in the literature, is another form of correction used when light does not fall uniformly on the ROI – a

standard material is not necessarily needed but it needs to be flat and uniform in color as the ROI – the next slide will clarify this through an example.



Practical approaches

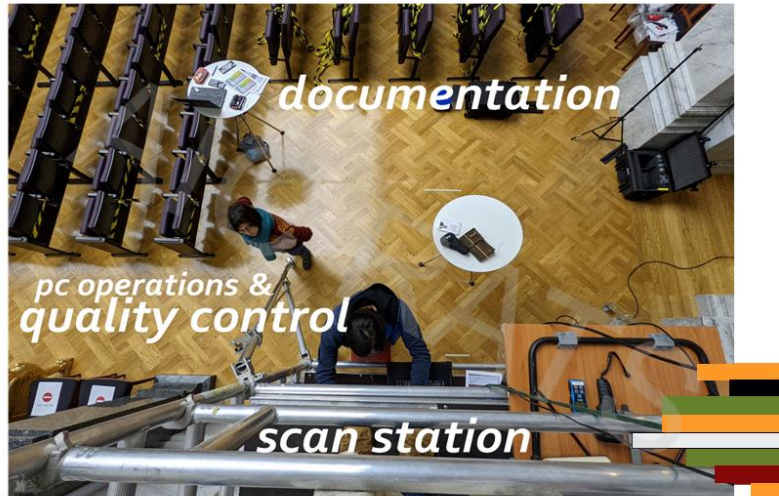
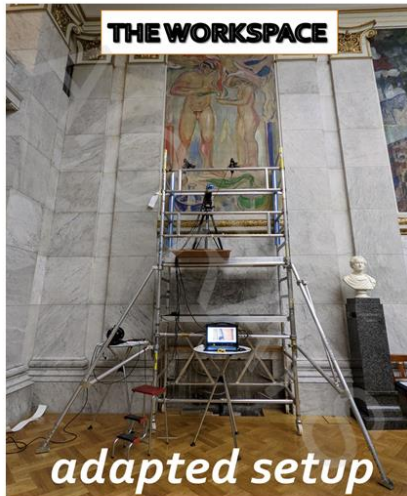


One particular adaptation was necessary for the HSI acquisitions taken at focal distance of 3.0 m. There is no known commercially available standard that extends the entire length of the field-of-view of this lens, and therefore an indirect, roundabout way was used to capture and calculate light and spectral distribution for later *flat-fielding*.

A sheet of matte, white blotting paper with a surface texture more or less similar to that of the painting was selected as a replacement for the Spectralon® standard. It was important to ascertain that the paper was free of optical whiteners, the fluorescence of which would interfere with spectral calibrations. This is easily done by shining a UV light (UVA should suffice) in the dark onto the paper - if the paper fluoresces (usually a very bright white or blue-tinged white) then it should not be used for this purpose.

The blotting paper was introduced into the field-of-view using the same method as for the Spectralon® reference, and was hung taut and planar to the surface (it is crucial that it is as planar as possible to have as much as possible the same lighting distribution as on the painting surface) using masking tape. The blotting paper does mask certain areas of the ROI, and therefore if conditions are all kept constant, a repeat scan of the same area can be taken without the blotting paper then.

A WORKING PROTOCOL



To wrap up this section, the following slides will provide a possible working protocol for carrying out HSI acquisitions *in situ* on a scaffolding. The adapted setup is shown above on the left. The workspace is divided into three sections (right), and each should be ideally occupied by one person. This means that a team of at least three people is necessary to perform any form of *in situ* HSI capture.

The **documentation station** is where all acquisitions are managed and documented. All metadata is registered here prior to and after every scan. Any modifications to setups should be noted in the interest of repeatability of experiments.

The **PC operations and quality control point** is where the cameras are remotely controlled through the software. The operator here is responsible for managing the scan parameters, optimizing them as required and reporting to the operator at the documentation station. The quality of scan data is also checked here with a trial scan prior to the actual acquisition of data.

The **scan station** is where the camera is found and is manually supervised and surveilled. It is recommended that this operator is a conservator familiar with the apparatus who can closely monitor the artworks during scans as well as the equipment itself. Communication from the scan station with the other stations is absolutely key, and should be well established prior to any scan campaigns.



Practical approaches

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A WORKING PROTOCOL

Photos by J. Cutajar and A. Babini



The proposed workflow for HSI acquisitions in the context of monumental paintings is presented as follows in 12 consecutive steps. The workflow is particularly adapted for situations where different lenses are being used, which necessitates recalibration of the scan station at each lens change.

Affix standard: up on the scaffolding, the reflectance standard should be placed into the desired ROI, securing that it is stable and planar to the artworks surface.

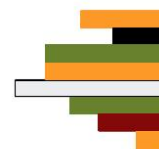


Practical approaches

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A WORKING PROTOCOL

Photos by J. Cutajar and A. Babini



Change lenses: on the ground, the appropriate lens should be inserted into the camera of choice. Keep in mind that each camera (e.g. between the HySpex VNIR-1800 and SWIR-348) will have different field-of-views and require slightly different focal distances for the placing of the tripod holding the camera.

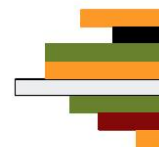
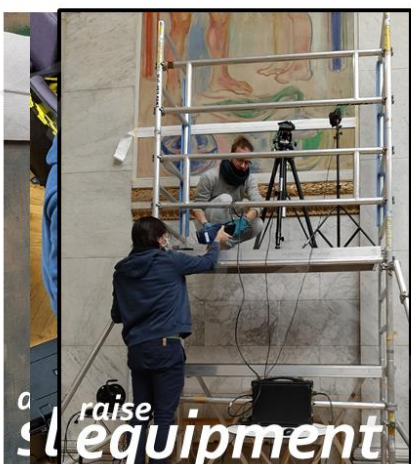


Practical approaches

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A WORKING PROTOCOL

Photos by J. Cutajar and A. Babini



Raise equipment: the prepared camera with chosen lens is transferred safely and carefully up to the scan station.

A WORKING PROTOCOL

Photos by J. Cutajar and A. Babini



Screw in and wire camera: the camera is screwed into position on the tripod with care – it is recommended to keep screws together and labelled at all times, ideally in a sealable plastic bag so as to mitigate against dropping them down the scaffolding. The camera is then subsequently wired carefully, making sure that no cables are too taut and that movement of the rotating platform does not cause the wire to catch at any point. It is also important to wire the camera such that tripping hazards on the scaffolding platform are minimized.

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A WORKING PROTOCOL

Photos by J. Cutajar and A. Babini



Position camera: the camera is placed into position to capture the ROI in question. The sliding platform is recommended to translate the camera and tripod across the platform. The height of the camera should also be adjusted to that of the ROI.

Practical approaches

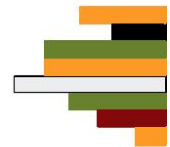
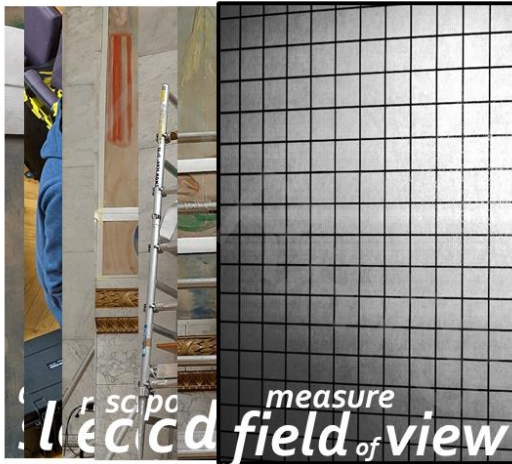
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A WORKING PROTOCOL

Photos by J. Cutajar and A. Babini



Measure distances: the geometries of the camera equipment are measured as metadata. The perpendicular distance of lens to the surface of the painting and the height of the camera are to be noted.



Measure field of view: a test scan is run to check that the current field of view matches the ROI intended for capture. To double check this, a measuring laser pointer can be placed at the position of the camera lens and the ROI is reconfirmed following the trajectory of the laser as the rotating platform of the tripod moves.



Practical approaches

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A WORKING PROTOCOL

Photos by J. Cutajar and A. Babini



Adjust camera: based on the previous step, any necessary changes to the camera's position should be made. The new position can be noted at this point for metadata collection with the operator at the documentation station.



Practical approaches

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A WORKING PROTOCOL

Photos by J. Cutajar and A. Babini



Adjust and test lights: the lights are adjusted into the required position to obtain the best signal for acquisition. This involves running a series of trial scans to check that the best acquisition conditions have been achieved with the latest lighting positions.



Practical approaches

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A WORKING PROTOCOL

Photos by J. Cutajar and A. Babini



Further adjustments: continued adjustments are made if necessary, both with the camera position and the lighting.

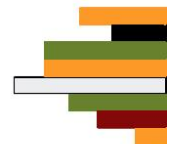


Practical approaches

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A WORKING PROTOCOL

Photos by J. Cutajar and A. Babini



Measure distances (again): once a final setup is decided upon, all geometries are measured, including those for the camera, as well as for the lighting, which include perpendicular and diagonal distances from the camera, the distance from the center of the field-of-view to the lights, height of the lights, and the distance between the two lights. These distances will help

in ensuring repeatability of the experiment if needed, and can also be important for post-processing calculations when adjusting for the lighting conditions.

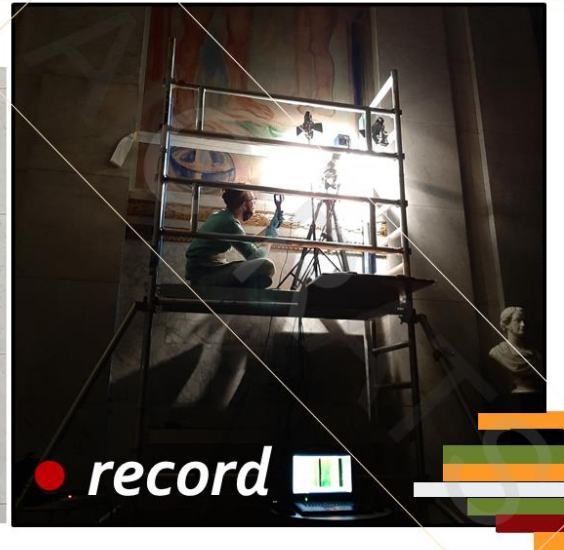


A WORKING PROTOCOL

Photos by J. Cutajar and A. Babini

Practical approaches

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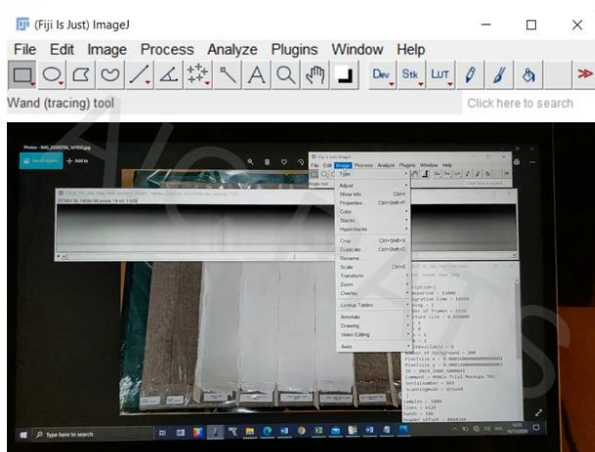
Record: once all the steps have been completed and all metadata has been collected, the lights of the space in question are all turned off (if possible), and the operator at the scanning station sits still by the camera tripod. The halogen lights are turned on, and the scan is launched, whilst the temperature gain on the surface of the painting is monitored and then registered. The operator at the PC station monitors the acquisition at all times. Once the scan ends, the halogen lights are turned off, and no further scans of the same area are taken until the surface temperature cools down to room temperature. The protocol can then be followed from the beginning once more.

Processing data together

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POSTPROCESSING

Pillay, R., J. Y. Hardeberg, and S. George. 2019. "Hyperspectral calibration of art: acquisition and calibration workflows." *Journal of the American Institute for Conservation* 58(1–2): 3–15.



PRE-PROCESSING

Dark current correction

Sensor calibration

POST-PROCESSING

Raw hypercube

Radiance values

Reslicing

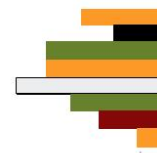
Flat fielding

Illumination correction

Spectral calibration

Processed hypercube

Relative/absolute
reflectance values



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SECTION 4

The previous section has dealt with the capture and acquisition of HSI data. More often than not, the post-processing of data that follows is what is most time-consuming, and it is of great importance to do this correctly, as it will influence all interpretations of the results.

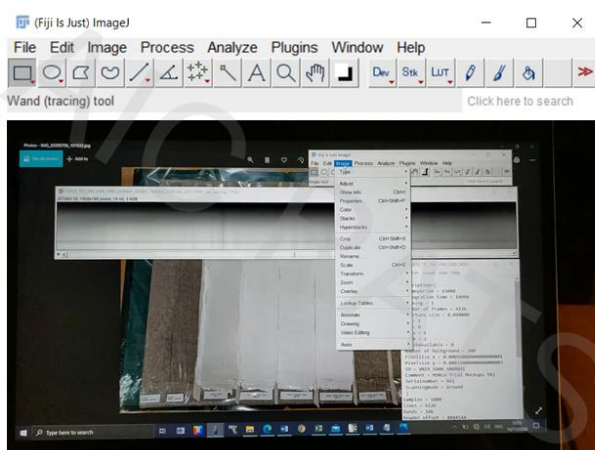
The paper by Pillay *et al.* (2019) cited on the slide lays down the groundwork for a standardized post-processing protocol. The steps involved are simplified and highlighted in the orange sections above. The cited workflow however requires a solid understanding of image post-processing and computer programming, and therefore the next slides will propose a workflow to carry out the same procedure using a user-friendly, freeware program called FIJI (Fiji Is Just ImageJ), more accessible to conservators particularly, as well as conservation scientists.

Processing data together

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POSTPROCESSING

Pillay, R., J. Y. Hardeberg, and S. George. 2019. "Hyperspectral calibration of art: acquisition and calibration workflows." *Journal of the American Institute for Conservation* 58(1–2): 3–15.



PRE-PROCESSING

Dark current correction

Sensor calibration

POST-PROCESSING

Raw hypercube

Radiance values

Reslicing

Flat fielding

Illumination correction

Spectral calibration

Processed hypercube

Relative/absolute
reflectance values

Raw to radiance



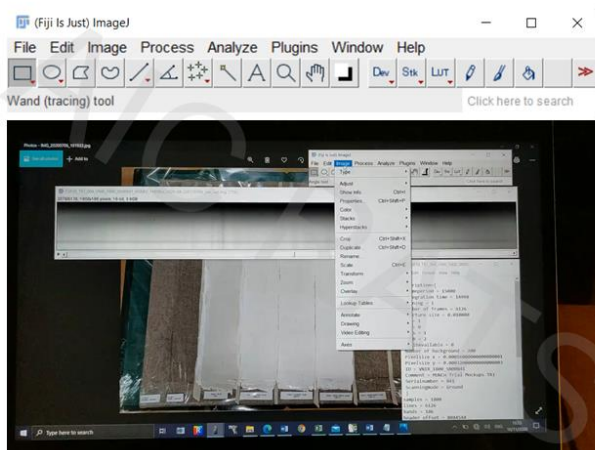
The first step however does involve proprietary software to convert the raw captured hypercube to radiance values (radiance is a measure of the amount of reflected light reaching the camera sensor at each wavelength band). The software used is complementary to the HySpex™ cameras used, and is called HySpexRaw2.0 (right). Using this software, the file is saved as a .hypspx file (same as input file), and is saved as a 32 bit float data type. The software then carries out the radiometric calibration automatically.

Processing data together

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POSTPROCESSING

Pillay, R., J. Y. Hardeberg, and S. George. 2019. "Hyperspectral calibration of art: acquisition and calibration workflows." *Journal of the American Institute for Conservation* 58(1–2): 3–15.



Reslicing of a hypercube in FIJI (ImageJ)

PRE-PROCESSING

Dark current correction

Sensor calibration

POST-PROCESSING

Raw hypercube

Radiance values

Reslicing

Flat fielding

Illumination correction

Spectral calibration

Processed hypercube

Relative/absolute
reflectance values

Raw to radiance



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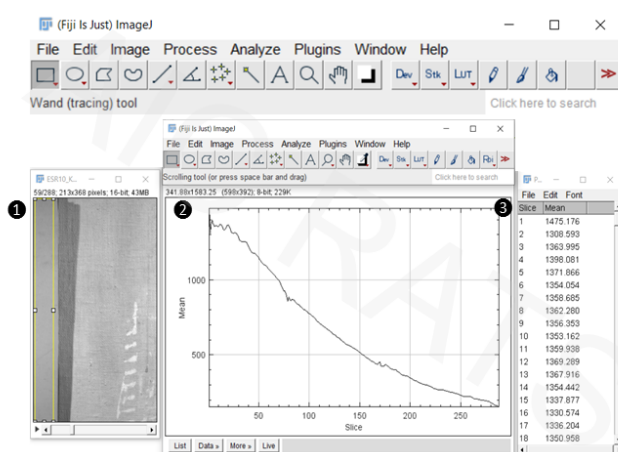
The radiometrically calibrated hypercube (i.e. with values in radiance) is then opened in ImageJ. By selecting Image ▢ Stacks ▢ Reslice, the software then opens a prompt where the options to “Start at top” and “avoid interpolation” are selected. The software then reslices the hypercube. This means essentially that the orientation of the hypercube is mathematically rearranged so that it is possible to look at the 3D datacube from the perspective of the image.

Processing data together

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POSTPROCESSING

Pillay, R., J. Y. Hardeberg, and S. George. 2019. "Hyperspectral calibration of art: acquisition and calibration workflows." *Journal of the American Institute for Conservation* 58(1–2): 3–15.



Spectral calibration in ImageJ

PRE-PROCESSING

Dark current correction

Sensor calibration

POST-PROCESSING

Raw hypercube

Radiance values

Reslicing

Flat fielding

Illumination correction

Spectral calibration

Processed hypercube

Relative/absolute
reflectance values

Raw to radiance



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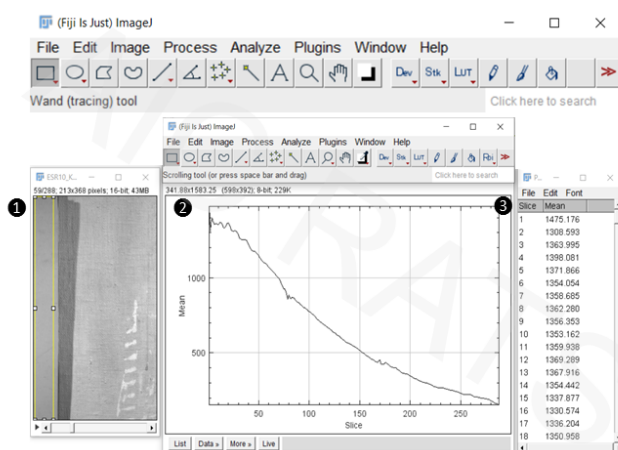
Once reslicing is complete, it becomes possible to commence the flat-fielding operation. This involves firstly selecting the entire of a region on the Spectralon® reference (shown in step 1 above). The radiance spectrum of this ROI is then obtained by following the path Image ▢ Stacks ▢ Plot Z-axis profile (shown in step 2). By clicking on the “List” tab when viewing the spectrum, the data can be copied. It is normal that these values range in the thousands.

Processing data together

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POSTPROCESSING

Pillay, R., J. Y. Hardeberg, and S. George. 2019. "Hyperspectral calibration of art: acquisition and calibration workflows." *Journal of the American Institute for Conservation* 58(1–2): 3–15.



Spectral calibration in ImageJ

PRE-PROCESSING

Dark current correction

Sensor calibration

POST-PROCESSING

Raw hypercube

Radiance values

Reslicing

Flat fielding

Illumination correction

Spectral calibration

Processed hypercube

Relative/absolute
reflectance values

Importing a text image (.txt)

	A	B
1	1475.176	
2	1308.593	
3	1363.995	
4	1398.081	
5	1371.866	
6	1354.054	
7	1358.685	
8	1362.28	
9	1356.353	
10	1353.162	

39

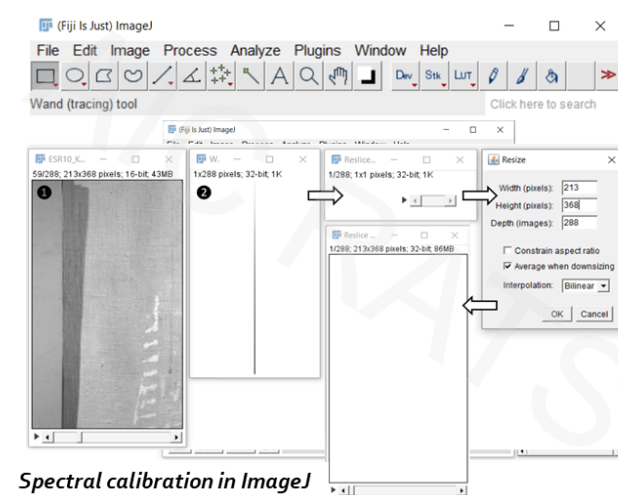
Once the spectral data is copied, it can be pasted into an empty Excel sheet (see right). Only the values should be kept in the file as shown above. This Excel sheet is then saved as a .txt file.

Processing data together

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POSTPROCESSING

Pillay, R., J. Y. Hardeberg, and S. George. 2019. "Hyperspectral calibration of art: acquisition and calibration workflows." *Journal of the American Institute for Conservation* 58(1–2): 3–15.



Spectral calibration in ImageJ

PRE-PROCESSING

Dark current correction

Sensor calibration

POST-PROCESSING

Raw hypercube

Radiance values

Reslicing

Flat fielding

Illumination correction

Spectral calibration

Processed hypercube

Relative/absolute
reflectance values

Importing a text image (.txt)

	A	B
1	1475.176	
2	1308.593	
3	1363.995	
4	1398.081	
5	1371.866	
6	1354.054	
7	1358.685	
8	1362.28	
9	1356.353	
10	1353.162	

40

Going back to ImageJ, the previously saved .txt file is imported as a Text Image from the File tab (step 2 above). This text image now needs to be processed in a similar fashion as the hypercube. The text image is therefore resliced first. The resliced file then needs to have its

dimensions readjusted to match those of the hypercube (mathematical image operations can only be performed correctly on images of the same dimension, as applies to vectors and matrices) – this is done by following the path Image ▢ Adjust... ▢ Size. After this step, the text image and hypercube are of comparable dimension and ready for the next step.



