Revisiting the surface, Edvard Munch and varnishes

A group case study and non-invasive approach to conservation decision-making for painting collections

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Thesis for the degree of Doctor of Philosophy (PhD)

2022

UiO : Department of Archaeology, Conservation and History
University of Oslo

Faculty of Humanities

Series of dissertations submitted to
the Faculty of Humanities, University of Oslo

Figure 01. The Munch Room c.1937 (Arbeiderbevegelsens arkiv og bibliotek, Oslo)

'Når de stilledes sammen gik der med engang en klang igjennem dem og de blev helt annerledes end enkeltvis. Det blev en symfoni…'

'When they were positioned together there immediately arose a resonance between them and they became totally different than when [displayed] individually. It became a symphony…'

Edvard Munch*

*Munch Museum: MM N 46, note 1930-34.

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Acknowledgements

This PhD would not have been possible without the generosity of my employer, the National Museum of Art, who have fully supported and facilitated my research on one of the most important painting collections in Norway. The thesis was designed and carried out independently although countless persons have guided and encouraged me through this four-year academic journey (2018–2022).

First and foremost, I would like to thank my supervisors. Since moving to Norway in 2001, Tine Frøysaker (University of Oslo) has always encouraged and backed my interest in research, believing in me whilst also openly sharing her profound knowledge on Munch. My absolute gratitude goes to Ella Hendriks (University of Amsterdam), whose vast experience and expertise has provided me with solid guidance, immense support, perspective, excellent feedback, motivating challenges as well as comfort when my courage has been running out. I am grateful to Adriana Rizzo (Metropolitan Museum of Art) for generously sharing her time and extensive expertise with the FTIR analyses and to Elena Platania (University of Oslo) for her assistance and ability to make conservation science comprehendible. A special thanks is due to Francesco Caruso (Swiss Institute for Art Research) who introduced me to pFTIR and was instrumental in getting the project started, helping to shape the research.

My sincere gratitude also goes to Piotr Targowski, and Magdalena Iwanicka (Nicolas Copernicus University) for the use of their OCT equipment, sharing of knowledge, expertise, and their enthusiasm for the project. They have influenced this work in multiple ways. Piecing together history of the Munch collection would not have been possible without the invaluable insights and help from Nils Messel and his contributions are deeply acknowledged. I have also had the privilege to learn from my Munch colleagues, Øystein Ustvedt, Mai Britt Guleng, Vibeke Waallann-Hansen and Wenche Volle. Furthermore, I am grateful for the fruitful discussions with the following Munch scholars and conservators, Hans-Martin Frydenberg Flaatten, Unn Plahter, Mille Stein, Johannes Rød, Lasse Jacobsen, Hilde Bøe, Marie von Möller, Trond Aslaksby, Fridrik Bertelsen, Jin Ferrer, Irina Sandu, Inger Grimstad and Noëlle Streeton (University of Oslo). I would like to thank Geert Van der Snickt (University of Antwerp) for the useful constructive criticism at the midway and deeply appreciate the generosity of Solfrid Sakkariassen and Inger Draugedalen for access and sampling at Munch's House in

Åsgårdstrand. The following people have also offered their help to different parts of the research, Duncan Slarke, Knut Ormhaug, Bjørn Egil Andersen, and Elisabeth Vik Forsberg.

Beside my advisors, I would like to thank my present and past superiors at the museum who have allocated me the time to undertake the research, Rolf Yngve Uggen and Kari Skytt Andersen, Francoise Hanssen-Bauer, and Kari Greve. A special thanks is due to my colleagues in photography, Morten Thorkildsen, Ina Wesenberg and Vidar Ibenfeldt and all those working in the library and archives. Børre Høstland for all your technical help and enthusiasm with the IRR and UVA photography and to Per Gisle Galåen and Hildegunn Gullåsen who have always made a special effort to obtain the relevant literature. Also deserving gratitude are Robin Coulthard and Eirin Øgård Kinn who helped prioritise access to the paintings. To all my colleagues in conservation I am indebted to you for having taken on my tasks so that I could pursue this research. Thank you, Laura Homer and Simone Tosca, for your friendship, kind support, and continuous encouragement during difficult times.

My sincere gratitude goes to Nina Gram Bischoff and Hanne Gram Simonsen (University of Oslo) for reading my final draft and providing useful comments. Special thanks are due to Alexandre Pedersen for moral support and helping with the layout and to James Black for proof reading. A big thank you to my Munch PhD gang, Lena Stoveland and Jan Cutajar, as without you this would have been a very lonely journey.

Finally, I would like to thank my parents who have always supported my career decisions and especially my mother who taught me structure in my work. However, this project would not have been feasible without the love, encouragement, support, interest, and endless discussions about research methodology with my wife Carmen. Lastly, to my two wonderful boys, Elliot, and Malachy, for tolerating an absent father these last six months and providing me with the best distraction.

Thierry-Olivier Ford
April 2022

Abstract

Edvard Munch (1863–1944) is well represented worldwide, but the National Museum of Art is the first Norwegian public institution to have collected, endorsed, displayed and conserved Munch's art during his lifetime. The 57 paintings, acquired over a 79-year period (1891–1970), are still regarded as the most iconic ensemble in the museum. Since 1909, these paintings have been presented as a single-artist collection and exhibited through the curated Munch Room display concept. Between 1909 and 1993 many of the unvarnished paintings were controversially varnished.

This thesis aims to gain knowledge about the painted surfaces and non-original varnishes in this Munch collection. A group case study was used to establish the historical context and a non-invasive methodological approach explored for the technical investigations. The conservator's perspective was key in the choice of user-friendly, cost-effective and practical examination techniques. Portable Fourier transform infrared spectroscopy and optical coherence tomography were tested as the two main diagnostic techniques. The theoretical framework of 'object itineraries' was employed to trace the conservation narratives of the paintings over time.

The findings contextualise and give a more objective perspective of the museum's past varnish practice. A complete varnish survey of the collection (1909–2019) was created, and three varnish time periods were identified as relevant historical markers. The diagnostic techniques helped to shed new light on Munch's painting technique and surface effects from his earlier period (1884–1900). Finally, the four interlinked papers contribute to a decision-making model with a flexible design framework that can be adapted to similar collections.

In sum, this thesis provides knowledge about non-original varnishes and the conservation history of this Munch collection. Moreover, it contributes to our knowledge of conservation methodology, long-term care, decision-making strategies and the base of Munch's artistic legacy.

Sammendrag

Maleriene til Edvard Munch (1863–1944) er godt representert over hele verden, men Nasjonalmuseet var den første offentlige institusjonen i Norge som samlet, støttet, utstilte og konserverte Munchs arbeider i hans levetid. De 57 Munchmaleriene som ble innkjøpt gjennom en periode på 79 år (1891–1970), er fremdeles ansett som museets mest ikoniske samling. Siden 1909 har disse arbeidene vært presentert som en én-kunstner-samling og utstilt i det kuraterte Munchrommet. I perioden 1909–1993 ble mange av de ufernisserte maleriene fernissert, noe som har vært kontroversielt.

Målet med avhandlingen var å oppnå ny kunnskap om de malte overflatene og ikke-originale fernissene i denne Munchs samlingen. Til dette formål ble en gruppe-kasus-studie valgt for å etablere den historiske konteksten og en ikke-invaderende metodologisk tilnærming til de tekniske undersøkelser. Konservatorens perspektiv var sentralt i valget av brukervennlige, kostnadseffektive og praktiske undersøkelsesmetoder. De to diagnostiske teknikkene som ble prøvd ut, var bærbar Fourier transform infrarød spektroskopi og optisk koherenstomografi. Som teoretisk rammeverk ble 'object itineraries' brukt for å etterspore konserveringshistorien til maleriene over tid.

Resultatene setter den tidligere fernisseringspraksisen ved museet i sammenheng og gir den en mer objektiv tolkning. En fullstendig oversikt over fernisseringen i samlingen (1909-2019), ble utviklet, og tre fernisseringsperioder er identifisert som relevante historiske markører. De diagnostiske teknikkene har bidratt til å kaste nytt lys over Munchs maleteknikk og overflateeffekter fra hans tidligere periode (1884–1900). Til sist bidrar de fire artiklene samlet til en beslutningsmodell med et fleksibelt rammeverk som også kan anvendes på lignende malerisamlinger.