Processing data together

1
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5

POSTPROCESSING

Pillay, R., J.Y. Hardeberg, and S. George. 2019. "Hyperspectral calibration of art: acquisition and calibration workflows." *Journal of the American Institute for Conservation* 58(1–2): 3–15.

The screenshot shows the Fiji ImageJ interface with several windows open. On the left, a 'Spectral calibration in ImageJ' window displays a spectral calibration curve. In the center, a 'Resize' dialog box is open, showing dimensions of 213x368 pixels. On the right, the 'Image Calculator' window is open, showing the operation 'Divide' being performed on 'Image1: ESR10_KJ_1M_001_SWIR_' and 'Image2: Reslice of WhiteRef for AIC'. Below the calculator, a table shows the resulting values for spectral reflectance.

Wavelength (nm)	Relative Spectral Reflectance
8	1362.28
9	1356.353
10	1353.162

The last step involved is performing a simple image processing operation. By following the path, Process ▢ Image Calculator... in ImageJ, it is possible to divide the hypercube in radiance values by the Spectralon® text image (as shown above on the right). The resultant image will present a datacube providing values for relative spectral reflectance. Spectral reflectance provides a measure of the ratio of reflected to incident light for each wavelength.

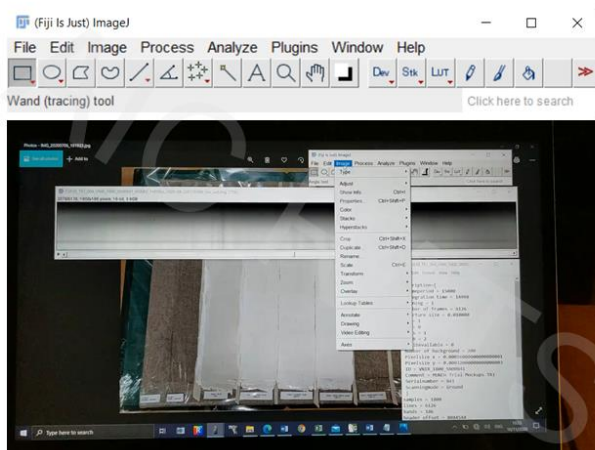
The process is considered to have been carried out successfully if the values for spectral reflectance of the newly generated image are contained in the interval $[0, x]$, where x is a value dictated by the spectral reference's reflectance (x is 1 for 100% reflectance, 2 for 50% reflectance, etc.). For both spectral calibration and flat-fielding, it is possible to obtain a datacube presenting absolute spectral reflectance values, which normally range in the interval $[0, 1]$ (excluding fluorescence phenomena). This is done by performing an image multiplication in the Image Calculator with the latest hypercube by the manufacturer's reference standard (provided in this case by Spectralon®) – the datacube can now be further explored according to need, either within FIJI (ImageJ) itself, or using other programs and methods

Processing data together

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POSTPROCESSING

Pillay, R., J. Y. Hardeberg, and S. George. 2019. Hyperspectral calibration of art: acquisition and calibration workflows. *Journal of the American Institute for Conservation* 58(1–2): 3–15.



Reslicing of a hypercube in FIJI (ImageJ)

PRE-PROCESSING

Dark current correction

Sensor calibration

POST-PROCESSING

Raw hypercube

Radiance values

Reslicing

Flat fielding

Illumination correction

Spectral calibration

Processed hypercube

Relative/absolute
reflectance values

Processed hypercube

VISUAL ANALYSIS

False colour images

PIGMENT/BINDER IDENTIFICATION

Reflectance plots

Spectral unmixing

Segmentation

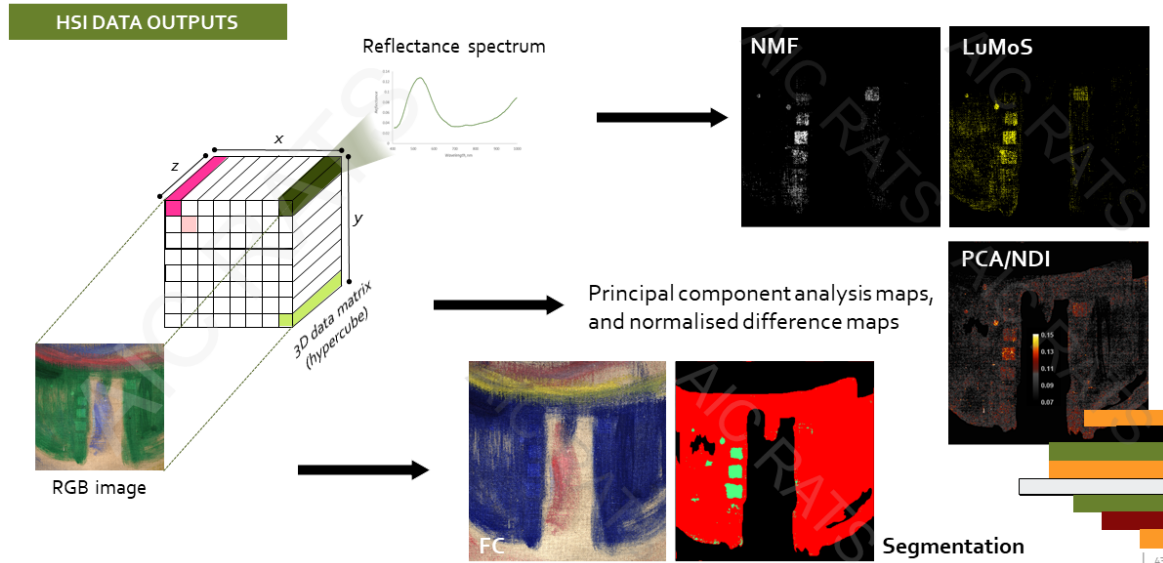
EXPLORATORY ANALYSIS

Principal components

With the post-processing of the hypercube finally completed in ImageJ, the data can be further explored. Some of the different ways of doing so are represented on the right of the slide in the red sections. The next slides illustrate these processes in a more visual manner.

The proposed workflows for this presentation end here, and the remainder of the content illustrates some of the potential results that can be extracted once the data has been captured and processed. Directions to where more results may be found are also indicated.

Processing data together



The HSI data outputs contained in a hypercube can be interpreted in three ways (left): as a collection of three-channel images (grey-scale images, from which RGB images can be prepared), as a 3D data matrix, or as a collection of reflectance spectra. For each one, there are different ways of analyzing the data.

Working only with RGB images (and therefore pixel values), false color images can be generated to guide the interpretation of materials and direct further areas of investigation. The pixels can also be classified into groups (a process called *segmentation*) based on differences and similarities – in this case, cleaned areas and soiled areas of the cleaning tests have been simplistically mapped.

Working with the reflectance spectra allows for a richer interpretation based on chemical information. The spectra can be used, via computation with algorithms (such as NMF and LuMoS listed above) to perform material identification and also to unmix (i.e. separate) mixtures of materials. In this case, the difference in spectra of the binder between soiled and cleaned areas has been used to map the cleaning tests in the ROI highlighted, with varying degrees of success.

Working with the 3D data matrix, by using a multivariate statistical analysis approach, allows even more powerful analyses to be carried out which are spectral-based and statistically significant. The next slides illustrate work which is being developed in this direction at the time of writing, and will form part of my final doctoral thesis.

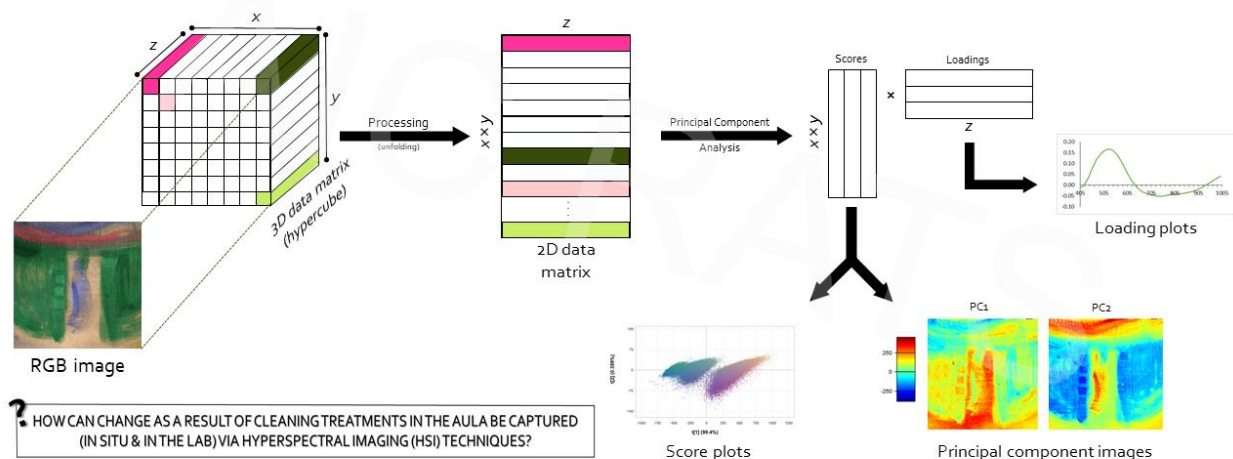
Processing data together

1
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HSI DATA OUTPUTS

PRINCIPAL COMPONENT ANALYSIS

Cutajar, J.D., Babini, A., Deborah, H., Joseph, E., Hardeberg, J.Y., Frøysaker, T. 2022. Hyperspectral imaging analyses of cleaning tests of Edvard Munch's monumental Aula paintings. *Studies in Conservation*. DOI: 10.1080/00393630.2022.2054617



| 44

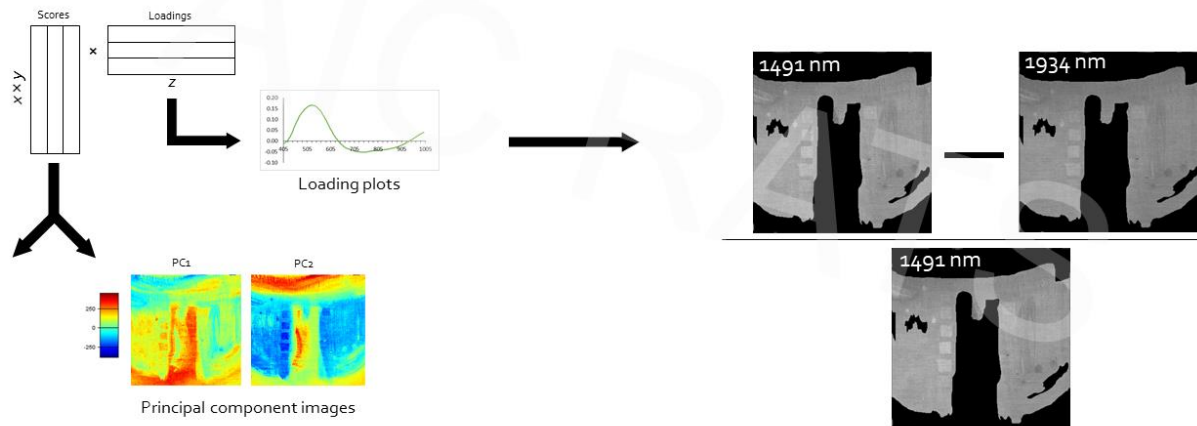
One tool for multivariate statistical analysis of hyperspectral data is called principal component analysis (PCA). In simple words, it allows the user to mathematically simplify a vast amount of data to reveal the most significant datasets and the variables of greatest impact (see slide). In this case, the PCA can let us know which spectral bands are responsible for the statistically relevant differences observed between soiled and cleaned areas on *Kjemi*. A full explanation of this technique, and related results can be found in the paper cited on the slide, which forms part of the IIC 2022 Biennial Preprints.

Processing data together

HSI DATA OUTPUTS

Lugli *et al.* (2021). DOI: 10.1016/j.talanta.2021.122126.

NDI MAPPING

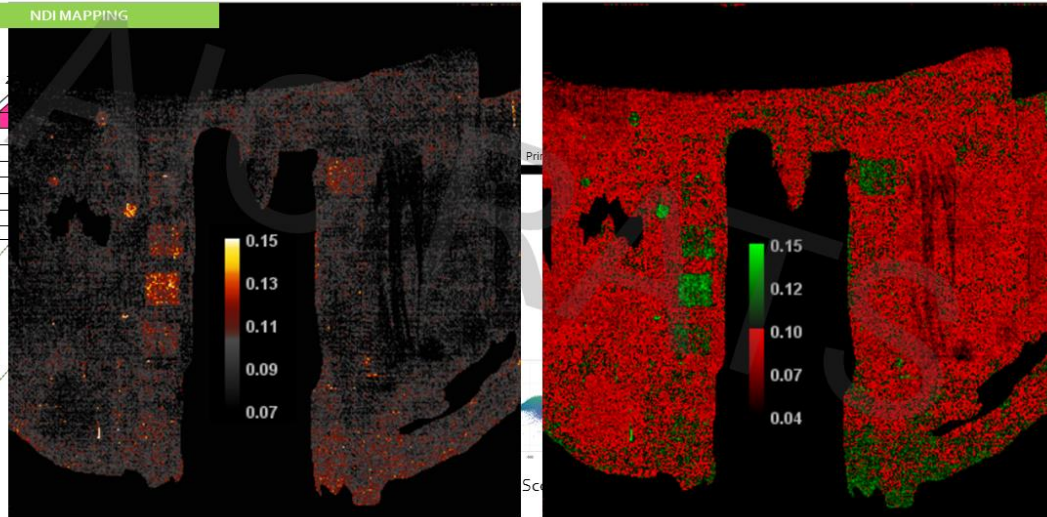


Once it is known which spectral bands are of most importance, it is also possible to note if certain bands are characteristic to certain materials or areas, in this case soiled areas and cleaned areas in the SWIR. By using another mathematical process to generate what are known as normalized difference images (NDI, a technique which has already been used in the heritage field by Lugli *et al.* 2021 to map collagen in ancient bone remains, see reference above), this information can be used to generate image-based maps illustrating where the spectral signal of one material over another is stronger or weaker.

HSI DATA OUTPUTS

Lugli *et al.* (2021). DOI: 10.1016/j.talanta.2021.122126.

NDI MAPPING

Hyperspectral
image

An example of NDI maps for soiling on *Kjemi* are shown here, where higher values as indicated on the scale bar are associated with spectrally cleaner areas. As mentioned earlier, this work is still under progress, and will be presented fully in an upcoming publication by the authors.



Conclusions

1
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LEARNING OUTCOMES

Interdisciplinary practice is key at all stages –
THIS TAKES TIME AND ENERGY

COLLABORATION

First HSI investigation of Munch's Aula paintings
(MONUMENTAL PAINTINGS IN CONTEXT)

HSI IN THE AULA

Low-cost adaptations for scaffolding work, **PROPOSED WORKFLOW** for any similar situations

PRACTICAL APPROACHES

Specialist knowledge needed for equipment and capture,
but also **PROCESSING** and **INTERPRETATION**

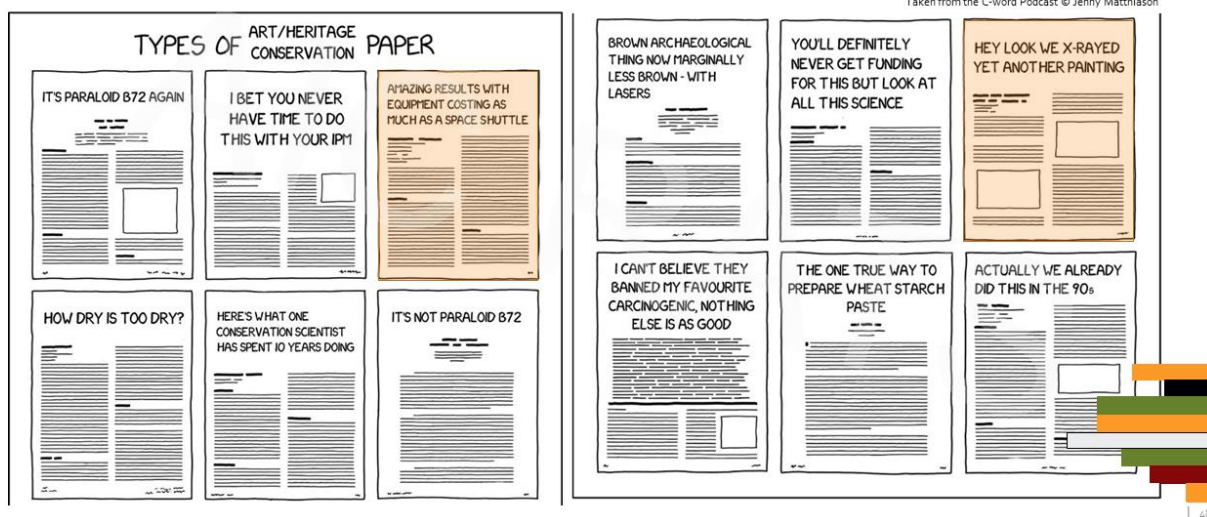
PROCESSING DATA TOGETHER

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SECTION 5

To conclude, here is a summary of the content covered in the slides, with the major takeaway from each section presented. Interdisciplinary collaboration is key to any such work of large scale crossing the conservation-restoration, conservation science and imaging science disciplines. As a result of this cooperation, the novelty of this work has been brought forward by successfully performing the first ever HSI acquisitions of Edvard Munch's Aula paintings. HSI allows us to investigate these artworks in a non-contact, non-invasive manner across a monumental scale. The experiences from this project have allowed two workflows to be proposed, one for capturing HSI acquisitions on a scaffolding where time and cost restrictions limit the use of more costly, automated and robotized (but more accurate and reliable) procedures; and another workflow for the flat-fielding of hyperspectral data in ImageJ. Processing and interpreting the data forms a large part of any spectral imaging campaign, and once again this phase was only possible in very close collaboration with all the team members, which brings us back to the importance of working together interdisciplinarily.

PUBLICATIONS



Finally, a small note about dissemination of the work in this project. To end on a comical note, here is a spoof of typical conservation papers in the literature... I'm sure we all have come across one or the other (or perhaps have even penned one ourselves!). I highlight the two formats that our project might precariously be falling into...

PUBLICATIONS



... and to counter this, highlighted in green are the four publications associated with my doctoral research. The AIC Paintings Postprint from 2020 is still under publication. The *Studies in Conservation* paper on PCA mapping (which was touched upon at the end of this talk) can be found online and open-access at the following DOI: 10.1080/00393630.2022.2054617. This RATS postprint is at the time of writing being written up for submission to the *JAIC*, whereas the CHANGE project will be publishing a book in 2023 with all of its most relevant findings. One chapter will deal with HSI in the Aula in the context of cleaning science. Keep an eye out for these last two publications, coming soon!



Finally, just like with every research project, there is an endless list of people without whose help no progress would have been made. All our colleagues at the UiO Conservation Studies and NTNU Colour and Visual Computing Laboratory are wholeheartedly thanked, as well as the UiO Aula guard staff for providing access to the Aula. We also would like to thank the AIC for providing a platform for presenting this research to you in the RATS session, and a big thank you goes to the RATS team for their organization and hospitality.

Last but not least, thank you very much for having read this, and please do not hesitate to contact us for further information or collaboration.

Permeation of Acetic Acid, Formic Acid and Water through PET: Implications for Encapsulation

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Original Abstract

The permeation of vapors through PET was measured to determine the micro-environment within a PET enclosure. Since formic acid and acetic acid are by-products of paper on aging, these gases were studied. It is expected that the permeation of vapors varies according to the size of the diffusing molecule: smaller molecules such as water should diffuse faster than larger molecules such as acetic acid. The data shows that the permeation P of the vapors varies according to $P_{\text{water}} > P_{\text{formic acid}} > P_{\text{acetic acid}}$ through PET and the corresponding molecular diameters σ vary according to $\sigma_{\text{water}} < \sigma_{\text{formic acid}} < \sigma_{\text{acetic acid}}$. While the permeation of formic acid was approximately 20 times slower than the permeation of water, the permeation of acetic acid was too slow to be measured. The results show that the PET will trap acetic acid but allow the permeation of formic acid. The permeation of water vapor through 3 mil, 4 mil, and 5 mil was also measured. Implications of these results on encapsulated materials will be discussed.

Annotated Presentation

Permeability of PET by water, acetic acid, and formic acid: A study of the microenvironment of encapsulated documents

P.M. McGuiggan, A.K.I. Hall,
M. McGath, S. Zaccaron,
L. Pasternack, W.D. Minter



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UNIVERSITY

Thank you to the AIC and the RATS organizers for the opportunity to present our work.

Funding: NEH Encapsulation: Past, Present, and Future

- 1) M.K. McGath, A.K.I. Hall, S. Zaccaron, J. Wallace, W.D. Minter, P.M. McGuggan, "Stewing in its Own Juices? The Permeability of PET by Water and Acetic Acid", *Restaurator*, 38(4), 355 – 382 (2017)
- 2) A.K.I. Hall, M.K. McGath, W.D. Minter, P.M. McGuggan, "The breathability of PET to water vapor: Thickness effects", *Journal of the American Institute for Conservation*, 59:1, 40-52 (2020)
- 3) P.M. McGuggan, A.K.I. Hall, M.K. McGath, L. Pasternack, "The Permeability of PET by Formic and Acetic Acid Vapors", *Studies in Conservation*, March (2022)

This work was funded by a grant from the NEH. Three papers have been published on this work and will be the basis for this talk.

Permeation: Why put N₂ in car tires?