Oppsummert bidrar denne avhandlingen med ny kunnskap om ikke-originale fernisser og konserveringshistorien til denne Munch-samlingen. Videre bidrar den til økt forståelse av museets konserveringsmetoder og beslutningsstrategier for langsiktig bevaring av Munchs malerier, og utvider vårt kunnskapsgrunnlag for Munchs kunstnerskap.

Abbreviations

ATR	attenuated total reflectance
c	circa
CB	Christen Brun (1828–1905)
CCD	Charged-coupled device detector
Ch(s)	chapter(s)
cm	centimetre
cm^{-1}	reciprocal wavelength unit
°C	degrees Celsius
D	donated painting
DRIFTS	Diffuse reflectance infrared Fourier transform spectroscopy
DR	Diffuse reflectance
ER	External reflectance
FIR	far-infrared (25–300 µm or 400–10 cm^{-1})
FT	Fourier transform
FTIR	Fourier transform infrared spectroscopy
GC-MS	Gas chromatography-mass spectrometry
HB	Harald Brun (1873–1927)
ICOM	International Council of Museums
ICOM-CC	International Council of Museums – Committee for Conservation
IR	Infrared
IRR	Infrared reflectography
IRUG	Infrared & Raman Users Group
JTM	Jan Thurmann-Moe (1927–2018)
KODE	Art Museums and Composer Homes, Bergen
kV	kilovolt
LEP	Leif Einar Plahter (1929–2016)
log	logarithm
LR	Ludvig Ravensberg (1871–1958)
min	minutes
MIR	mid-infrared (2.5–25 µm or 4000–400 cm^{-1})
mL	millilitre
mm	millimetre

MM	Munch Museum (Oslo)
mW	milliwatt
n	refractive index
NG	The National Gallery of Art, Norway (Nasjonalgalleriet)
NG.M.	The National Gallery of Art's inventory prefix code for paintings
NIR	near-infrared (0.7–2.5 µm or 14000–4000 cm^{-1})
nm	nanometre
NM	The National Museum of Art, Norway (Nasjonalmuseet)
no.	number
OCT	Optical coherence tomography
ODH	Ole Dørje Haug (1888–1952)
P	purchased painting
pFTIR	portable Fourier transform infrared spectroscopy
pXRF	portable X-ray fluorescence spectroscopy
®	registered trademark
sdOCT	Spectral domain optical coherence tomography
sect(s)	section(s)
THM	Thermally assisted hydrolysis and methylation-gas chromatography
™	Trademark
UV	Ultraviolet
UVA	long wave Ultraviolet radiation (320–400 nm)
VIS	Visible reflected (image)
W	watt
Woll M	Gerd Woll catalogue number
WWII	Second World War (1939–1945)
µA	microamp
µm	micrometre

Terminology

Conservation

The English umbrella term '*conservation*' is used throughout the text as a compromise and for readability (Muñoz Viñas 2020: xi). Its meaning follows ICOM-CC's (International Council of Museums – Committee for Conservation) 2008 resolution, which describes, '*all measures and actions aimed at safeguarding tangible cultural heritage while ensuring its accessibility to present and future generations*'.[1] The ICOM-CC term encompasses the following three categories: (1) '*Preventive conservation*': the indirect measures employed to minimise and reduce deterioration carried out within the context or surroundings of the painting(s); (2) '*Remedial conservation*': the direct actions applied to a painting to prevent or reduce further damage and loss; and (3) '*Restoration*': actions directly applied to a painting aimed at facilitating its aesthetic appreciation. Due to ambiguities and overlaps between these three categories (Muñoz Viñas 2005), the '*conservation*' umbrella term was chosen. In certain instances, the terminology from the three categories is used more specifically such as with the term, '*restoration varnishes*'.

Conservator

The word '*conservator*' is employed as a generic term throughout the thesis to describe persons in charge of the treatment of paintings at the museum since 1870. This is because internationally the same professional can either be called a '*conservator*' or '*restorer*'. The differences in terminology are dependent on the degree of training, the translation of the terms, and different national and institutional historical traditions (Muñoz Viñas 2020: xi; Pinto 2021). In the Norwegian language, only the word '*konservator*' exists. At the museum, past use of the term has incorporated three different prefixes, '*kunstkonservator*' (art conservator), '*tekniskkonservator*' (technical conservator) or '*malerikonservator*' (paintings conservator). All describe persons who had received conservation training and were specifically employed as '*konservators*' by the museum. Over the past 150 years, the basic '*conservator*' apprenticeship requirements at the museum have risen to the academic level of university training involving both theory and practice. Thus, in context of the National Museum, the term '*conservator*' is employed to encompass this broad spectrum of trained professionals.

[1] https://www.icom-cc.org/en/terminology-for-conservation.

Microinvasive

The term '*microinvasive*' refers to the physical microsampling of material extracted from a painting for analytical purposes. The physical integrity of the painting should be respected in so far as the number and size of the samples should be limited to very small amounts (Janssens and Grieken 2004).

Non-invasive

The term '*non-invasive*' denotes any analytical method, tool or technique that does not require the physical removal (sampling) of original material from a painting. In this thesis, all non-invasive techniques used rely on the interaction of electromagnetic radiation with materials.

Varnish

In the context of this thesis, the word '*varnish'* is used interchangeably to describe any transparent protective or decorative coating with a resinous (natural or synthetic) egg white and/or wax content. It can refer to either the final and unified transparent top layer applied to a paint surface, or to an intermediate layer which has been selectively employed by the artist or '*conservator'* to control paint saturation.

Artist's varnish

An '*artist's varnish*' refers to the artist's use of '*varnish*' as opposed to that applied by a '*conservator*'.

Restoration varnish

A '*restoration varnish*' refers to the '*varnish*' applied by a '*conservator*' which is either brushed or sprayed and typically covers the entire painted surface. However, it can also be applied locally.

1. Introduction

Norway's National Museum of Art (NM) houses one of the most important collections of paintings by the artist Edvard Munch (1863–1944). Historically, the first public Munch collection, it consists of a total of 57 paintings,[2] hereafter, referred to as the NM Munch collection. These artworks represent a broad, yet highly significant spectrum of Munch's artistic career (1881–1920) and can be described as the 'crown jewels' of the museum. This term is employed with reference to the paintings being at the core of the NM's collections both in terms of cultural identity and international *renommée*. The NM Munch collection represents a large corpus of paintings by a single artist with an important collective historical context in terms of acquisition and display.

Today's museums are required to balance five defining tasks outlined by the International Council of Museums (ICOM): '*acquisition, conservation, research, communication and exhibition of the tangible and non-tangible heritage of humanity and its environment*'.[3]

This thesis explores the aspects of conservation and research through a group case study of the entire NM Munch collection. The primary focus concerns previous criticisms of past non-original, restoration varnishes applied to a large number of the Munch paintings (Stein and Rød 2015). This called for the renewed interpretation of the varnishes through the revisiting of the paint surfaces.[4]

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[2] Between 1891 and 2021 the NM has built up a collection of Munch's art which consists of 57 paintings, 164 graphic works, 14 drawings, 4 original prints in books and 4 posters (Ustvedt and Yvenes 2022).

[3] According to ICOM Statutes (Vienna, 24 August 2007): 'A museum is a non-profit, permanent institution in the service of society and its development, open to the public, which **acquires, conserves, researches, communicates and exhibits** the tangible and intangible heritage of humanity and its environment for the purpose of education, study and enjoyment.' https://icom.museum/en/resources/standards-guidelines/museum-definition/.

[4] The title of the PhD thesis was inspired by a series of lectures entitled 'Revisiting the Surface' organized by the Munch, Modernism, and Modernity a Research Group in 2015. https://www.mynewsdesk.com/no/nasjonalmuseet/pressreleases/munch-konferansen-2015-revisiting-the-surface-1249296.

It was the author's custodian role as a paintings conservator, charged with the monumental task of how best to take care of the NM Munch collection, that inspired this research. The thesis is an article-based study consisting of four interlinked papers which are presented chronologically in a sequence intended to reflect the thought process from a museum conservator's perspective (chs. 3 and 6).

The following introductory section outlines the museum context of the NM Munch collection (sect. 1.1), the Munch Room and group display legacy (sect. 1.2), an introduction to varnish (sect. 1.3), 19th-century varnishing traditions in relation to Munch's paintings (sect. 1.4), and the past conservation of the paintings (sect. 1.5). This background research builds up to the thesis's overarching objective, primary and secondary aims, three research themes and hypothesis (sect. 1.6).