Air is 80% N₂, 20% O₂



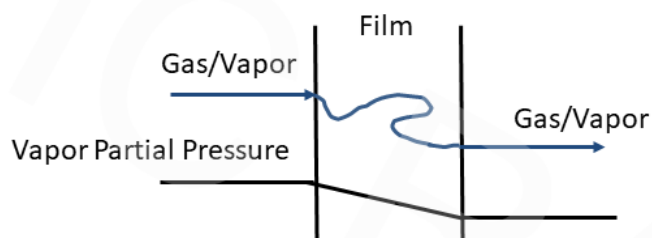
- 1) Nitrogen molecule ($\sigma = 0.364$ nm) is slightly larger than oxygen molecule ($\sigma = 0.346$ nm), so doesn't permeate as fast through the tire
- 2) Easier to get dry N₂ than dry air, and moisture ($\sigma = 0.28$ nm) changes pressure, diffuses, can corrode materials

<https://www.actiongatortire.com/nitrogen-vs-air-tires/>

molecular diameter = σ

Permeation is the process of penetration of gases, vapors, or fluids through a solid material. Industrial applications such as packaging tailor permeation properties to extend shelf life. Many produce products such as lettuce retain their freshness due to the polymer packaging film that controls the flow of gases and moisture through the packaging. In automobiles, tires become flat due to the loss of air through the rubber. Some manufacturers are inflating the tires with nitrogen instead of air. Since nitrogen has a slightly bigger molecular diameter than oxygen, it permeates more slowly through the tires. In addition, it is easier to obtain dry nitrogen. The presence of moisture in the gases cause large pressure changes when it condenses and is therefore less desirable within your tires than dry gases.

Permeation



Permeation is a 3 step process:
adsorption
diffusion
evaporation

For permeation to occur, gas or vapor molecules must adsorb to the surface of the film, travel through the amorphous or porous portion of the film, and evaporate from the other side of the film. The rate of this movement of vapors depends on the properties of the diffusing species, the properties of the film, the thickness of the film, and the partial pressure of the diffusing species on either side of the film.

Encapsulation

A paper document is placed between two sheets of polyethyleneterephthalate (PET) polymer and the PET is sealed on 1, 2, 3, or 4 sides



<http://spec.lib.miamioh.edu/home/wp-content/uploads/2013/08/1-sleeve.jpg>

- Developed by the Library of Congress in the 1970's
- Used as a layer of support
- Protects document from fluids, biological materials, etc

Library of Congress Preservation Office: *The Physical Protection of Brittle and Deteriorating Documents by Polyester Encasement*, Washington, D.C.: Library of Congress Preservation Office, 1975.

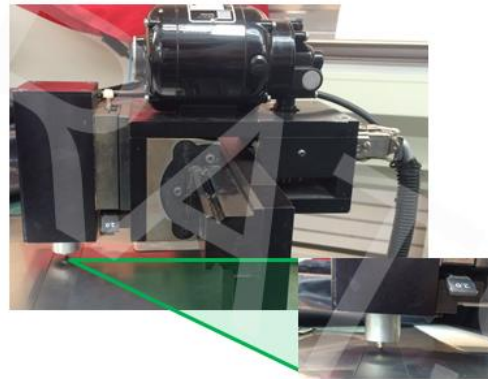
Library of Congress Preservation Office: *Polyester Film Encapsulation*, Washington, D.C.: Library of Congress Preservation Office, 1980.

Encapsulation is the process of placing a document between two thin polymer sheets. It is used to support the document and can protect the document from fluids, biological contaminants and certain airborne contaminants. The polymer film is typically biaxially oriented polyethylene terephthalate (PET).

Encapsulation

The polyester film can be sealed with either heat or ultrasound:

- The polyester is sealed on two (i.e. L-sleeve), three, or all four edges. This creates a 'sandwich' where the document is enclosed.
- We use an ultrasonic welder (40,000 cycles/s and 12 cm/s)



Minter, W.: Polyester encapsulation using ultrasonic welding. *Library Hi Tech* 1(3) (1983): 53–54.



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Once the document is placed between the two plastic sheets, the sides can be sealed to hold the document between the sheets. The sides can be sealed on two, three, or all four edges.

Frequently Asked Questions

1. What are the effects of encapsulation on the paper?
Will the material deteriorate faster if encapsulated?
2. Does the deterioration depend on deacidification?
Should the material be deacidified before encapsulation?



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Although encapsulation supports the document, the polyester film will hinder the exchange of gases between the ambient and the document. This will lead to a microenvironment within the encapsulate that may be different, at least temporarily, than the ambient environment. Because of this, questions concerning how the encapsulation affects the aging of the enclosed document need to be addressed.

Besides mechanical support

PET film may limit transmission of gases – into or out of encapsulate

Beneficial

- 1) O_2
- 2) SO_2 , NO, NO_2
- 3) H_2O

Detrimental

- 1) H_2O
- 2) Acetic Acid
- 3) Formic Acid
- 4) HCl

Besides providing mechanical support and stopping liquids and greases from penetrating the PET and damaging the document, the PET will limit transmission of gases and vapors through the film. For some gases, such as ambient NO_2 , it is desired to keep the ambient gases out of the encapsulate so they don't degrade the document. For other gases such as acetic acid which is formed by cellulose degradation, it is desired to remove the acetic acid from the encapsulate environment. Therefore, it is important to know the rate that these gases permeate through the film.

Specifications for Archival PET

2009 Library of Congress Specifications

The specification states that the polyester film must be “clear, colorless, [biaxially oriented/stressed/drawn]” and “must not contain any plasticizer, surface coatings, UV inhibitors or absorbents, and must be guaranteed to be non-yellowing with natural aging”

Library of Congress Preservation Office, 2009. Specifications for Polyester : Poly (ethylene-terephthalate) Film For the Storage of Artifacts. *Library of Congress Preservation Directorate Specification Number 500-500 – 16*, pp.1–2.



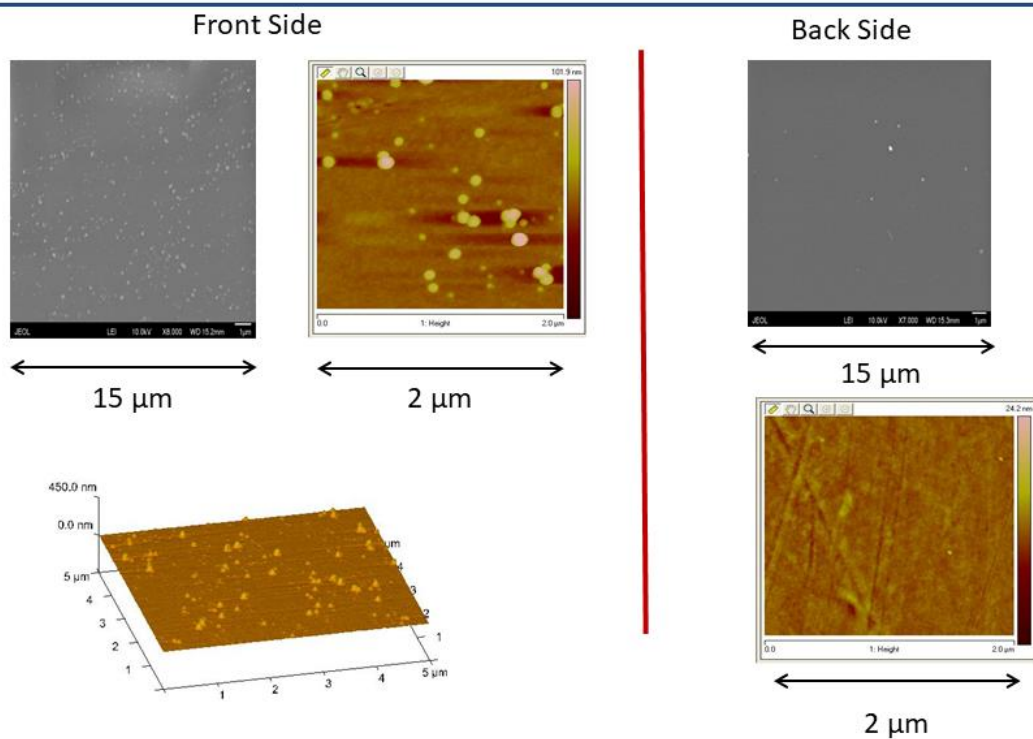
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The Library of Congress has published specifications regarding the type of PET that should be used for archival purposes. These specifications are given above.

Characterization of PET: Presence of Slip



SEM and AFM images of the surface of the PET film

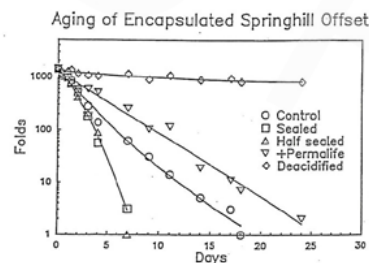
In order to check the surface of the PET, atomic force microscopy (AFM, $2 \times 2\ \mu\text{m}$ images) and scanning electron microscopy (SEM, $15 \times 15\ \mu\text{m}$ images) were run on both sides of the film. The small particles on the surface reveal the presence of a slip on the front side of the PET. The particles are approximately $0.1\ \mu\text{m}$ in diameter. EDS analysis of the surface could not identify the specific chemistry of the slip since it was within the noise of the instrument, although a silicate or acrylate material is expected for the composition of the slip particles. The purpose of the slip is to prevent adhesion between the PET sheets.

Past Studies

What are the effects of encapsulation on the paper?

1) Studies by Library of Congress (C. Shahani)

- encapsulated papers aged at $T = 80^{\circ}\text{C} - 90^{\circ}\text{C}$ and 25% - 65% humidity for 25 days
 - MIT fold test showed increase in brittleness for encapsulated acidic paper on aging as compared to unencapsulated acidic paper



Library of Congress Preservation Office: Polyester Film Encapsulation, Washington, D.C.: Library of Congress Preservation Office, 1980.

Shahani, C.: Accelerated aging of paper: Can it really foretell the permanence of paper. Preservation Research and Testing Series 9503 (1995): 1-18.



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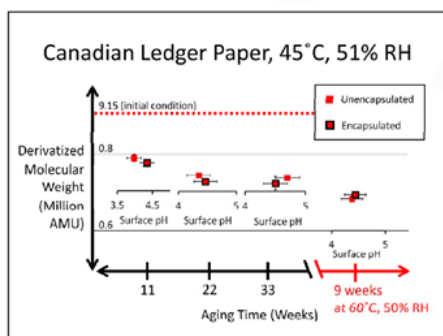


Past studies by C. Shahani at the Library of Congress showed that the brittleness of artificially aged, encapsulated acidic paper increased compared to artificially aged, unencapsulated acidic paper.

Past Studies

2) Studies by JHU HSC (Baty and Minter)

- 4 papers (pre-1970)
- encapsulated papers aged at $T = 45^\circ\text{C}$ for 33 weeks
- encapsulated papers aged at $T = 60^\circ\text{C}$ for 11 weeks
- testing by pH and SEC (cellulose MW)



- No significant difference in pH or cellulose MW between encapsulated acidic sheets and unencapsulated acidic sheets

Minter, W.; Baty, J.: *The Role of Polyester Film Encapsulation—With and Without Prior Deacidification—On Paper Degradation, Studied Using Long Term, Low-Temperature Aging*. American Institute for the Conservation of Historic and Artistic Works, 41st Annual Meeting. 29 May–1 June 2013, Indianapolis, IN. Research and Technical Studies Postprints., 4, 186-239, 2013

Other studies by J. Baty and W. Minter at JHU showed no significant difference in pH or cellulose molecular weight between artificially aged, encapsulated acidic sheets and artificially aged unencapsulated acidic sheets.

Past Studies: Comparison

2 studies - 2 apparently different answers

If only Temperature differences compared:

- Reaction rates vary exponentially with T
- rates double every 5 °C

		<u>At 20 °C</u>
Aging studies translate to	45 °C	→ 20 years
	60 °C	→ 54 years
	80 °C	→ 284 years

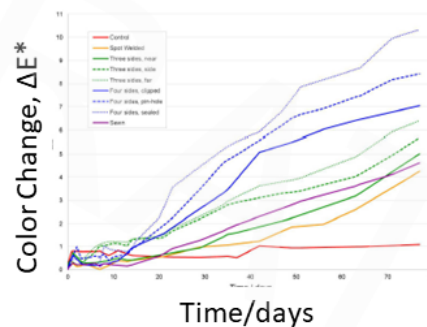
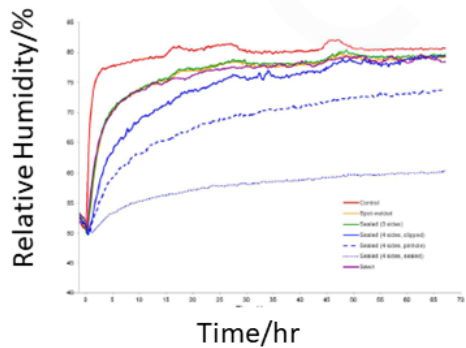
Another variable: PET $T_g = 80\text{ °C}$, so experiments compared above and below T_g

Although the studies seem to give different conclusions, the two tests were run at different conditions. Most notably, the first study aged the encapsulates at 80 °C – 90 °C for 25 days whereas the other aged the encapsulates at 45 – 60 °C for up to 33 weeks. Since the glass transition temperature, T_g , of PET is 80 °C, one study investigated the aging above the T_g whereas the other was below the T_g . The vapors and gases only permeate through the amorphous part of the PET, and therefore the diffusion of gases and vapors through the PET might be different above and below the T_g . In addition, since different temperatures were used, the aging rates for the two experimental studies are quite different. Therefore, it is not surprising that different results were observed.

Current Studies: Micro-environment within Encapsulation

**What is the micro-environment within the envelope?
Does the envelope trap gases which might affect the paper?**

- 1) British Library Study of the Micro-environment within the enclosure
 - a) Measure humidity change within enclosure when placed in a humid environment
 - b) encapsulate acidic paper and place AD strips within micro-environment



Conclusions: **Encapsulation protects document from humidity fluctuations**
 Encapsulation creates a micro-environment for acidic gases

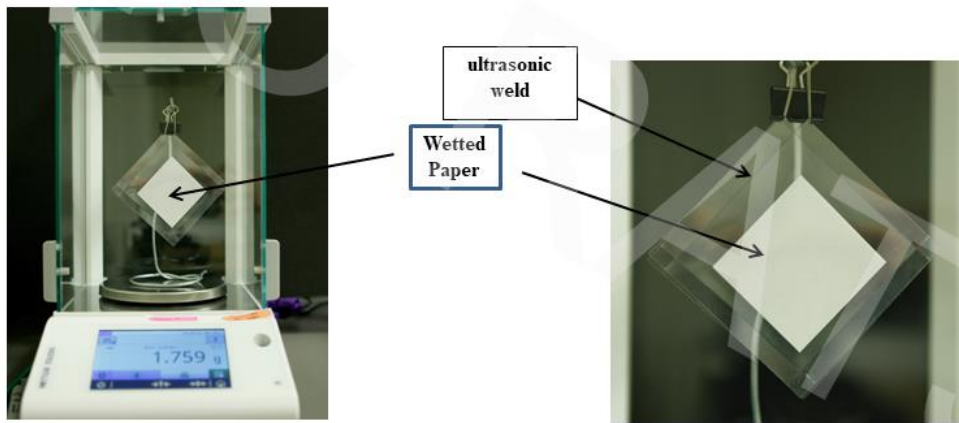
Garside, P., Walker, O.: The formation of microenvironments in polyester enclosures. *Journal of Conservation and Museum Studies* 13(1) (2015): 1–4.

Another study by Garside and Walker at the British Library investigated the micro-environment that is formed within an enclosure. In this study, an encapsulated film was placed in a humid environment and the change in the relative humidity within the enclosure was measured. This study clearly showed the movement of water vapor from the ambient into the encapsulate. The time required for equilibrium conditions depended on the method used to seal the enclosure. The increase in acid vapors was also measured when acidic paper was placed in the encapsulate and acid indicating strips were used to measure the acid content of the microenvironment within the enclosure. These studies showed that moisture can be transported through the encapsulate and that a microenvironment can be formed within the encapsulate, at least temporarily.

Current Studies: Micro-environment within Encapsulation

2) JHU HSC study of the permeation through the PET enclosures

Encapsulate wet paper and measure the rate of mass loss



McGath, M.K., A.K.I. Hall, S. Zaccaron, J S Wallace, W. Minter, and P.M. McGuiggan, "Stewing in Its Own Juices? The Permeability of PET by Water and Acetic Acid." *Restaurator* 38 (4): 355–82 (2017).

In our studies, our goal was to quantify the rate of permeation by measuring the rate of mass loss when wetted papers were encapsulated. In these studies, a balance was used to measure the mass loss.

Specifics of the Materials

Materials

Paper: Cellulose (only) – Whatman #1

Liquids: water (pH ~ 6), acetic acid, formic acid, HCl

PET: Archival PET (3 mil, 4 mil, and 5 mil)

Liquid saturated paper (0.65-1.3 times heavier than paper)

Generally sealed 4 sides with ultrasonic welder

Testing environment: TAPPI room (50% RH and $T = 23\text{ }^{\circ}\text{C}$)

PET: $T_m = 255\text{ }^{\circ}\text{C}$

$T_g = 80\text{ }^{\circ}\text{C}$

% Crystallinity = $33 \pm 4\%$



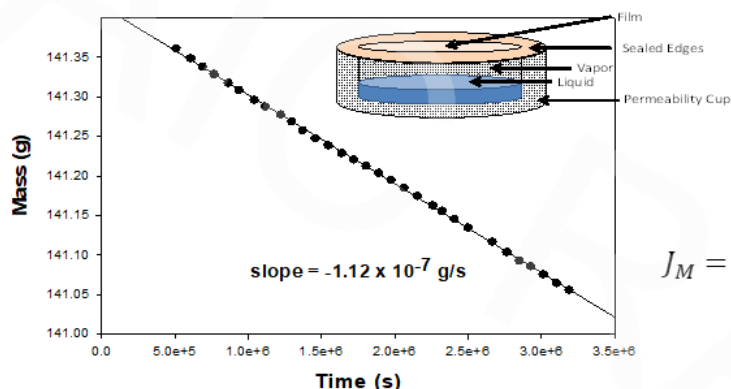
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For these studies, we wetted Whatman Filter Paper #1 with water, acetic acid solutions, formic acid solutions, and HCl solution. 3 mil, 4 mil, and 5 mil archival PET was used for the encapsulation. DSC showed the PET had a melt temperature $T_m = 255\text{ }^{\circ}\text{C}$, glass transition temperature $T_g = 80\text{ }^{\circ}\text{C}$, and percent crystallinity of $33 \pm 4\%$. It is important to know the crystallinity since permeation only occurs through the amorphous part of the PET. The paper was first saturated with a liquid, with the liquid added being 0.65 – 1.3 times heavier than the paper. The PET was generally sealed on all 4 sides using an ultrasonic welder, enclosing the wetted paper within the PET enclosure. The experiments were run in a constant humidity, constant temperature room set to 50% humidity and $23\text{ }^{\circ}\text{C}$.

ASTM Method: Permeability Cup Measurement of Flux



Flux, J_M

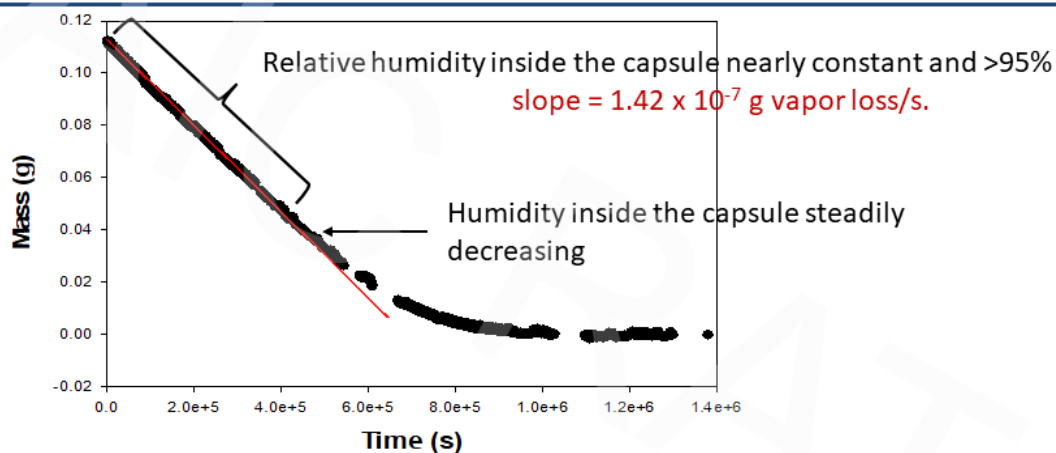
$$J_M = \frac{(\text{mass of permeant})}{(\text{area}) \times (\text{time})} = \frac{1}{A} \frac{dM}{dt}$$

$A = 25 \text{ cm}^2$

Ambient Humidity = 50%

The measurements are based on an ASTM method using a permeability cup. In permeability cup experiments, a cup holds a liquid reservoir. The film is placed above the reservoir, leaving an air gap, and the outer edges of the film clamped, ensuring that the only vapor loss is through the film. The permeability cup is then placed on a balance and the mass loss is measured as a function of time. The data shows that there is a constant mass loss of vapor with time. Since the amount of vapor going through the film depends on the area of the film, the flux is calculated by taking the rate of mass loss, as given by the slope of the mass vs time graph, and dividing by the area. Note that these measurements took approximately 35 days.

Drying of an encapsulated sample of Whatman filter paper
 #1, water wetted
 3 mil PET

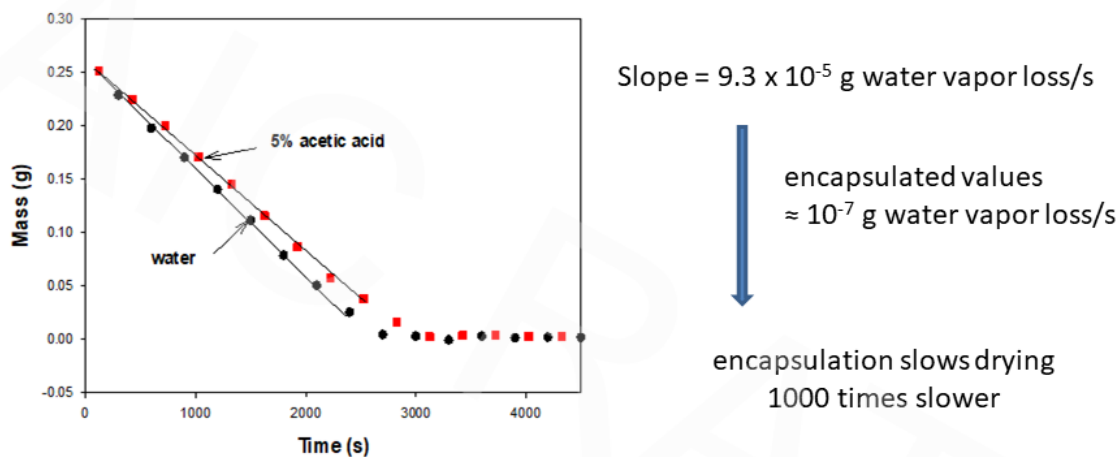


The data beyond 4×10^5 s represents non-steady state drying inside the capsule as the relative humidity inside the capsule decreases from approximately 95% to 50%, the RH of the ambient environment.

Mass shown represents added liquid mass

Instead of using the permeability cup, a similar measurement was taken by wetting paper, encapsulating it between two sheets of PET film, sealing all 4 of the edges, and measuring the mass loss vs time of the encapsulate. The data shows an initial rate of mass loss that is constant. During this time, the humidity inside the encapsulate is relatively constant and > 95%. After 4.6 days (4×10^5 s), the humidity inside the encapsulate decreases leading to a decrease in the rate of mass loss. At long times, the rate of mass loss = 0 and the paper is dry, relative to the ambient humidity. For this measurement, the PET thickness was 3 mil (0.003 in = 0.0762 mm).

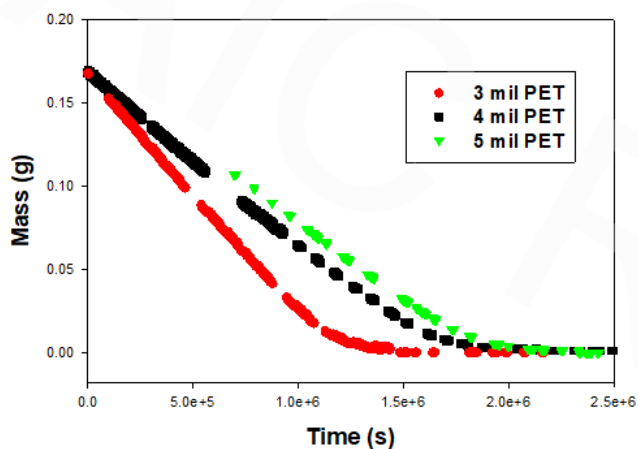
Drying of unencapsulated Watman #1 in Air



The measured mass is tared by the “dry” weight of the paper.
The ambient RH = 50%.

Compared to the drying of wetted Whatman filter paper in air, the rate of mass loss was approximately 1000 times slower when encapsulated. For unencapsulated paper, the rate of drying of paper wetted by 5% acetic acid was similar to the rate of drying of paper wetted by water.

Drying of water wetted Whatman filter paper encapsulated by 3 mil, 4 mil and 5 mil PET.

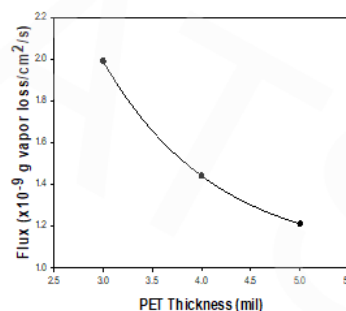


The ambient RH= 50%

$A \approx 77 \text{ cm}^2$

$$J_M = \frac{(\text{mass of permeant})}{(\text{area}) \times (\text{time})} = \frac{1}{A} \frac{dM}{dt}$$

$$\begin{aligned} J_M &= 1.99 (\pm 0.13) \times 10^{-9} \text{ g vapor loss/cm}^2/\text{s} \quad (3 \text{ mil}) \\ &= 1.44 (\pm 0.09) \times 10^{-9} \text{ g vapor loss/cm}^2/\text{s} \quad (4 \text{ mil}) \\ &= 1.21 (\pm 0.08) \times 10^{-9} \text{ g vapor loss/cm}^2/\text{s} \quad (5 \text{ mil}) \end{aligned}$$



The drying of an encapsulate containing water wetted paper was measured using different thicknesses of PET. The rate of drying of encapsulated, wetted Whatman filter paper is fastest when encapsulated by 3 mil PET film and slowest when encapsulated by 5 mil PET film. This is to be expected since it takes longer for the vapor to travel through a thicker film.

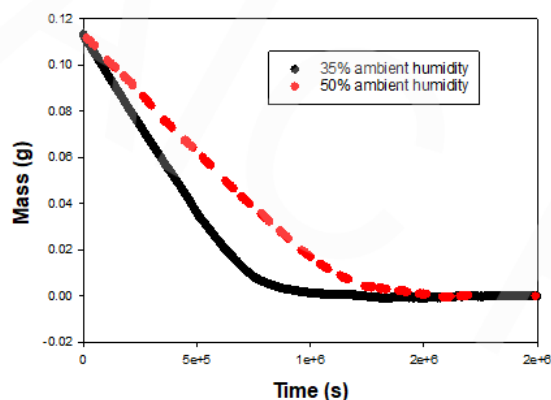
Models

Flux	$J_M = \frac{(\text{mass of permeant})}{(\text{area}) \times (\text{time})} = \frac{1}{A} \frac{dM}{dt}$	
Permeability Coefficient	$P = J_M \frac{x}{(P_2 - P_1)} = DS$	
$\underline{J_M}$		\underline{P}
$1.99 (\pm 0.13) \times 10^{-9} \text{ g vapor loss/cm}^2/\text{s}$	$\xrightarrow{3 \text{ mil}}$	$1.08 (\pm 0.06) \times 10^{-14} \text{ g cm/cm}^2/\text{Pa/s}$
$1.44 (\pm 0.09) \times 10^{-9} \text{ g vapor loss/cm}^2/\text{s}$	$\xrightarrow{4 \text{ mil}}$	$1.04 (\pm 0.07) \times 10^{-14} \text{ g cm/cm}^2/\text{Pa/s}$
$1.21 (\pm 0.08) \times 10^{-9} \text{ g vapor loss/cm}^2/\text{s}$	$\xrightarrow{5 \text{ mil}}$	$1.09 (\pm 0.07) \times 10^{-14} \text{ g cm/cm}^2/\text{Pa/s}$
Average P = $1.07 (\pm 0.07) \times 10^{-14} \text{ g cm/cm}^2/\text{Pa/s}$		

x = film thickness, P_2 = ambient partial pressure, P_1 = inside encapsulate partial pressure

Since the rate of mass loss per area of the film (flux) depends on the film thickness and the partial pressure difference on either side of the PET film, these values can be taken into account when calculating the Permeability Coefficient, P . When the flux is scaled by the partial pressure difference and film thickness, the Permeability Coefficient is the same for all three film thicknesses.

Drying of water wetted Whatman filter paper encapsulated by 4 mil PET



At 35% ambient RH,

$$\text{slope} = 1.52 (\pm 0.02) \times 10^{-7} \text{ g water vapor loss/s}$$



$$P = 1.11 (\pm 0.05) \times 10^{-14} \text{ g cm/ cm}^2 \text{ /Pa/s}$$

At 50% ambient RH,

$$\text{slope} = 1.04 (\pm 0.03) \times 10^{-7} \text{ g vapor loss/s}$$



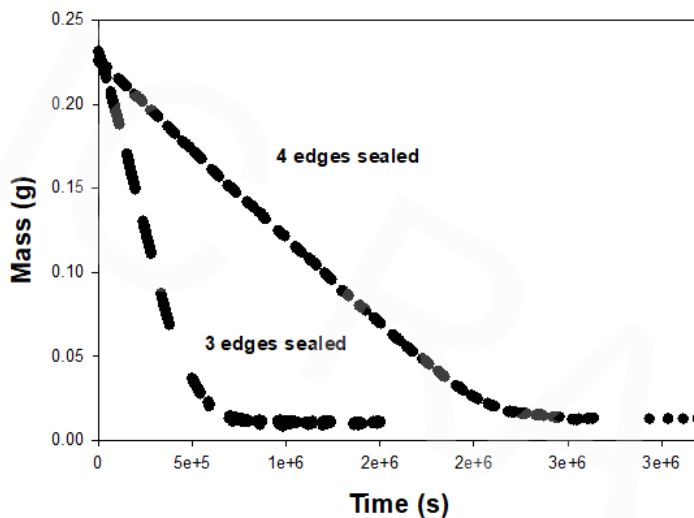
$$P = 1.04 (\pm 0.07) \times 10^{-14} \text{ g cm/ cm}^2 \text{ /Pa/s}$$

$$P = J_M \frac{x}{(P_2 - P_1)} = DS$$

Expect P to be the same for both measurements

As expected, the mass flux is greater when the partial pressure difference (i.e. the driving force) is greatest. Therefore, the flux is greater when the ambient humidity is 35% compared to when the ambient humidity is 50%. Initially, the relative humidity inside the encapsulate is approximately 100%. Although a faster mass loss is observed when the ambient relative humidity is 35% than when the ambient relative humidity is 50%, the Permeability Coefficient P has the same value since that pressure difference has been taken into account.

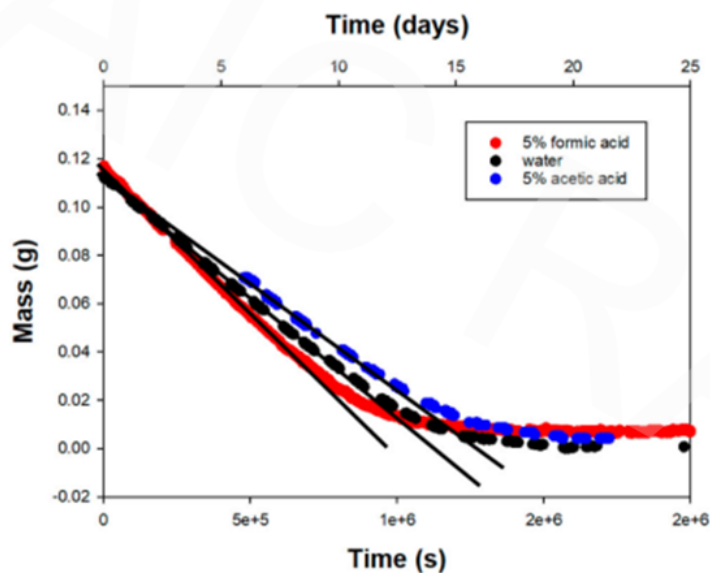
3 sides vs 4 sides sealed



The rate of mass loss as given by the slopes of the lines: 4.3×10^{-7} g mass loss/s and 1.07×10^{-7} g/s for three edges sealed and four edges sealed, respectively.

The rate of mass loss is dependent on how the encapsulate is sealed. The rate of mass loss is greater when only 3 edges are sealed than when all 4 edges are sealed. The open edge allows some of the vapor to effuse out of the open side of the encapsulate rather than permeating through the PET film.

Drying of encapsulated samples of Whatman filter paper wetted by water, 5% acetic acid, and 5% formic acid.



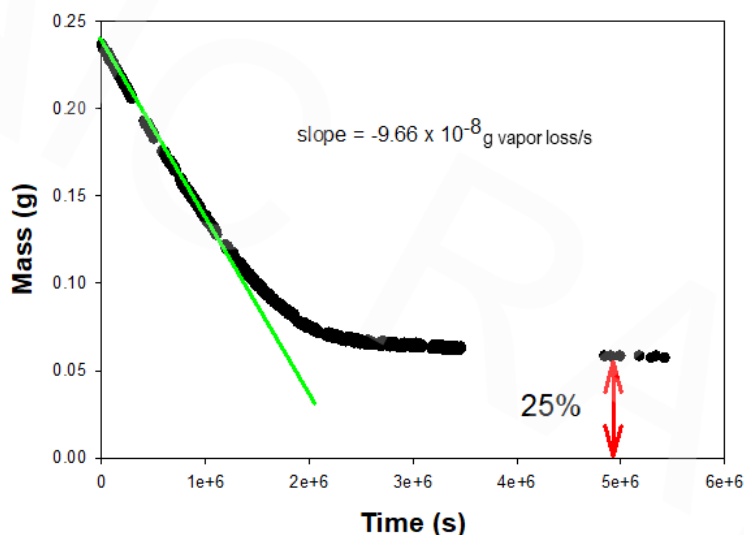
Slope $\sim 1.07 \times 10^{-7}$ g vapor loss/s

What is diffusing out – only water or acid or both?

P.M. McGuiggan, A.K.I. Hall, M.K. McGath, L. Pasternack, "The Permeability of PET by Formic and Acetic Acid Vapors", *Studies in Conservation*, March (2022)

The rate of mass loss for Whatman filter paper wetted by 5% formic acid, 5% acetic acid, or water and then encapsulated by 4 mil PET show a similar value, with the acid solutions drying slightly slower than the water wetted sample. These experiments only show that something is diffusing out of the encapsulate, but doesn't identify if it is only water vapor or both water and acid vapor molecules.

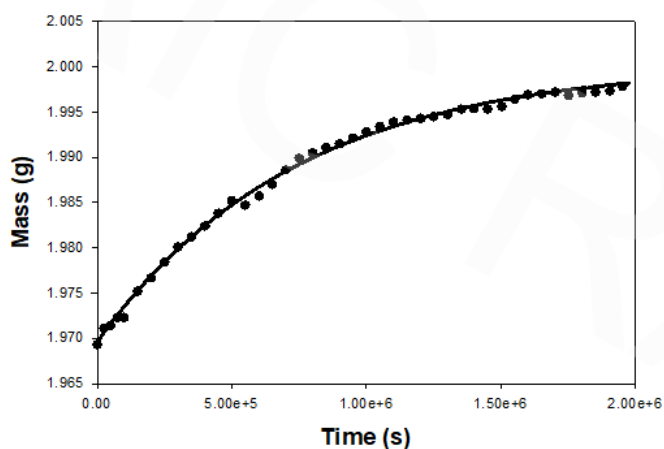
Encapsulated Cellulose wetted by 30% Acetic Acid



Note: does not dry completely

In order to identify the vapor diffusing out, we measured the rate of mass loss of Whatman filter paper wetted by 30% acetic acid and encapsulated by 4 mil PET. The initial rate of mass loss is slightly less than measured for water wetted encapsulates, but the mass of the “dried” encapsulate at long times was approximately 25% greater than the initial pre-wetted value. This indicates that the acetic acid remains within the encapsulate and does not diffuse through the PET. The mass loss is due to the loss of water vapor in the acetic acid solution. Although the high concentration of acetic acid may harm the film and such high concentration is not seen in paper degradation, these measurements were run as a reference.

Mass vs time for an encapsulated film of Whatman #1 containing 235 μL glacial acetic acid.

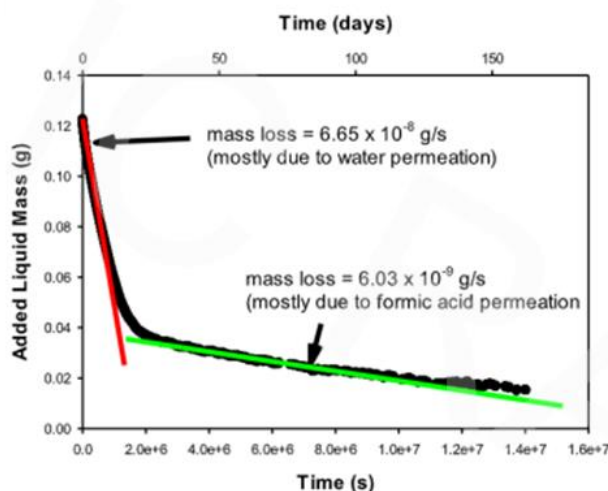


Mass increases – water vapor diffusing into the encapsulate

The solid curve is a 3 parameter exponential rise to maximum fit to the data given by $\text{Mass (g)} = 1.9696 + 0.0307(1 - \exp(-t/7.37 \times 10^5))$ where t = time in s.

Surprisingly, the mass vs time measurement of Whatman filter paper wetted by 100% acetic acid and encapsulated by 4 mil PET showed an increase in mass. Because the acetic acid cannot move through the PET quickly, the water molecules from the ambient air travel through the PET film to decrease the activity of the acetic acid. Although the high concentration of acetic acid may harm the film and such high concentration is not seen in paper degradation, these measurements were run as a reference.

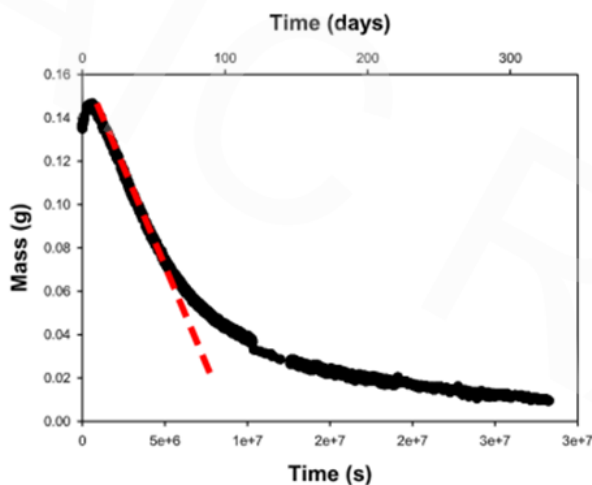
Cellulose wetted by 30% Formic Acid, Encapsulated



External RH = 50%

The rate of mass loss of Whatman filter paper wetted by 30% formic acid and encapsulated by 4 mil PET shows a different behavior than previously seen with the 30% acetic acid solution. There is an initial rate of mass loss that is most likely due to the loss of water vapor (primarily) followed by a much slower rate of mass loss at longer times which is likely due to the permeation of formic acid. At long times, the total mass loss is nearing the total amount of liquid added, demonstrating that both the water vapor and formic acid vapor are diffusing out of the encapsulate. Note that these measurements took nearly 1/2 year to complete. Although the high concentration of formic acid may harm the film and such high concentration is not seen in paper degradation, these measurements were run as a reference.

Cellulose wetted by 100% Formic Acid, Encapsulated

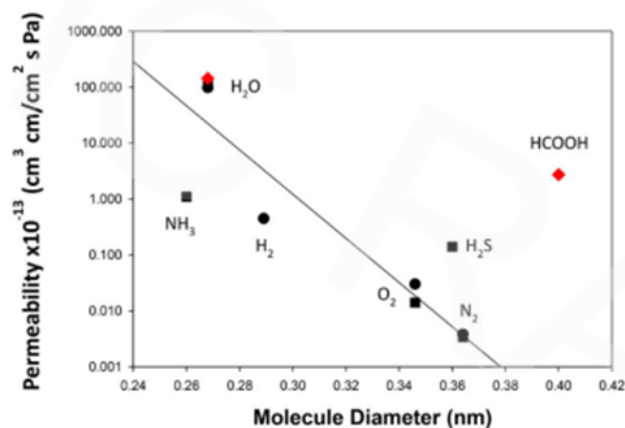


Slope $\sim 2 \times 10^{-8}$ g/s

Note the long time – almost 1 year

The mass vs time measurement of Whatman filter paper wetted by 100% formic acid and encapsulated by 4 mil PET showed an initial increase in mass followed by a decrease in mass, with the final mass of the encapsulate approaching the pre-wetted value. This demonstrates that the formic acid had permeated through the film. Although the high concentration of formic acid may harm the film and such high concentration is not seen in paper degradation, these measurements were run as a reference.

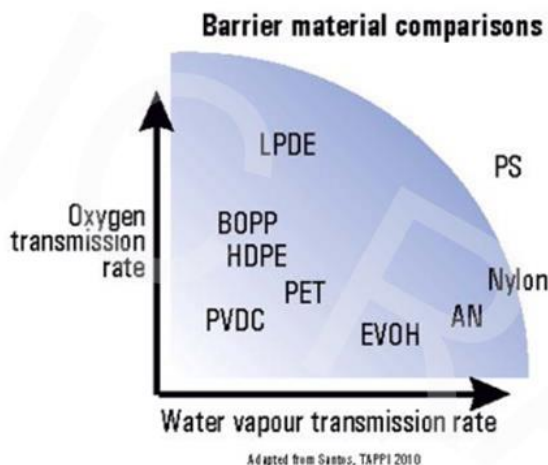
Permeability of biaxially oriented PET vs Penetrant Molecular Diameter



Kinetic Diameters Acetic Acid $\sigma = 0.44$ nm Assuming monomers
Formic Acid $\sigma = 0.40$ nm

Weast, Robert C, ed. 1978. *CRC Handbook of Chemistry and Physics*. 58th ed. West Palm Beach: CRC Press, Inc.

Using previously published Permeability coefficients as well as our own data (red diamonds), there is a clear correlation between the measured Permeability and the molecular diameter of the diffusing molecule. Since the Permeability of acetic acid was too low to be measured, this molecule was not on the diagram, but a linear extrapolation of the data approximates the Permeability of acetic acid through PET to be $P \approx 1 \times 10^{-19}$ cm³ (cm/cm² / s /Pa) and for formic acid, the data suggests and expected Permeability of $P \approx 1 \times 10^{-17}$ cm³ (cm/cm² / s /Pa). Most likely, in our measurements, the formic acid swelled the PET leading to a larger measured permeability than predicted.



<https://www.versaperm.com/materials/PET%20Polyethylene%20terephthalate%20-%20vapour%20permeability.php>

The permeation of a material depends not only on the permeant but also on the properties of the film. It is possible to tailor the desired barrier properties by changing the chemistry and structure of the polymer material. Published studies on the barrier properties of various films shows the ability of each polymer film to allow the transmission of water vapor and oxygen.

Can we find a material that is permeable to acetic acid?

Material	Permeability (mlm ⁻² MPa ⁻¹ per day)			
	N ₂	O ₂	CO ₂	H ₂ O
PE (0.922)	120	300	2,300	5,300
PE (0.954 – 0.960)	18	71	230	860
PP (0.910)	-	150	610	4,500
PVC	2.7	8.0	67	10,000
PVdC	0.07	0.35	1.90	94
PS	19	73	590	80,000
PA (Nylon 6)	0.67	2.50	10	47,000
PET (MylarM)	0.33	1.47	10	8,700

<https://www.versaperm.com/materials/PET%20Polyethylene%20terephthalate%20-%20vapour%20permeability.php>

Kinetic diameters $\sigma =$

- 0.28 nm H₂O
- 0.33 nm CO₂
- 0.346 nm O₂
- 0.364 nm N₂
- 0.44 nm acetic acid

Often, the permeability of N₂, O₂, CO₂, and H₂O through various polymer films can be found in the literature. As a first guess for what films might be permeable to acetic acid, we might want to choose a polymer that has a large permeability to N₂ since the molecular diameter of nitrogen gas is relatively large. Since the permeability of N₂ through PE is larger than the permeability of N₂ through PET, this material might be an interesting material to investigate.