1.1 The Munch collection

Norway's first National Museum of Art was established in 1837 and its collections were opened to the public in 1842 (Solbakken and Kongssund 2020). The museum was subsequently renamed for a short period as the State Museum of Art (Statens kunstmuseum) and it took 40 years before the painting collections were finally accommodated in a permanent exhibition space.[5] This building, known as the former Norwegian National Gallery of Art (Nasjonalgalleriet, NG), housed the 57 Munch paintings until its closure in 2019. In 2003, the NG's collections became part of a new National Museum of Art (hereafter referred to as the Norwegian National Museum of Art, NM and Nasjonalmuseet in Norwegian). The creation of this new national art institution was the result of a political decision to fuse four existing museums into one state-of-the-art museum building which will open on 11 June 2022.[6]

Historically, there exist four main public collections of Munch paintings in Norway. The NG was the first Norwegian museum to acquire a painting by Munch with its purchase of his small

[5] The collection of paintings opened to the public on 7 February 1882 and were displayed on the second floor of the newly opened museum of sculpture (Solbakken and Kongssund 2020).

[6] The NM consists of the former art collections belonging to the NG (Nasjonalgalleriet), the Museum of Decorative Arts and Design (kunstindustrimuseet), the National Museum of Contemporary Art (museet for samtidskunst) and the Museum of architecture.

study in 1891 entitled *Night in Nice* (Woll M 224) (Thiis 1933a; Willoch 1937). Munch's 11 monumental decorations for the University of Oslo's assembly hall, known as the Aula, are the second public collection in terms of chronology. These were painted between 1909 and 1916 (Ydstie et al. 2011) and represent one of the most important examples of his site-specific art covering a surface area of 220 m² (Frøysaker 2007; Stoveland 2021). The third major collection of paintings is located on the west coast of Norway in the former Bergen Municipal Art Museum.[7] This group of 44 Munch paintings[8] is largely comprised from a donation of artworks which formerly belonged to the business owner and merchant Rasmus Meyer (1868–1916) (Ormhaug 2006). Finally, the fourth main collection initially consisted of the 1026 paintings originally recorded at Munch's Ekely studio which were bequeathed to the city of Oslo after the artist's death in 1944 (Langaard 1964). A third of the best-preserved paintings from this collection were first shown in a separate exhibition organised at the NG in July 1945 (Jacobsen 2019). This helped to pave the way for their permanent care and display with the establishment of the Munch Museum (MM) in 1963. The MM's collection now consists of 1158 paintings (Solheim 2019).

In terms of collection history, the NM's 57 Munch paintings were well documented following the appointment of the museum's first official director, Jens Thiis (1870–1942). There exist two main accounts that are contemporary with the sequence of Munch acquisitions, both of which were written by former directors. The first is composed as a biography of the artist (Thiis 1933a) and the second as a biography of the museum's first 100 years since the opening vernissage of 1842 (Willoch 1937). In addition to these sources, presentation of the Munch paintings can be traced through numerous exhibition catalogues, museum guides and publications spanning the period 1907–2019 (Statens Kunstmuseum 1907; Thiis 1933b; Onsager 1942; Willoch 1950; Nasjonalgalleriet 1955).[9]

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[7] Now part of Bergen Art Museums and Composer Homes (KODE).

[8] 32 Munch paintings were donated to the Bergen Municipal Art Museum by Meyer's family after his death in 1916 and these were first exhibited publicly as a collection in 1924 (Bergens Kommunale Kunstsamlinger 1978). The Bergen collection also includes 8 paintings from Rolf Stenersen and 4 paintings acquired by the Bergen Municipal Art Museum between 1923 and 1925 (Bergen Billedgalleri 1963).

[9] There are 7 editions of the Nasjonalgalleriet *Illustrated Guide* (1955, 1961, 1965, 1970, 1975, 1977, 1987).

The most up-to-date, comprehensive and critical overview of the NM Munch collection is provided by Messel's historical essay written for the museum's revised Munch catalogue (Messel 2022). The study employs a chronological approach, placing the Munch acquisitions in context with parallel research regarding the institution's history and the former NG building (Skedsmo and Waaler 1998; Solbakken and Kongssund 2020). Through the NM's prolific acquisition history, Messel has demonstrated a clear notion of contemporary recognition for Munch's art (Berman 1994; Guleng 2016). This is supported by the references from the various members of the museum's acquisition committees, who expressed an early interest in the artist's work as well as providing financial support in the form of scholarships.