Copolymers of PET

Polycyclohexylenedimethylene Ethylene Terephthalate (PETG)

Eastman Kodak

.25 mm film = 10 mil

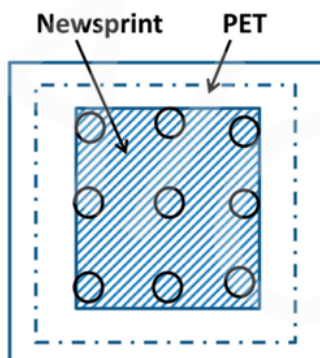
Transparent, amorphous

Permeability ($\text{cm}^3 \text{ mm}/\text{m}^2/\text{day}/\text{atm}$)

	CO ₂	O ₂	N ₂
PETG 10 mil	31.5	9.8	3.9
PET 3 mil		34	9.2

<https://www.triforestlabware.com/Download/PETG-Gas>

Copolymer of PET, such as PETG, may be an option. However, even though the permeability of N₂ through a thicker film of PETG is smaller than the permeability through a thinner PET film, similar film thicknesses are still expected to show that PET is more permeable to N₂ than PETG.



Schematic diagram of the encapsulated newsprint where the PET enclosure had holes on one side of the PET. The dashed line is the ultrasonic weld

Formic acid ambient atmosphere		ΔE
No PET		1.3 ± 0.5
PET, 4 sides welded		1.17 ± 0.5
PET, 3 sides welded		1.0 ± 0.5
PET with holes measured in holes		2.0 ± 0.5
PET with holes measured between holes		1.8 ± 0.5
NO ₂ ambient atmosphere		
No PET		17.1 ± 0.5
PET, 4 sides welded		1.0 ± 0.5
PET, 3 sides welded		3.1 ± 0.5
PET with holes measured in holes		13.2 ± 1.2
PET with holes measured between holes		14.4 ± 0.7

ΔE values for newsprint after exposure to formic acid and NO₂

We also investigated the ability of PET to protect a newsprint document by punching holes into the PET and using this porous PET film to encapsulate newsprint. These encapsulates were then placed in a chamber which exposed the encapsulates to NO₂ and formic acid vapors. The holes allowed the gases to not only discolor the paper which was exposed by the holes, but the vapor diffused through the paper and discolored the paper between the holes.

Conclusions

PET is permeable to water and formic acid

PET is not permeable to acetic acid (very long....?)

May not matter if paper keeps its acid.....

New materials will allow permeation to be tailored
– more studies needed



HERITAGE SCIENCE FOR CONSERVATION



JOHNS HOPKINS
UNIVERSITY

Thank you for listening to our talk. In this work, we measured the permeation of water and formic acid through PET. We did not measure any permeation of the acetic acid. Since the acetic acid is a larger molecule than water and formic acid, it is not easily transported through the polymer film. These studies investigated the permeation of gases through the film. If molecules do not evaporate from the paper into the atmosphere within the encapsulate, the permeation of vapors will not occur, no matter how permeable the vapor is. Therefore, these results are dependent on the rate of evaporation of the vapor from the document. Finally, more studies are needed to find a material that has suitable archival qualities and yet permits the permeation of large molecules such as acetic acid while providing mechanical support.

Investigating preservation strategies for cellulose ester objects

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Original Abstract

Objects made of cellulose ester plastics - cellulose nitrate (CN) and acetate (CA) – are known for their extreme instability. Many iconic 20th century artworks and artifacts made with CA and CN have gained notoriety as examples of severe degradation, and some have been categorized as ‘total loss’. Over the last thirty years studies have focused on the ageing behaviors of these materials, however research is still needed to better understand how to preserve this important part of our heritage. Therefore, part of the Preservation of Plastics Project at the Getty Conservation Institute (GCI) is dedicated to studying the deterioration of three-dimensional objects made of cellulose esters, as well as investigating strategies to preserve them by using reference materials and case studies. In 2017, in preparation for an exhibition organized by the Getty Research Institute (GRI), the GCI and GRI surveyed a collection of hair combs primarily made of CN. This survey provided an opportunity to study a large number of cellulose ester objects in varying conditions, investigate analytical methods to measure their stability and explore long-term storage solutions. Methods included ion chromatography (IC), size exclusion chromatography (SEC), gas chromatography/mass spectrometry (GC/MS), visual inspections, as well as acid detectors. Through the presentation of this case study, the paper aims to provide museum professionals with useful information and methodologies for approaching some of the challenges posed by these unstable materials.

Investigations of the binding medium of Mark Tobey paintings using pyrolysis-GC/MS

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Original Abstract

Mark Tobey was a 20th c. painter working in the Pacific Northwest, New York and internationally, and a key founder of the Northwest School. A painter of calligraphic temperas inspired by his spirituality, his extensive travel and innovative style established his work in the collections of major museums around the world. He was known to experiment with paint mixtures and his works are usually described as painted with gouache or tempera. Analysis of these paints is absent from the literature, and the lack of technical information on Tobey's specific binding medium presents challenges to conservators wishing to perform treatments such as consolidation or retouching. Both the terms "gouache" and "tempera" have historically shifted in meaning and can refer to a range of paint mixtures. This study sought to understand the composition of Tobey's paints by utilizing Pyrolysis coupled to Gas Chromatography Mass Spectrometry (Py-GC/MS) to identify key components of both reference binders and paint microsamples taken from twelve paintings by Mark Tobey from the collections of the Seattle Art Museum and the Jordan Schnitzer Museum of Art in Eugene, Oregon.

A Py-GC/MS method utilizing a TMAH methylating agent was modified from a published method and used to characterize a range of reference binders including plant gums, egg yolk, animal glue, linseed oil, resins and waxes. High pigment-to-volume ratios reduced the detection limits for egg and animal glue markers, though increasing the methylating agent increased this limit in mock-up mixtures with zinc oxide and egg yolk. Analysis of the Tobey painting microsamples with the optimized method indicated the main binder component was a polysaccharide, matching most closely to the gum tragacanth reference binder. Wax was detected in two paint samples, indicating it may have been used either in a binder mixture or applied afterwards to modify surface properties. Triterpenes in the chromatograms may originate from a resin medium such as copal or from the particle board substrates which often contain wood pulp. Strong palmitic and stearic acid peaks may derive from linseed oil or from egg. Work is ongoing to verify the presence of a protein binder in Tobey's tempera paints while analysis of paper samples included with paints will determine the likelihood of wood pulp as the contributor of the triterpenes.

Application of laser-induced breakdown spectroscopy (LIBS) for micro-sampling-based elemental analysis of cultural heritage objects

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Original Abstract

When working with cultural heritage objects it is always preferable to utilize non-invasive, non-destructive analytical techniques to get essential data that informs conservation efforts or art historical and other material culture studies. While this is the preferred approach, conservation scientists and conservators are routinely required to consider if sampling or application of a destructive method is worth the potential information to be gained. This talk will highlight several examples that demonstrate the advantages of laser-induced breakdown spectroscopy (LIBS) as a micro-sampling-based elemental analysis tool that is minimally destructive.

LIBS has been used to examine cultural heritage objects for many years, yet it remains an underutilized approach, especially in the USA. The advent of commercially available handheld LIBS systems within the past five years offers a unique opportunity for scientists and conservators to utilize the instrument conveniently and safely in a laboratory or museum setting. LIBS is a laser-based form of atomic emission spectroscopy that has the advantage of being able to simultaneously detect all elements from hydrogen through uranium. It can be used to analyze any type of solid and is especially sensitive to light elements that cannot be measured with X-ray fluorescence spectroscopy. LIBS analysis takes only a few seconds and is well suited for objects with patinas or corrosion since sequential laser pulses effectively clean the surface and provide data on the underlying material. The amount of sample removed with each laser pulse is on the order of nanograms, leaving an ablation spot that is often undetectable with the unaided eye.

At Yale's Institute for the Preservation of Cultural Heritage, we have used laser-induced breakdown spectroscopy for a variety of applications. When appropriate, we have employed LIBS to try to answer questions posed by conservators and curators. Examples of short-term projects we have undertaken include the examination of the silver plating on a 20th-century Chinese bridal necklace, analysis of a handle on a modern coffee pot to determine if loaning the object to an institution in another country would constitute a violation of the Convention on International Trade in Endangered Species (CITES), and investigation of a textile reputed to

have been woven with colored aluminum ribbon. This presentation will describe how LIBS and XRF are being applied to the study of the clay bodies and glazes found on over 100 Chinese ceramics. Data processing using machine learning tools is providing insight into the provenance of the objects. A library of over 400 samples of mahogany and mahogany look-alikes wood specimens have been analyzed using LIBS and pyrolysis gas chromatography-mass spectrometry to see if it is possible to identify the type of wood found in the collection of 18th and 19th-century furniture.

Pushing the Limits – The Portable Laser Ablation Micro-Sampling Technique and its Application in Cultural Heritage

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Original Abstract

Non-destructive, in situ elemental analysis using x-ray fluorescence spectroscopy (XRF), especially in the form of handheld instrumentation (pXRF), has made a great impact in the field of conservation and, more broadly, in the study of material culture. The use of this “gateway” analytical approach in collection settings quickly progresses from addressing qualitative questions about material identity and presence (e.g., is it brass or bronze; can we detect arsenic-based pesticide) to comparative studies requiring quantification. Increasing efforts in provenance research in collections will likely lead to greater demand for the geochemical grouping and sourcing of artifacts. For these studies some limitations of XRF – lack of sensitivity to low-atomic number elements, inability to distinguish isotopes, and attenuation of bulk signals by surface modifications – can only be overcome by shifting to other analytical techniques, including inductively-coupled plasma mass spectroscopy (ICP-MS), multi-collector ICP-MS (MC-ICPMS) and thermal ionization mass spectroscopy (TIMS). These methods, however, require sampling, including scraping, micro-drilling, scoring, and flaking, or the use of fine saws, which often leave visible lacunae and in the case of brittle materials, like glass, may lead to the initiation of microcracks and catastrophic failure.

The relatively recent development of portable laser-ablation (pLA) sampling modules overcomes these sampling-related challenges and makes trace element and isotope analysis of objects much more feasible and potentially more broadly accessible by decoupling the sample removal step from the subsequent (MC)-ICP-MS or TIMS analysis step. A pulsed laser beam is used to ablate microscopic amounts of material from an object while suction by a vacuum pump collects the particles onto pre-cleaned Teflon™ filters, which are later processed in a clean laboratory with low blank (picogram sensitivity) geochemical protocols and then analyzed. The ablation pits created by the devices are less than 0.15 mm in diameter and barely notable by the unaided eye.

This paper introduces two pLA sampling devices, based on visible green (532 nm) and ultraviolet (213 nm) pulsed lasers, and details their implementation as part of a trace element

analysis workflow for cultural heritage objects. While the green laser device is more compact and portable than the UV pLA module, it is primarily effective for the sampling of opaque and dark materials. Though a bit bulkier, the UV pLA is still portable and can successfully ablate materials regardless of color and transparency, making it ideal for sampling glass and porcelain objects without the risk of introducing microcracks. The utility of the 532 nm pLA device will be illustrated through two case studies. The first involves the analysis of jade artifacts in European and US museums that allowed the reconstruction of vast pre-colonial exchange and mobility networks of jadeite – omphacite jade artifacts in the Caribbean. The second is an ongoing study of Mycenaean gold objects in museums across Europe, which highlights how pLA sampling can make feasible the study of artifacts that would have previously been considered off-limits. We showcase the potential of the newer UV pLA device through the analysis of reference materials and preliminary case studies.

Annotated Presentation

The slide features a dark blue background with a central rectangular area showing a microscopic image of a textured surface. The title is centered in white text over this image. Logos for Yale and the Center for Environmental and Earth Science are in the top corners. The presenter list is at the bottom, along with the event name 'AIC 2022 - RATS' and the date 'May 17th, 2022'.

Yale Institute for the Preservation of Cultural Heritage

**Pushing the Limits –
The Portable Laser Ablation Micro-
Sampling Technique and its Application
in Cultural Heritage**

Alice Knaf, Pablo Londero, Moritz Numrich, James Nikkel, Richard Hark, Ernst Pernicka, Anikó Bezur

AIC 2022 - RATS **May 17th, 2022**

My name is Alice Knaf and I'm here today to talk to you about recent advancements in portable Laser Ablation Micro-Sampling in Cultural Heritage; and why your research or conservation project can greatly benefit from this novel analytical approach.

Chemical fingerprinting and elemental mapping of materials encountered in cultural heritage objects have become increasingly prominent tools for answering questions about their provenance and manufacturing technology.

The Challenge of Geochemical Studies in Museums

Many archaeometry measurements require a sherd for dissolution (ICPMS, ICPOES, TIMS, MC-ICPMS) or insertion into a sampling cell (Raman, SEM, EMPA).

Modified LA-ICP-MS cells don't solve portability problem. Cost of these systems is high.

The goal:

- Element abundances
- Isotope compositions

Most museum objects can't be sampled in a visibly destructive way and can't travel !

MS applications are limited.



However, a disagreement exists when it comes to the questions of “sacrificing” small pieces of an object or painting for invasive analyses.

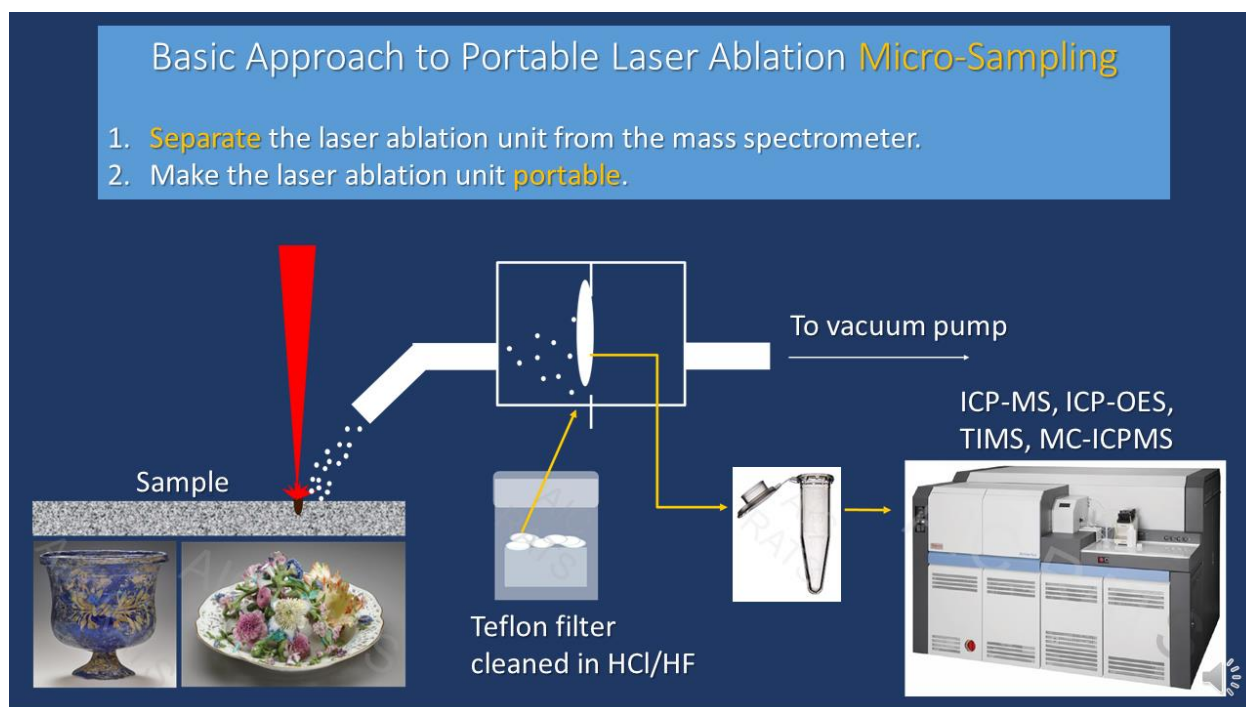
Elemental abundance analyses using laser ablation attached to inductively coupled plasma mass spectrometry (LA-ICPMS) have great potential due to the minimally invasive sampling procedure and the excellent sensitivity of the method.

This approach is particularly interesting for studies in cultural heritage as limits of detection and quantification for trace elemental analyses are in the lower parts per billion (ppb) and sub-ppb range. The application of LA-ICP-MS in cultural heritage research is, however, sometimes restricted because objects of interest are frequently too large to fit in a closed ablation cell or cannot be transported to the laboratory. Although larger chambers have been designed in recent years, several of which are commercially available, they are only applicable for relatively thin samples.

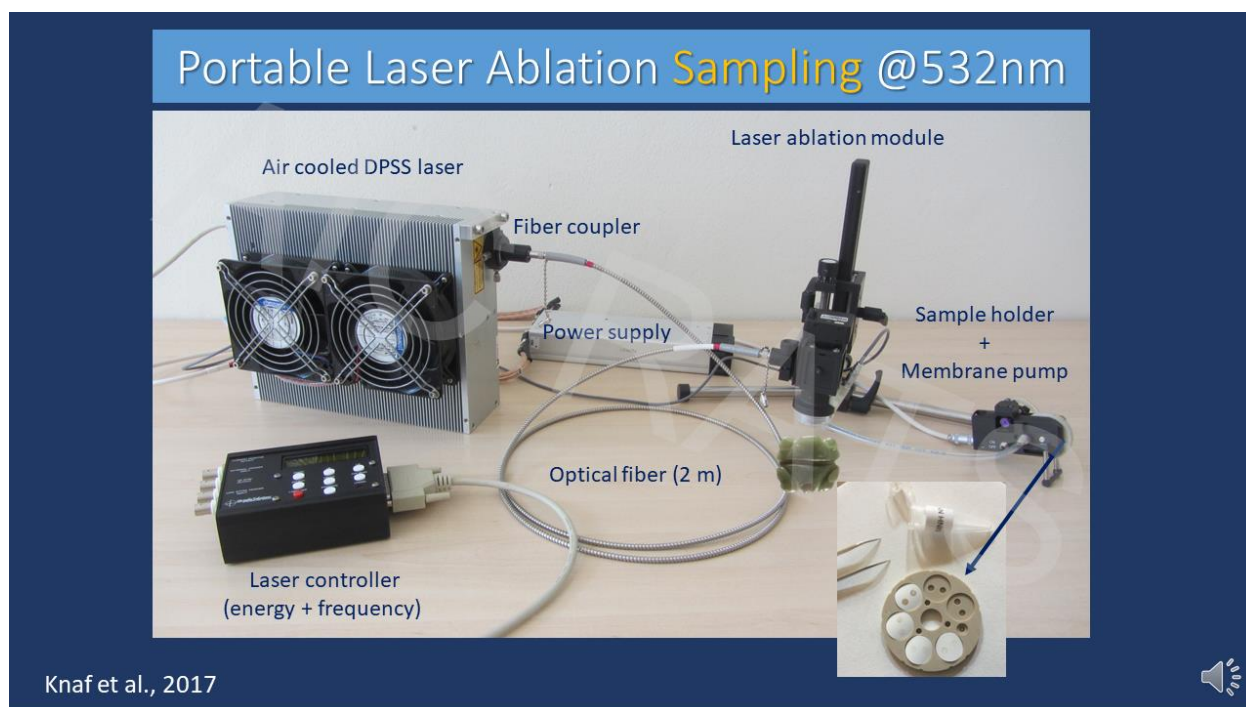


In some cases, classical non-destructive methods, used with portable instrumentation such as X-ray fluorescence analyses (pXRF) and Raman spectroscopy, or minimally invasive laser induced breakdown spectroscopy (pLIBS) might be sufficient to address certain types of research questions but have their limitations. They often need calibration with matrix matched standards, have poor analytical accuracy and precision, and in some cases cannot detect light elements. These methods are not capable of determining isotopic compositions and there are problems with obtaining representative analyses from objects with surface coatings or alterations, notably metal objects.

Destructive analyses offer advantages over non-invasive analytical methods. Compared to conventional sampling methods and strategies such as micro-drilling, scraping or cutting off material, novel laser ablation sampling methods are causing negligible damage, invisible to the naked eye.



An alternative approach was taken, involving modification of the conventional LA-ICPMS methodology to create a portable laser ablation sampling system (pLA) for use in art and archaeology. Besides elemental abundance analyses, the new set-up enables us to perform isotope composition analyses, and to determine with a high level of precision the elemental contents using isotope dilution techniques. The new methodology uses a portable minimal-invasive pulsed laser ablation sampling technique that can be used on location to collect samples onto Teflon™ filters for return to a clean laboratory for low blank geochemical procedures.



This picture shows the assembled portable laser ablation device which consists of a DPSS laser operating in the green light (532 nm). Attached is an optical fiber which leads the laser light through an ablation module and an open ablation cell onto the sample surface. The open ablation cell is connected via tubing to a sample holder which features a sample wheel with space for 6 filters. The ablated aerosols are sucked into the open ablation cell by an ambient airstream, generated by a membrane pump, and are deposited onto a filter. Each filter holds an ablated sample, is stored in a pre-cleaned centrifuge tube and can be returned to the clean lab for wet chemistry.

The long, 2 m optical fiber allows using the laser ablation module in hand-held mode to sample objects independent of size and shape.

A precondition for micro-sampling are technical improvements of analytical devices allowing accurate and precise analysis of small amounts of material in the range of $\mu\text{g-mg}$. The limiting factor to the successful application of (ultra) low blank geochemical techniques is the incorporation of extraneous material. Low blanks need to be achieved during sampling and subsequent chemical purification. Moreover, a sample representative to the matrix should be obtained to assure reproducible results.

Green Light Laser Sampling Device “in action”

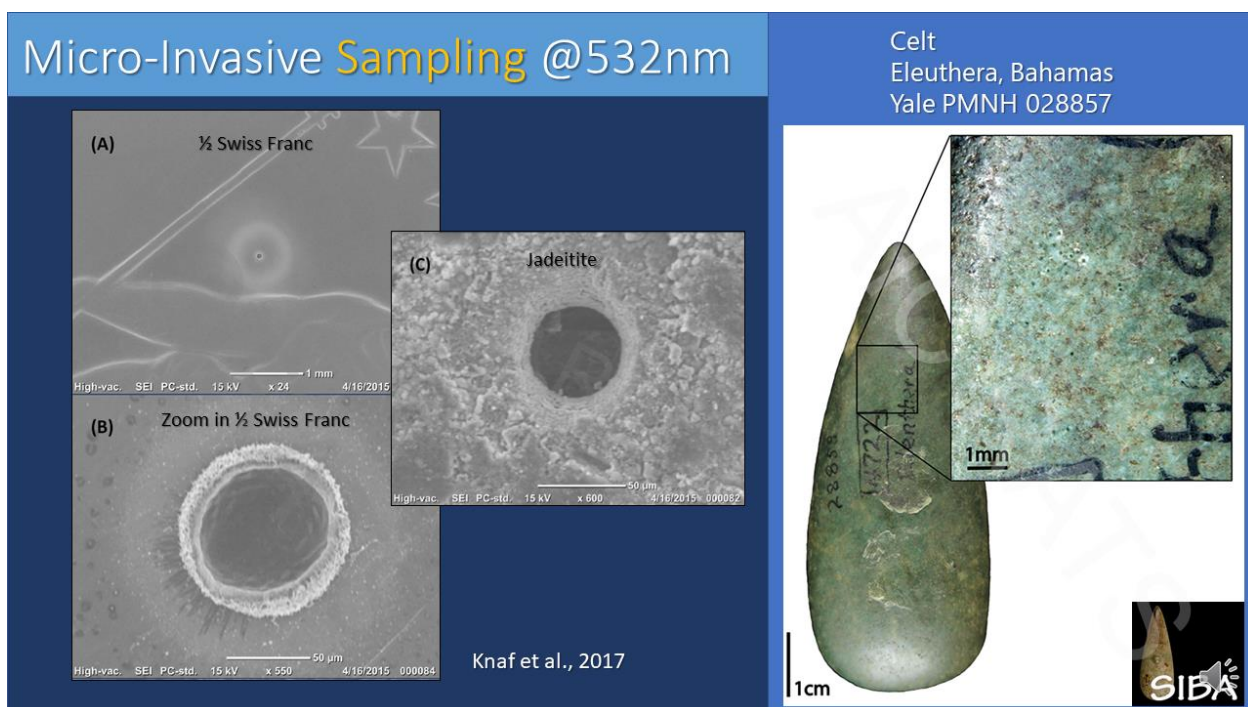


@ American Museum of Natural History, New York



What I really would like to highlight is that prestigious objects that have previously not been allowed for sample-based analyses, can now be analyzed by applying this sampling technique which opens new horizons in revealing important information, such as provenance. This novel approach allows to eliminate the discrepancy between “There is this really valuable and important object in our collection – but we don’t know anything about it”

These pictures show the green light laser in action at the AMNH in New York, where we sampled precolonial jadeite jade objects from the Caribbean.



I really would like to emphasize that the damage that the sampling process is causing is insignificant. Even with a magnifying glass one would have to search for the ablation pits. The crater dimension and sample quantity primarily depend on the choice of optical fiber.

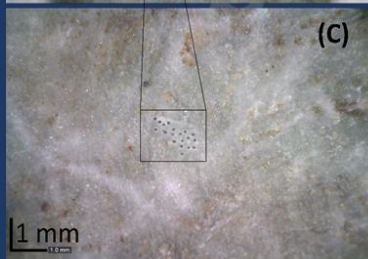
Ablation pits produced by normal fibers measure between 100-130 µm in width and depth visible to the right, while tapered fibers create pits half that size which are shown on the left.

Due to the inaccuracy of the sample volume taken, exact trace element abundances of the sampled material cannot be determined. More importantly, however, is the fact that trace element ratios are unaffected by imprecise volume and can be used for provenance and authenticity analysis.

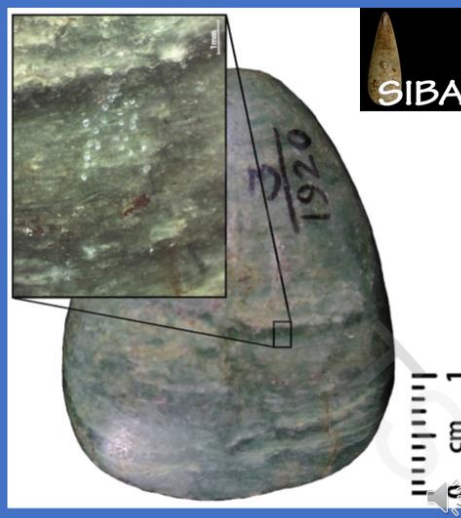
Micro-Invasive Sampling @532nm



Frog Pendant, Jadeite
Grenada, Pearls
50 – 250 AD
Willcox Collection
Knaf et al., in prep.

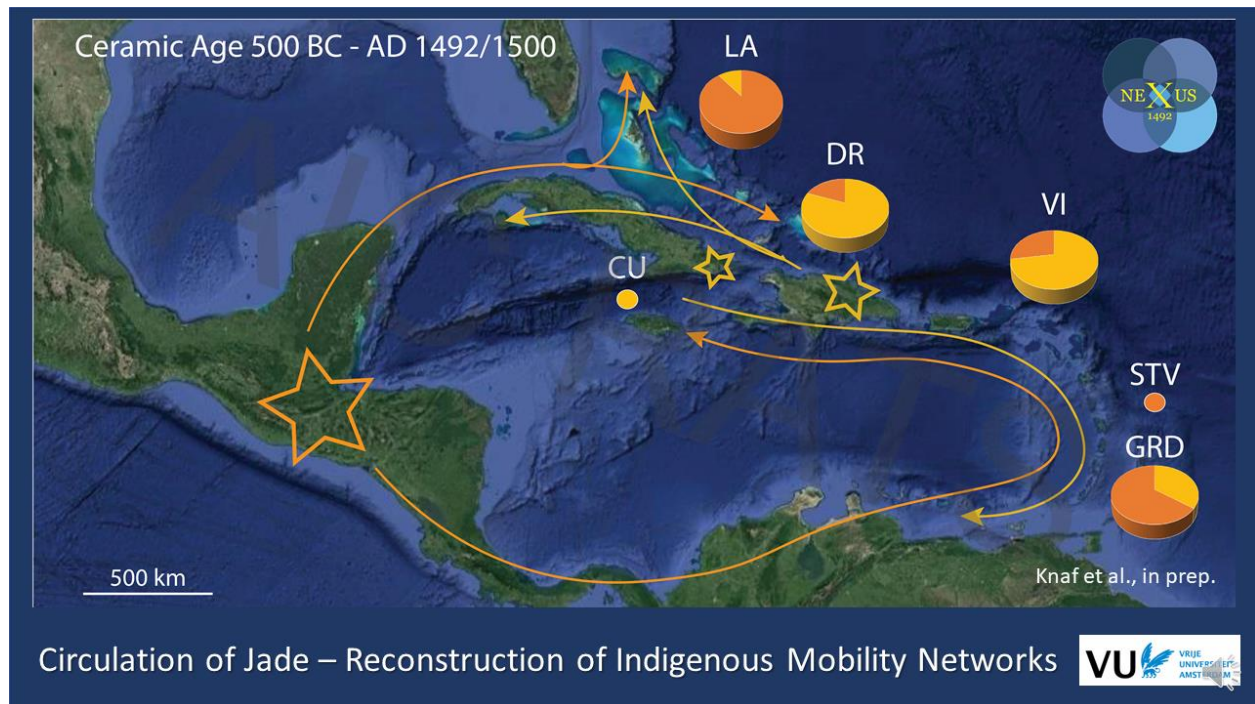


Celt NMAI 031920
National Museum of the American Indian
Ostapkowicz, Knaf & Davies, 2022



Depending on the concentration of the element of interest and to gain a representative sample, we might need more than 1 ablation. It is an indispensable precondition to have an idea about the materiality of the sample and a rough estimate about elemental concentrations. This is generally the case through previous experience, literature research or by applying non-destructive semi-quantitative analyses such as XRF.

There is always a tradeoff between the impact of sampling versus the valuable information we are gaining through destructive analyses. But, even when ablating a sample for 20 times as shown on the frog pendant to the left and the celt to the right, the impact on the object is negligible. The 20 ablations are macroscopically not visible.



The method was successfully applied to sample and analyze over 350 precolonial Caribbean jade artefacts. The geochemical fingerprints were compared to a conventionally established database of more than 100 jade source rocks from Guatemala, Cuba and the DR indicated on the map by the stars. The determined provenance outcome of artifacts recovered from Cuba, the Lucayan Archipelago, the DR, the Virgin Islands, St. Vincent and Grenada are shown in the pie charts.

This study unraveled indigenous long-distance transfers (> 4000 km) of raw materials, pre-forms or finished objects connecting Caribbean islands with the Central- and South American continent.



Mask of Agamemnon
Gold funeral mask
Mycenae, Peloponnese
1550 -1500 BC
National Archaeological Museum of Athens



Gerda Henkel Foundation: *Mycenaean Gold - Investigations on Origin, Distribution and Authenticity*

Austrian Academy of Science: *A new approach for Golden Treasures – Innovative Analyses in Archaeometry*



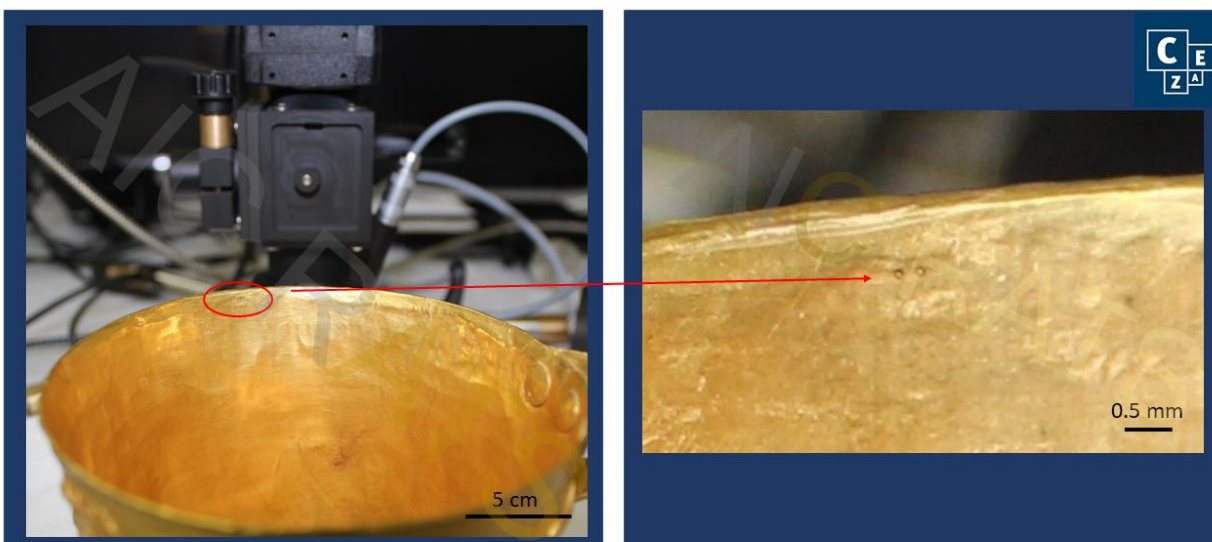
Gold Necklace
Poliochni, Lemnos
Early Bronze Age, 2400 - 2000 BC
National Archaeological Museum of Athens



To this day, the spectacular finds of gold from the Mycenaean civilization continue to fascinate both scientists and the general public. However, fundamental questions about these gold objects remained unanswered.....until NOW!

I am sharing here the work of my co-authors Prof. Ernst Pernicka and Moritz Numrich who are based at the Curt-Engelhorn-Centre for Archaeometry in Mannheim, Germany.

In this project, laser ablation sampling of a representative selection of Bronze Age gold objects was carried out in the National Museum in Athens and in other European museums, to answer questions about the classification of the material, its origin and possible purification processes of the gold used in the Bronze Age. The latter is also of particular importance for the identification of recent forgeries. Another aim of the project is to determine the number of workshops involved in the production of these objects based on the conducted geochemical analyses.

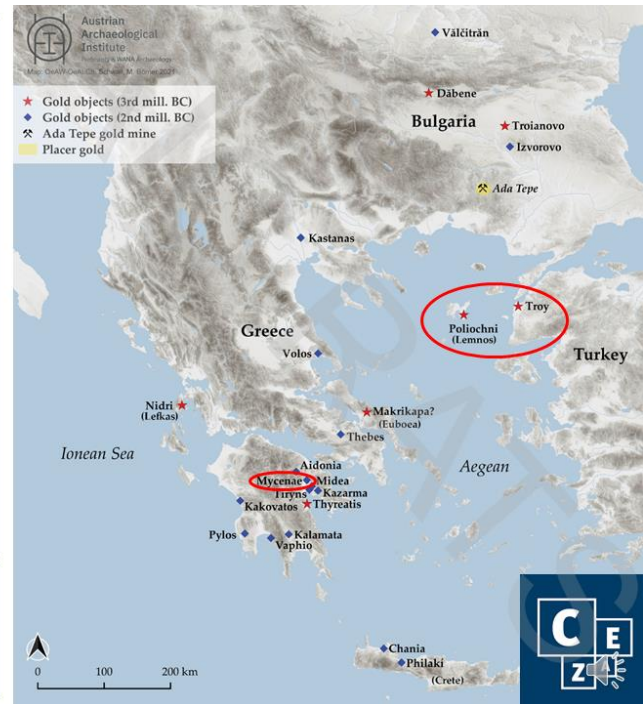
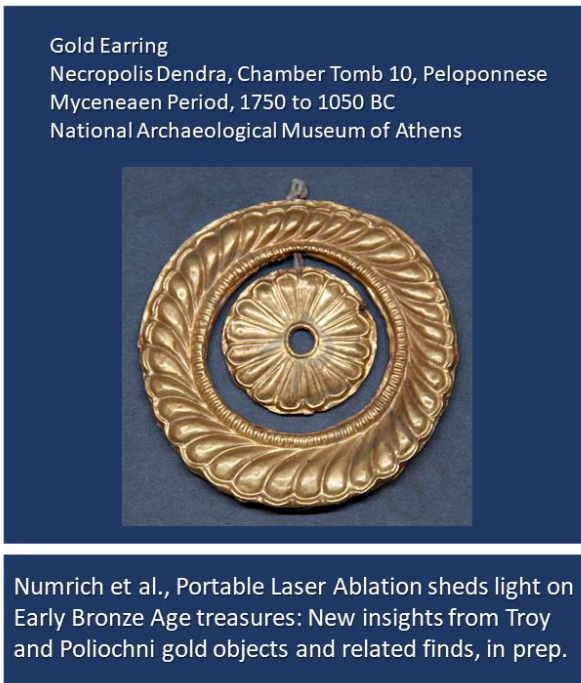


Ablation pits in a golden Mycenaean cup, Vapheio tholos tomb, Lakonia, 15th century BC

Pictures taken by Moritz Numrich, curtesy of the Curt-Engelhorn-Center for Archaeometry



The material classification is based on the main elements of gold, namely Au, Ag, Cu; and the trace elements in the gold, the PGE platinum group elements, especially Pd Palladium and Pt Platinum, but also Sn Tin, Sb Antimony, Co Cobalt, Pb Lead, and Bi Bismuth. Analyses was performed on 12.5 microgram which is achieved by 2 ablations.



Where does the Bronze Age gold come from? – This question is the focus of this research project

Preliminary results from Troy and North-Eastern Aegean settlements point towards the exploitation of West Anatolian gold deposits located around modern-day Izmir in the Early Bronze age 5000 years ago.

However, it seems that during the Late Bronze age, the West Anatolian source was not used anymore, and the gold in Mycenae most probably derived from Egypt.

Limitations of Portable Laser Ablation Sampling @ 523 nm


nm

Translucent samples cannot be ablated.
Semi-translucent samples can take several minutes to ablate sufficient material.
Slow ablation introduces increased background from ambient air.

↓

Ablation at 213 nm = UV Laser

Strong absorption cross-section for most materials.
Efficient ablation means less background from ambient air.

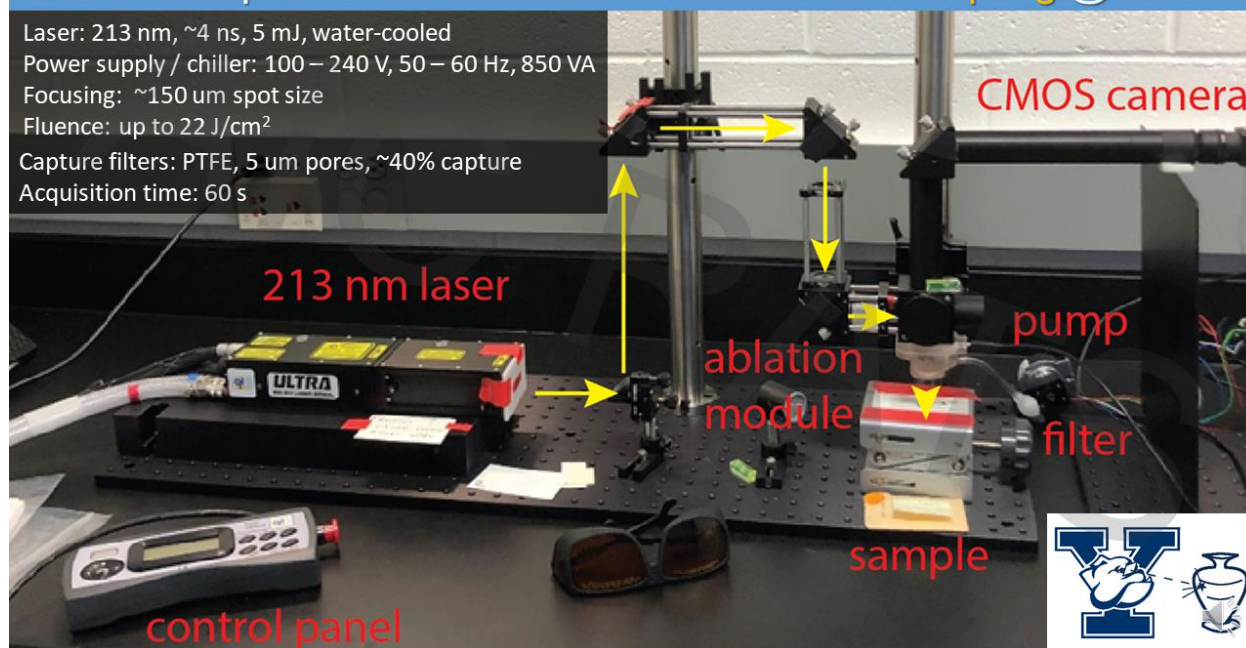


I have demonstrated the great potential the green light laser offers and its successful application.

However, it can take several minutes to ablate sufficient material from semi-translucent samples, and slow ablation introduces increased background from ambient air. To overcome the fact that translucent and transparent materials cannot be efficiently ablated with a laser operating in the visible range, we at the Institute for the Preservation of Cultural Heritage at Yale University are currently taking another approach.

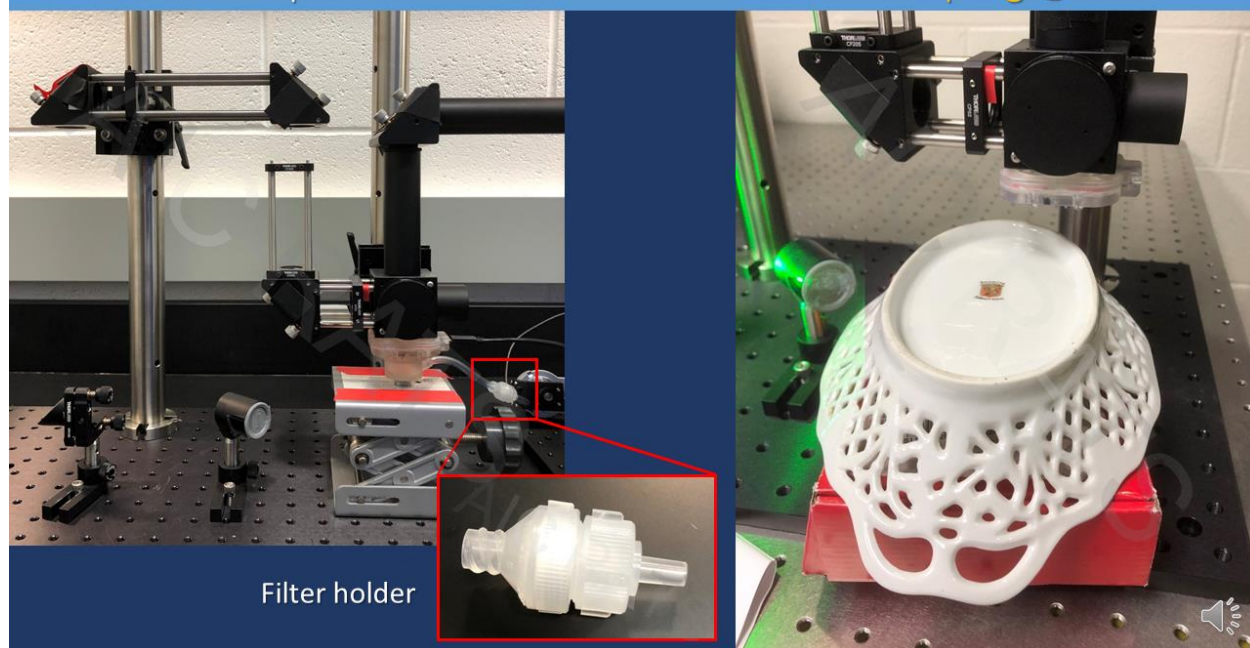
Current Implementation of UV Laser Ablation Sampling @ YALE

Laser: 213 nm, ~4 ns, 5 mJ, water-cooled
 Power supply / chiller: 100 – 240 V, 50 – 60 Hz, 850 VA
 Focusing: ~150 μm spot size
 Fluence: up to 22 J/cm²
 Capture filters: PTFE, 5 μm pores, ~40% capture
 Acquisition time: 60 s



We exchanged the green laser against an UV Laser. The advantage is an efficient ablation of translucent and transparent materials, introducing less background from ambient air and a higher sampling yield.

At the same time, using a short wavelength laser impacts portability, as the system needs a bigger power supply, and the laser requires a chiller. Nonetheless, the system can be transported conveniently in a vehicle.

Current Implementation of UV Laser Ablation **Sampling** @ YALE

We are currently focusing on the optimization and validation of the system by redesigning individual parts, such as the ablation head/pump/camera/sample wheel.

Isotope Composition Analyses: **TIMS** vs. **MC-ICPMS****Reproducible analyses of samples as little as:**

2ng of Sr
300 pg Nd
200 pg Pb

BUT**Lengthy analyses:**

Only 21 samples/standards per run
+
Slow and complex sample load on filaments
+
> 1 h manual measurement per sample or standard

**Fast analyses:**

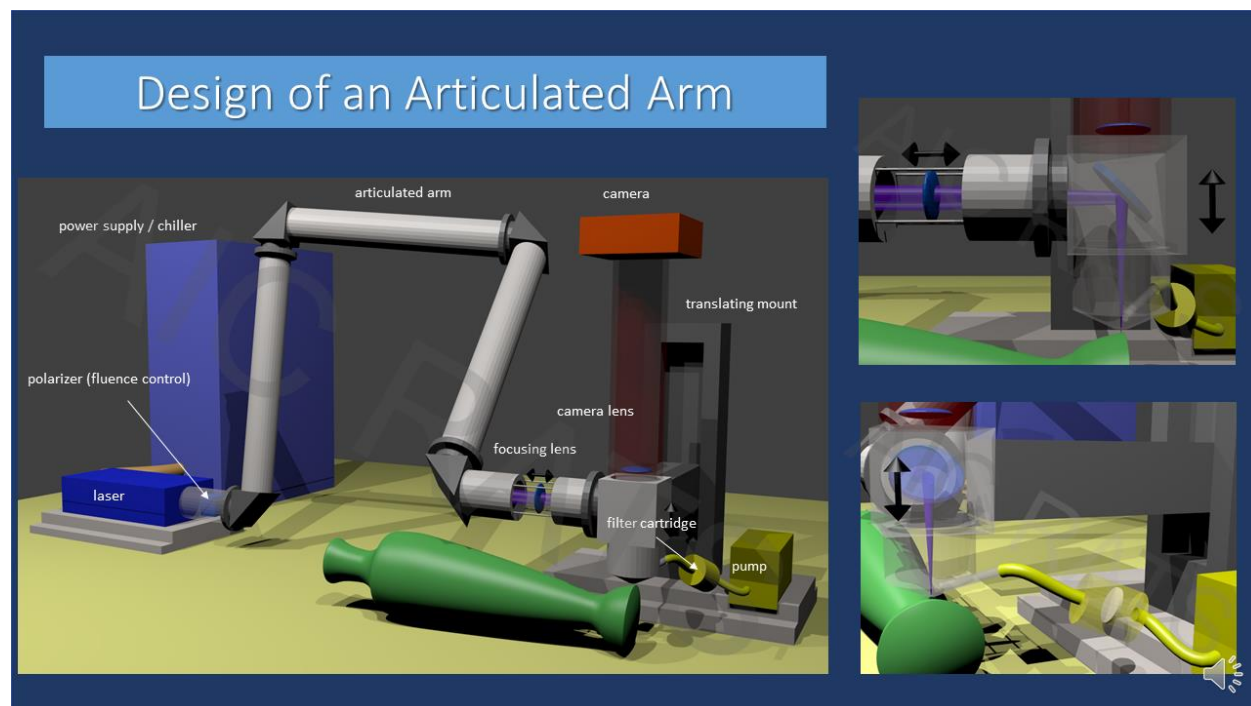
Simple, liquid sample introduction via nebulizer and spray chamber
+
Autosampler with place for 120 samples/standards
+
Analyses runs automatic, e.g. over night

BUT**Reproducible analyses requires:**

Sample solutions > 100 ppb, e.g. Sr > 100 ng per sample

Additionally, we are completing the proof-of-concept testing, which involves the sampling and subsequent trace element and isotopic composition analysis of NIST and Corning standard reference glasses using ICP-MS and MC-ICPMS in a clean room environment.

Compared to thermal ionization mass spectrometry, multi collector-ICPMS enables us to reduce the time for sample preparation and analyses significantly. However, to achieve reproducible and precise results comparable to TIMS more material, and hence ablations per sample are needed.



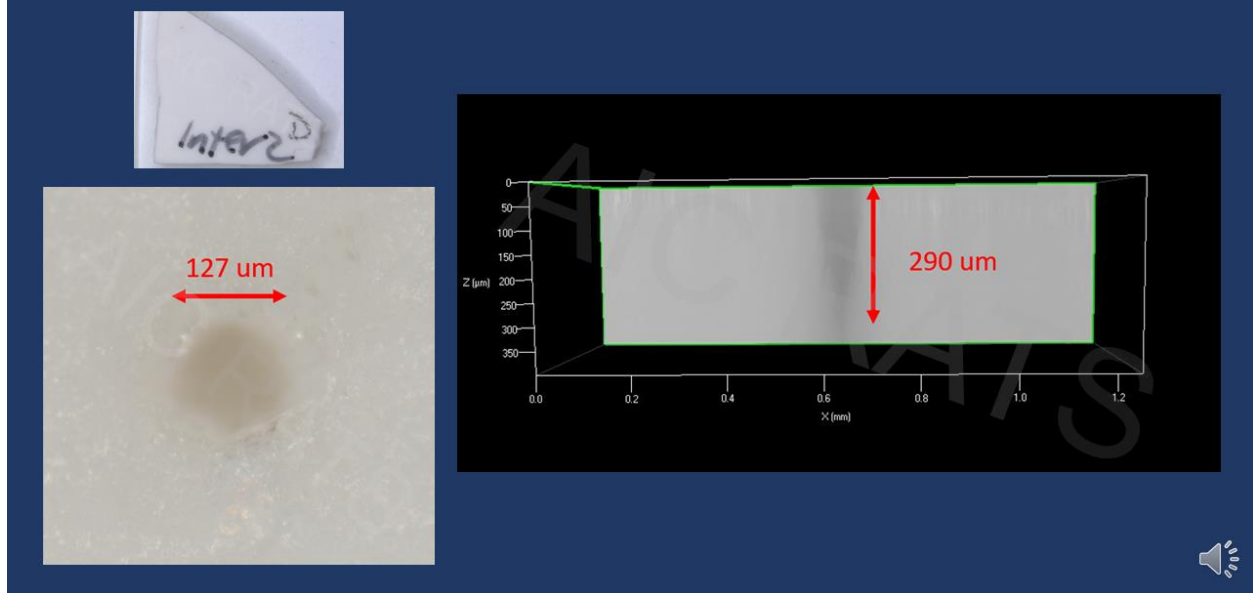
It is planned to design an articulated arm to encase the laser beam, which will make the system safer to work with, as well as more robust and portable.

UV light with a wavelength shorter than 260 nm causes degradation in conventional optical fibers at the power level of this pulsed laser.

Therefore, the current device features an open beam path which is a safety concern.

In a subsequent stage the redesigned UV pLA sampling tool and analytical method will be applied to a well-defined case study involving objects from Yale's collections, such as early American Stiegel glasses or Chinese porcelain from the Yale University Art Gallery.

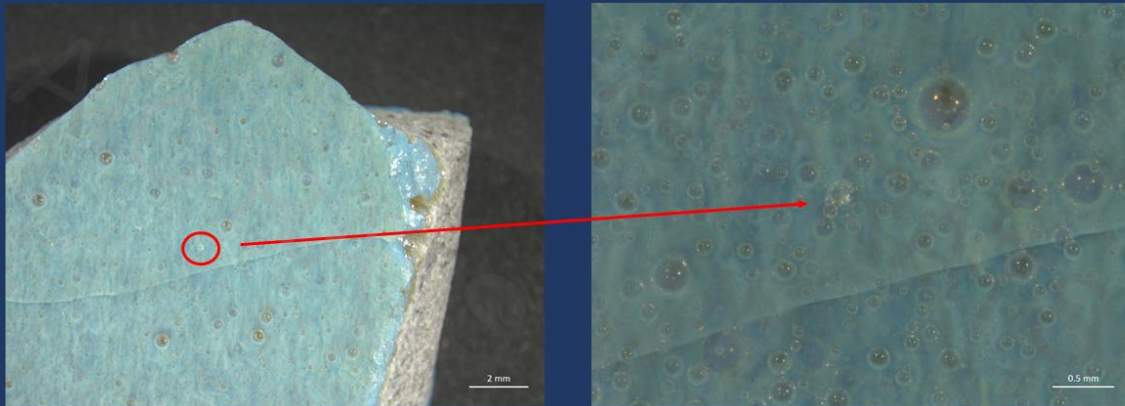
Dimensions of Ablation Pit in a reference Porcelain Sherd



As with any kind of sampling there is a concern of the structural and aesthetic impact. To provide reinsurance about the insignificant impact on the object I am going to show you several ablated surfaces of different materials which my colleague Richard Hark will pass through the audience.

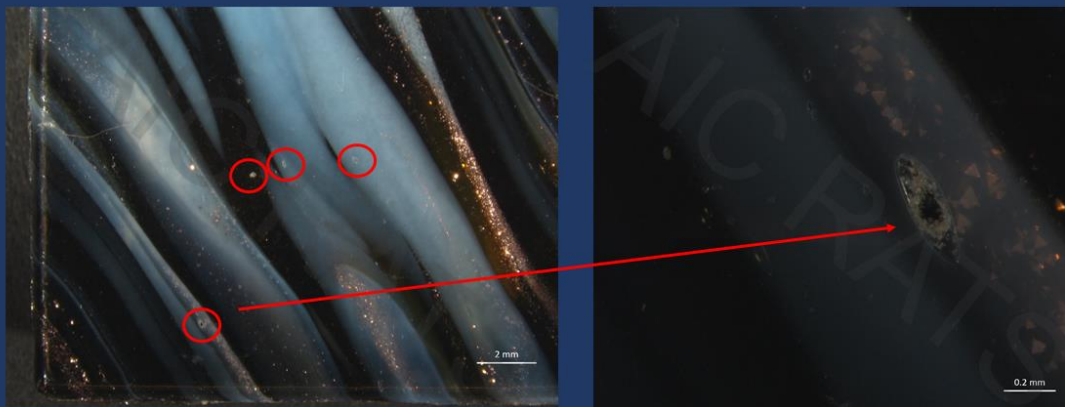
The generated ablation pits have a diameter of approximately 130 μm , are 300 μm deep and exhibit a classical conical profile.

Ablation Pit in a Ceramic Sherd



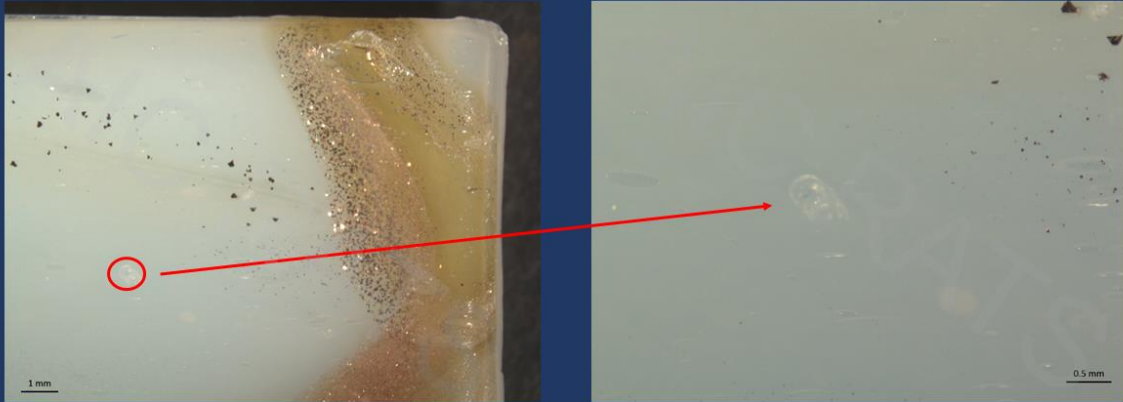
To the left displayed is an ablation pit in a glazed ceramic sherd and to the right a blow up of the ablated area.

Ablation Pits in a Multi-Colored Glass Tile



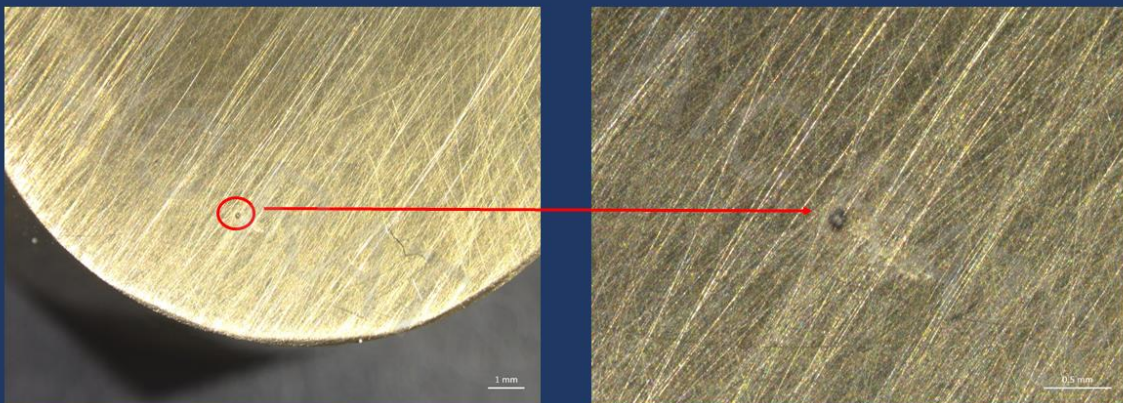
Same here to the left displayed is an ablation pit in a dark multi-colored glass tile and to the right a blow up of the ablated area.

Ablation Pit in a White Glass Tile



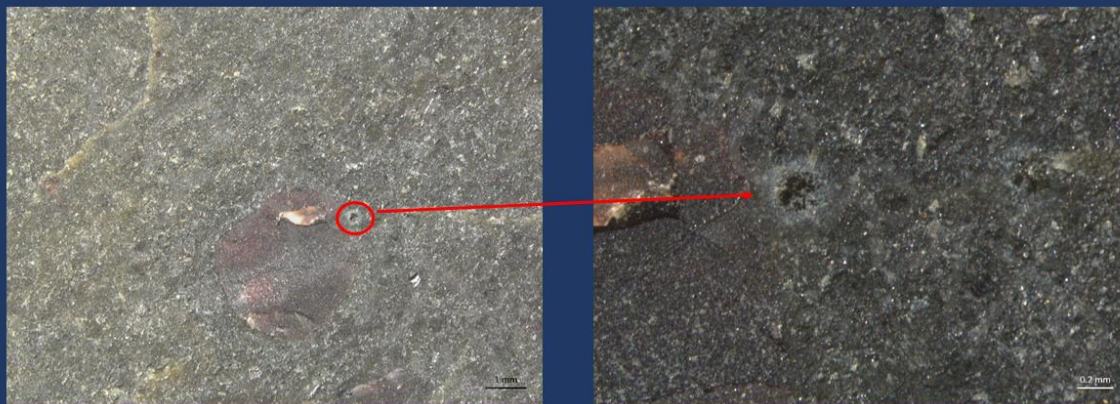
To the left displayed is an ablation pit in a light colored glass tile and to the right a blow up of the ablated area.

Ablation Pit in a Metal



To the left displayed is an ablation pit in a metal and to the right a blow up of the ablated area. The dark halo around the ablation pit will disappear by whipping, similar to the 2 ablations you saw before in the gold cup from ancient Greece.

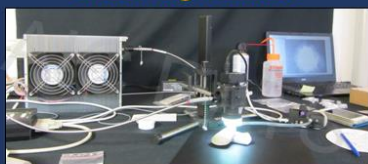
Ablation Pit in a Rock



And finally, to the left an ablation pit in an eclogite rock next to a garnet and to the right a blow up of the ablated area.

YOU HAVE THE CHOICE

Green Light Laser



Effective sampling limited to opaque materials
Portable and compact, can travel in a plane

OR

UV Laser



Samples all types of material effectively
Portable but bulky, can travel in a car



Requires less material than MC-ICPMS
but slow analyses

OR



Fast analyses
but requires more material than TIMS



To summarize, the approach to the right is what we are currently using at Yale but you have the choice and can swap lasers and analytical methods depending on your needs and the availability of instrumentation in your area.

I hope that I was able to demonstrate the great opportunities this sampling approach offers compared to non-destructive analyses. This sampling tool can be implemented in a conservation setting and used by a conservator. The analyses, data reduction and evaluation are supposed to be performed by a scientist.



.....and with that, I am happy to answer any questions you may have. Thanks for your attention.

Isotope and trace element analyses using portable laser ablation at the Field Museum: A progress report

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Original Abstract

The study of museum anthropological collections needs to be undertaken with no or very limited damages to the objects. With this constraint in mind, the Elemental Analysis Facility at the Field Museum has developed applications with laser ablation – inductively coupled plasma – mass spectrometry (LA-ICP-MS) for the determination of the elemental composition of ancient materials including glass, ceramic and copper-based alloys. However, objects must fit into the laser chamber which is a major limitation for larger objects, inducing sample selection bias. With portable laser, a relatively novel sampling technique, that leaves damages invisible to the naked eyes, micro sampling is possible virtually anywhere and on any type of objects without any limitation of size. Aerosols produced via ablation are deposited onto a Teflon filter. The ablated material can then be directly analyzed for elemental composition via LA-ICP-MS but can also be subjected, after dissolution, to isotope analysis (Pb and Sr) via thermal ionization mass spectrometry or multicollector-ICP-MS. We have been exploring the capabilities of this approach for the elemental and isotope analysis of copper artifacts and for the isotope analysis of glass, bone and ceramic objects to attempt the reconstruction of patterns of trade and migration.

Minimally invasive, on-site sampling by portable laser ablation

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Original Abstract

Elemental and/or isotope ratio analyses can provide insights in the authenticity, origin, age or manufacturing processes of ancient artifacts or pieces of art. Given the value and the irreplaceable character of the objects being examined, nondestructive analytical methods are generally preferred. However, they may lack specificity for the raised question due to a limited detection capability. Trace element and isotope ratio determinations, providing higher discrimination power, must therefore be carried out in specialized laboratories using various instrumental techniques such as inductively coupled plasma- or thermal ionization mass spectrometry after removing a representative amount of material from the object of interest. To minimize the damage through sampling, we developed a laser-based sampling method (portable laser ablation: pLA) that extracts a minute amount of material from the region of interest by focusing a laser beam to a spot of 40- 60 microns in diameter, leaving a barely visible crater at the surface after sampling. Compared to conventional sampling methods as microdrilling or scraping, the method can effectively reduce the amount of sample to the low microgram range, minimize contamination through contact-less sampling and precise control of the sampled region by direct visual observation of the ablated region. The ablated material is then collected on clean filter disks, which are analyzed in the laboratory.

Its compact design allows it to be carried to remote sites to collect samples that cannot be brought into the laboratory directly. The system has already been successfully used in studies concerning archaeometry, conservation and art. In this presentation, we will discuss the characteristics of the pLA system, its operating principles and features for the analysis of major, minor and trace elements as well as isotope ratio determinations. For better control of the total mass removal, acoustic detection has been implemented recently. This new feature increases the reproducibility in sampling and allows for better positioning of the sampling unit relative to the sample surface.

Accelerated aging of red pigments in bleach: Case study paintings of Cristobal Lozano

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Original Abstract

Knowing the behavior of the agents of deterioration on pigments is an important step to proposing suitable conservation strategies in works of art, mainly when they are exposed to high humidity and polluting agents' environment. The city of Lima presents those conditions due to its geographic location and proximity to the sea. For this presentation, we approach the work of Cristobal Lozano (1705-1776), an exponent of Peruvian Viceregal painter, and focus, specifically on the red pigments present in his work. The Palacio Arzobispal de Lima Museum houses important works of this artist. Studies were carried out about Lozano's work, together with the research on the techniques and materials used during the 18th century in the viceregal territories. In addition to the documentation in the treatises of that time, it was possible to identify the pigments used by Lozano, to achieve the red tones: Minium, hematite, and vermilion. In this context, a set of experiments were conducted using linen mockup probes of the three pigments. They were exposed to UV light (399 nm) and sodium hypochlorite (NaClO), in a controlled chamber. The physical and chemical degradation resulting was verified and measured using pXRF and colorimeter techniques. The results obtained indicated the occurrence of chlorides and a change in the visible wavelength spectrum reflected by the pigments. This study allows us to observe the different degradation of the three pigments in the presence of light and pollutants, in an accelerated aging environment.

Keywords: Colonial period; Cristobal Lozano; Pigments; Vermillion; Accelerated aging.

A Manuscript and its Materials: A cross-disciplinary analysis of the materials used in the making of the 14th-century Gaelic Manuscript, The Book of Uihaine

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¹National Library of Ireland

Original Abstract

The Gaelic manuscript tradition is unique in Europe for its continuity and longevity, as well as its persistently scholar-driven emphasis. Manuscripts written in this tradition survive from 600 to 1900 AD. For a thousand years – down to 1600 - these manuscripts were written by religious and secular scribes on animal skin. These artefacts are invaluable sources for the history and literature of Gaelic Ireland.

While they continue to be mined for their literary, linguistic and palaeographical content, the study of the materiality of these books is still in its infancy. Beneath the text, the ink and the writing supports and the way they were employed inform us about the history of the book. Through analysis of the physical and chemical traits of these manuscript materials, we are able to understand more about the animal who gave its skin to make the page, the individual who created the parchment, the scribe who worked the page, and the many readers who have gazed on the book since it was created.

Under the aegis of the UCC Inks&Skins research project, this paper describes a humanistic and a scientific approach to the analysis of The Book of Uí Mhaine. This is a vellum manuscript written in Co. Galway, Ireland, for the O'Kelly clan in the late 14th-century, containing secular and devotional prose, poetry and genealogies. In format it is 44 x 27 cm, and now contains 161 folios.

This analysis was made with a view to presenting preliminary data on the materiality of this manuscript. Methodologies employed include the utilization of non-invasive and micro-invasive techniques: proteomics, X-Ray fluorescence spectroscopy (XRF), Raman micro-spectroscopy, quantum cascade laser (QCL) mid-infrared spectrochemical imaging. The proteomic analysis of The Book of Uí Mhaine is the first to be carried out on a Gaelic manuscript, and this is the first time that the assumption that calfskin is the writing-support of choice in Gaelic manuscripts has been scientifically tested and confirmed. XRF analysis allows us to compare the presence and levels of different elements between different scribal inks. In The Book of Uí Mhaine, this is used to not only compare the inks of different scribes, but to analyze ink used by a single scribe within any given section. These inks are universally iron-gall, but with some variations, including the possible use of carbon ink in finishing large initial letters.

XRF analysis has confirmed the use of vermilion and orpiment as the primary pigments in letter decoration in the manuscript. A solitary instance has been discovered, the decoration of an initial letter with copper- and lead-based pigments. Exhaustive observational analysis is used in conjunction with the aforementioned methods. This focuses on the preparation, the writing and the post-writing features of the manuscript. In addition to features such as scraping, ruling and pricking areas of particular interest are those containing rubrication, display text, pen-tests, colophons and marginalia. These features significantly alter the reader's experience of a text, and are vital to our understanding of the makeup of the Gaelic book.

Reviving Alexander Calder's Man-Eater with Pennants: a Technical Examination of the Original Paint Palette

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Original Abstract

Man-Eater with Pennants, a rarely exhibited sculpture in Alexander Calder's oeuvre, was commissioned by The Museum of Modern Art (MoMA) and installed in 1945. This was Calder's largest sculpture to date, towering 4 meters tall with a wingspan of over 9 meters. In order to exhibit the large mobile in Alexander Calder: Modern from the Start (2021) the derelict state of the sculpture had to be remediated. This initiated an investigation into the original paint colors hidden beneath repaint layers of doubtful color accuracy and uncertain date, and led to a collaboration between conservation scientists, conservators, curators, and the Calder Foundation. Non-invasive X-ray fluorescence (XRF) analysis on both sculptures was first carried out to elucidate the paints' pigment composition, followed by sampling for analysis to assess the paint stratigraphy and binders. Scrapings were analyzed by both micro Fourier-transform infrared (μ -FTIR) and Raman spectroscopies, while cross-sections were examined with optical microscopy and analyzed with Raman spectroscopy and scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM-EDS). This research identified pigments, colorants, extenders, and possible binders used in the original primary palette selected by Calder for Man-Eater. Analysis differentiated between the original paints, which contain Prussian blue, parachlor red, and chrome yellow, and the many layers of overpaint, which contained titanium white, molybdate orange, a variety of β -Naphthol reds, red lead and ultramarine. A model for Man-Eater, Mobile with 14 Flags, is also part of the museum's collection, and was first considered as a point of reference for the original colors. Similar analysis however indicates that the maquette was painted after the Man-Eater was first installed and therefore is not representative of the original colors. In addition to investigating an early primary palette for Calder's outdoor sculptures, this study helped develop the plan for the restoration of the original color scheme of Man-Eater. This talk will explore the scientific findings gained from employing this multi-analytical approach, and the treatment will be explored in a separate presentation by Lynda Zycherman and Abigail Mack titled "A Lesson in Balance and Adaptation: The Conservation of Alexander Calder's Man-Eater with Pennants."

Full Paper: Haddad A, Randall M, Zycherman L, Martins A. Reviving Alexander Calder's Man-Eater with Pennants: A Technical Examination of the Original Paint Palette. *Heritage*. 2021; 4: 1920–37.

Research and Technical Studies
Specialty Group & Wooden Artifact
Specialty Group Joint-Session
Presentations:

Identification of mahogany and look-alike woods in 18th- and 19th-century furniture using laser-induced breakdown spectroscopy (LIBS) and pyrolysis gas chromatography mass spectrometry (Py-GC/MS)

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Original Abstract

Mahogany was a valuable commodity sourced from the Caribbean in the 18th and early 19th centuries that was used in high-end furniture made in Great Britain and North America. In addition to the three species of “true mahogany”, there are many tropical hardwoods that are known by the appellation “mahogany” and distinguishing between the various species is challenging, especially once the wood has been incorporated into a piece of furniture. Another source of potential confusion is North American wood components treated to look like mahogany. Wood identification is important to appreciate the connections between the raw material sources and furniture manufacturing centers, to understand the choices individual craftsmen made in constructing these objects, and it aids objects conservators when treating these pieces. In addition, this work has obvious applications in the study of other wooden objects such as carved statues, panel painting substrates, frames, and architectural elements.

Identification of wood in cultural heritage objects is typically done by a wood anatomist using a variety of physical characteristics coupled with a visual examination of anatomical features found in microscopic images of thin sections. However, it is not always possible or desirable to obtain an appropriate sample for microscopic examination. An alternative is to use a chemotaxonomic approach that takes advantage of the presence of varying abundances of organic and inorganic chemical species to distinguish wood types.

The goal of an ongoing collaborative project with the Yale University Art Gallery is to use a combination of laser-induced breakdown spectroscopy (LIBS), pyrolysis gas chromatography-mass spectrometry (Py-GC/MS), and machine learning techniques to see if it is possible to discriminate between the three species of mahogany (*Swietenia*) and between mahogany and wood species with a very similar appearance with a goal of being able to identify woods found in the furniture collection. This presentation will highlight details of the project and the very

promising results that have been obtained after analysis of hundreds of samples of mahogany and look-alike woods as well as samples removed from the furniture.

Py-GC/MS is likely more familiar to conservators than LIBS. This powerful, laboratory-based technique has been used for the characterization of cultural heritage materials such as lacquers, resins, polysaccharides, and synthetic polymers. In the analysis of wood, Py-GC/MS targets the organic extractive components and requires only sub-milligram samples. It has been successfully used to distinguish between different species of ebony and rosewood. LIBS has been used to analyze a wide variety of cultural heritage objects and can provide elemental data on everything from paintings and statues to fossils and archeological artifacts. The method offers several attractive advantages such as the ability to simultaneously detect all elements, including light elements not accessible via X-ray fluorescence spectroscopy, high throughput in situ analysis (seconds), relatively low limits of detection (low ppm range), and the availability of robust, commercially available handheld instruments. LIBS is a micro-sampling technique, producing a small ablation spot (~100 microns) on the surface of the sample that is often not detectable without the aid of a microscope.

Study of the Mechanical Behavior of a 16th Century Panel under the Constraints of its Cradle, in Order to Establish an Equilibrium Point of the System. Between Interdisciplinarity and Serendipity.

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Original Abstract

The study carried out within the framework of a Master's thesis in conservation and restoration of painted panels, tends to improve the understanding of the behavior of the panel facing its cradle. But more globally to improve the understanding of painted panels by the complementarity science-experience. Indeed, the interdisciplinary study in several distinct phases and in partnership with the laboratory of mechanics and civil engineering of the University of Montpellier, the P' Institute of the University of Poitiers and the conservation department of ESA Saint-Luc Liège will allow us to understand the movements and deformations of the panel with specific optical methods: the digital image correlation and the projection of moiré fringes. The first results of the study were analyzed and interpreted by engineers specialized in wood mechanics and panel paintings conservators. This allowed us to outline the most appropriate treatment protocol for the work, while respecting the ethical and deontological rules of the restoration profession. The results of the study will enable the restorer to guide the conservator in a preventive conservation approach directly on the place of conservation of the work but also to act directly on the cradle and on the panel to establish a point of balance as precise as possible of the painted panel. The study is still in progress and all the phases have not yet been completed, but the first results already allow us to outline the treatment protocol and to establish certain study perspectives for the future.

Full Article in *WAG Postprints*

Twins with separate lives: a pair of Southeast Asian side tables with different treatment histories rooted in different cultures?

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Original Abstract

In 2004 and 2015 respectively, the National Heritage Board Singapore acquired two early 20th century side tables that form a pair. It was discovered that both tables had initially belonged to the same household but got separated later. Over time, the tables underwent different surface treatments which altered their visual appearances.

One of these tables will be displayed for the revamp of The Peranakan Museum's permanent galleries. The curator in charge asked the conservation department to select the table based on lesser treatment needs, as the opening date is set along a tight timeline.

The table acquired in 2004 (Table 2004) shows a black, matte to shiny, rather patchy and streaky surface. A visual examination indicates that the coating is black Asian lacquer with a very thin, modern synthetic coating on top. Something might have gone wrong during the last surface-refresher treatment. Especially the coating on the tabletop is very brittle and delaminates between its different layers which results in numerous losses.

The table received in 2015 (Table 2015) has a very smooth, semi-matte and dark surface which is heavily light-degraded in many areas. The appearance of those degraded areas has become rather dull and grey-greenish. In addition, these areas have become soft and almost powdery. The current coating is most likely a modern synthetic material.

Each of the two surfaces is in very bad condition and both tables would require a considerable amount of time for treatment.

Table 2015 was chosen at first, because there was a possibility that an original, intact coating lies below the degraded synthetic layer.

To aid the decision-making process, microscopic surface examination, cross section and chemical analysis were applied. Surprisingly, there was no evidence of an original coating system below the visible synthetic coating on Table 2015. Moreover, the conservation of this heavily degraded layer structure would be very difficult with possibly not very satisfying results.

Therefore, Table 2004 was considered. However, further examination, analysis and eventual selection of one of the tables for display are still pending.

All insights gained so far reveal an intriguing story of diversity of choices that have been made over time. What they have in common is the intention to preserve the characteristics of a black, semi-matte to shiny surface coating.

Technical Study and Conservation of Korean Late Joseon Dynasty Lacquerware

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Extended Abstract

Korean mother-of-pearl lacquerware, or the art of *najeon chilgi*, is richly decorated with an array of materials that fascinate: both the eye, with admiration for design, and the mind, wanting to know more about how these wares were made. The presentation describes the comprehensive conservation treatment and analysis of a group of four Korean mother-of-pearl lacquerware objects from the late nineteenth century that are in the collection of the Asian Art Museum, San Francisco. Examination of the manufacture and composition of two tables (round and twelve-sided), a tray, and a folding screen revealed that lacquer artists used a mixture of traditional lacquerware techniques and materials together with new materials and methods. This project is the first to offer a layer-by-layer analysis of late Joseon dynasty lacquerware. Close collaboration between conservators and conservation scientists was key to interpreting the objects' manufacture.

The lacquered objects are decorated exuberantly with inlay materials. In addition to mother-of-pearl, they are decorated with tortoiseshell, twisted and flat brass wire, golden-colored flakes made of brass, ray skin, and possibly horn. The decorative elements used on the objects follow a long Korean tradition of creating patterns on lacquered surfaces using inlaid elements. Three of the objects feature phoenix birds as the main design element, with beautiful flowing tail feathers. On the screen, each panel depicts a scene from the natural world. Ray skin is the dominant inlay material. In general, each object has a wooden substrate, adhered to the wood is a textile layer (in all cases a plainweave bast fiber), followed by a lacquer surface consisting of one or more layers into which is set the inlay elements. Analysis was performed to characterize the lacquer layers.

Figure 1 is a photomicrograph of a cross-section documented using visible and ultraviolet light. It illustrates the layers present on a sample taken from the round table. In the figure, a total of three layers were detected above the thick ground layer. The photomicrographs were used as a guide during separation of individual layers for subsequent analysis. Pyrolysis-gas chromatography-mass spectrometry with thermally assisted hydrolysis and methylation (THM-Py-GC-MS) was employed in the identification of organic material present in each layer (Schilling et al. 2016). The peak area percent composition of each layer is represented in a pie chart illustration for easier visual comprehension of the chemical makeup. The whitish ground layer (G) is a mixture of quartz, clay minerals, and coarse charcoal fragments agglutinated in drying oil and glue. The red lacquer layer (1) ranges in thickness from 3 to 5 μm and contains a

mixture of vermillion and small black charcoal particles intermixed with ottchil lacquer and drying oil. A thin, dark boundary line is present between (1) and (2), and no penetration of (2) into (1) is observed. An ultraviolet-induced (UV) orange fluorescing layer (2) is approximately 30 μm thick, containing shellac and drying oil. The top brownish layer (3) ranging in thickness from 5 to 20 μm also contains shellac and oil.

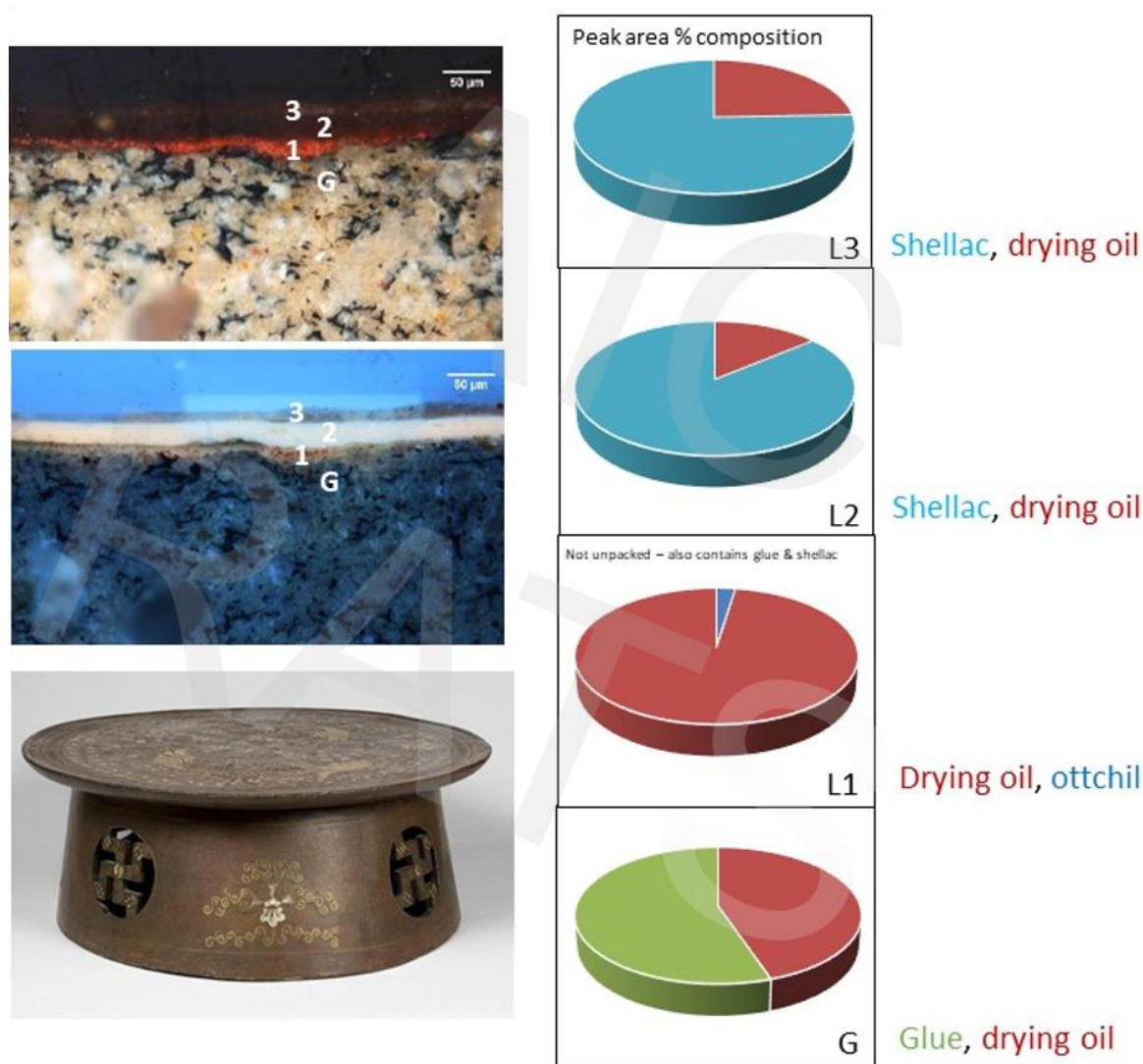


Figure 1. (Left top and middle): photomicrographs of a cross-section documented using visible and ultraviolet light, (left bottom) sampled object, (right) peak area percent compositions for locations L3, L2, L1, and G.

The twelve-sided table was the other object that contained three layers above the ground layer whereas samples taken from the folding screen and tray showed the presence of only two layers above the ground layer. Beside clay and siliceous minerals, phosphate originating from bone matrix was identified in the ground layers of the round table and folding screen. Iron oxide pigment was found in the red layer (1) of the twelve-sided table and tray. In comparison, vermillion pigment was found in layers (1) of the round table and folding screen. The presence

of those pigments over ground layers darkened with charcoal may likely influence the darker brown appearance of the objects. The surprising discovery of shellac, not only as a decorative coating but at multiple phases, points to the complex nature of Korean objects from the period (O'Shea *et al.* 2021).

Conservation treatment of these works consisted of stabilizing losses and securing lifting inlay. Losses in the lacquer, wire, and ray skin were filled with in order to preserve original surfaces and to allow the beauty of the design and its execution to be seen. For the lacquer, cast acrylic film was used to fill losses, while new wire was shaped and polished to fill losses in the wire. Textured removable paper fills were made to fill losses in the ray skin inlay.

In presenting this work, it is hoped that others will also engage in close examination of Korean lacquerware from the period. It is also hoped the results from the study will facilitate the advancement of partnerships with Korean counterparts to further scholarship about the manufacture of lacquerware objects from the late Joseon dynasty in general, and in particular, regarding methods employed by lacquer artists to minimize the incompatibility of shellac and drying oil during their application.

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Gloss measurement and Microscopic examination of Asian lacquer surfaces prior to cleaning

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Extended Abstract

Separating dirt from a degraded Asian lacquer surface can be one of the most challenging tasks in conservation treatment and miscalculation of the sensitivity of the surface can often cause additional damage. One aspect of this difficulty is that the surface characteristics can change in relation both the composition of the lacquer and the degree of degradation. How can the conservator assess the difficulty of that challenge?

Chemical analysis of the lacquer will give a good understanding of the nature of the individual composition; however, this tool is not universally available to conservators. Moreover, most objects contain several different lacquer formulations. Each material added to the anacard lacquer will contribute to the overall behavior. Understanding the vulnerabilities of the surface and how the appearance changes during aging is key to a developing a successful treatment.

Gloss measurement of the lacquer surface is the first step in the observation of changes. Gloss meters can vary in price and quality but even an inexpensive meter can provide one with valuable information on the state of the surface. To begin one can take base readings from the underside, interior or any surface that is relatively clean and has not been exposed to light. These readings can be compared to readings from the top, sides and any area that has been exposed to light. A comparison of the reading can indicate the level of degradation of the exposed surfaces, but one must be cautious in interpretation because a difference can also be due to dirt, or other coatings. Unfortunately, curved surfaces, and small interior areas cannot be measured so the gloss change alone cannot be used to evaluate an Asian lacquer surface.

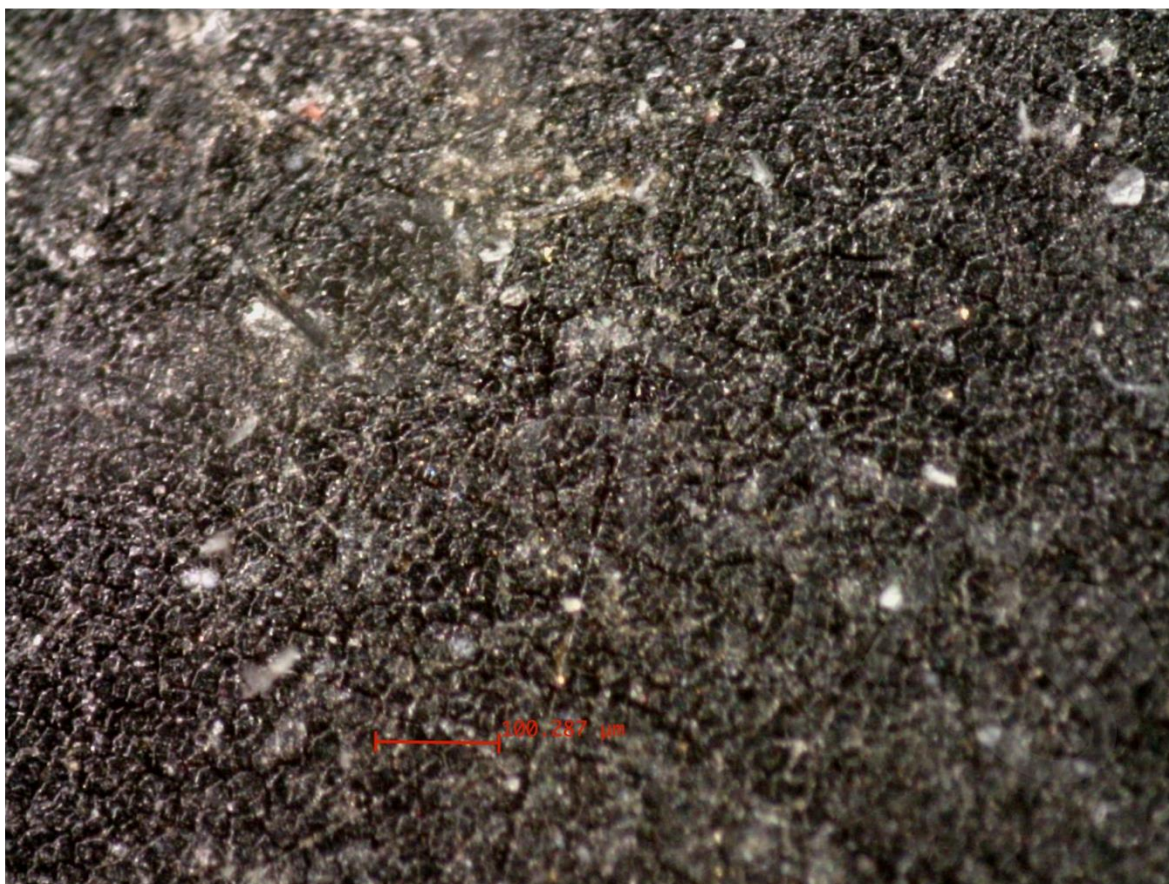


Figure. Image of Japanese Tea Kettle taken using Dino Lite Edge Microscope

Microscopy has always been beneficial but until the advent small portable digital microscopes their usage has not been convenient for directly viewing the surface of objects. During the past year the author has had the opportunity to examine over 80 Asian lacquer objects with the use of the Dino-Lite Edge microscope using both ring and coaxial lighting. Viewing objects at 415X to 450X with a variety of lamps assists in identifying surface features such as microcracking as well as understanding the distribution of soil, particulate matter and applied coatings. It is particularly important to identify the presence of microcracks as dirt can be picked up and moved into the cracks during treatment. This craquelure, with islands ranging between 25 to 50 microns in size, is not universal to all aged lacquer objects but appears frequently enough to merit continuing research.