Prior to Jens Thiis starting his directorship in 1908, the NM had already acquired eight major paintings by Munch alongside 70 works of art on paper. Despite the lack of funds and missed opportunities, this figure is significant when compared to many of Munch's contemporaries and older colleagues in terms of their total number of representative paintings in the collection (Skedsmo 1976; Messel 2022). The time frame 1909–1938 is particularly relevant due to an extra 35 Munch paintings having been acquired under director Thiis.[10] This large bulk of the collection was amassed through a combination of donations and purchases, some of which were sourced directly from Munch himself.

Jens Thiis's unequivocal promotion of both Munch and his art at the NM has resulted in an interesting legacy regarding the 57 paintings in terms of both content and display. Firstly, they represent a finely curated and 'hand-picked' ensemble of Munch's oeuvre largely acquired during the artist's lifetime (Willoch 1937; Skedsmo and Waaler 1998). Secondly, the quality of the paintings reflects a choice of central and iconic motifs, many of which are first versions[11] and subjects from Munch's *Frieze of Life.* The *Frieze of Life* refers to a sequence of motifs, originating from the 1880–90s which were intended as a collective display concept and visual representation of life (Mørstad 2004; Guleng et al. 2013). Thirdly, since 1909, there has been a group approach in terms of the painting's collective display tradition (Messel 2012; Lømo 2014; Messel 2022). These three factors have had an impact on how the paintings have been perceived in the NG building by directors, scholars and the public during the timeframe 1909–

[10] For the complete overview of the 57 Munch paintings and their acquisition dates see Appendix 7.1.

[11] First versions include: *The Sick Child* (Woll M 130), *Melancholy* (Woll M 284), *The Scream* (Woll M 333), *Madonna* (Woll M 366) and *The Dance of Life* (Woll M 464).

2019 (Ustvedt 2004; Guleng 2022). Their historical significance as a single-artist collection is also coupled with the rise of Munch's own status over time. This increased interest in Munch is reflected through the history of in-house solo exhibitions combined with a steady increase in public interest and international demand in terms of frequency in loans.

1.2 The Munch Room

Director Jens Thiis's first rehang of the NG's galleries in 1909 marks the beginning of a distinct display legacy for NM's Munch paintings in terms of their collective presentation. Since this date, they have been historically perceived and continue to be presented as a specific group (Borud 2015). Initially, the paintings were first hung together on one wall (Messel 2022). However, as the NM's collections grew, the collective group display became limited to a selection of the core and iconic motifs which were split between different walls and rooms (Berman 2013). By 1924, Jens Thiis had managed to clear one room dedicated to the artist's paintings due to the recent North wing building extension (Kongssund 2005) (Appendix 7.3, Figure 21).

The director's promotion of Munch's art at NM was coupled with the general surge of artistic nationalism after Norway achieved complete independence from Sweden in 1905 (Berman 2013). Contextually, Thiis's involvement as a member of the selection committee for the decoration of the university's Aula was also significant. The Oslo University Aula is located just across the road from the NG building and Munch's success in securing this commission further increased his national and international status (Berman 2013). This runs parallel with a general scramble for the acquisition of his best pieces by important private collectors from both abroad and at home (Flaatten 2019). Two of Munch's most important patrons and donors to Norwegian public institutions were Rasmus Meyer in Bergen and Olav Schou (1861–1925) for the NG in Oslo[12] (Skedsmo 1976). As argued by Berman, the growth of interest in Munch's paintings probably also helped to fuel Thiis's competitive incentive and enthusiastic acquisition policy for the NG, 'in which Munch's art symbolically culminated the story of artistic nation building' (Berman 2013: 167). However, it is the director's specific approach to a collective presentation of a single artist which is significant to the context of this study.

[12] The city of Oslo was named Christiania/Kristiania between 1624 and 1924.

Jens Thiis's 1909 group display strategy for the Munch paintings, being framed around the life and work of the painter, places the artist as context (Solhjell 2016). This approach most probably stems from 19th-century European exhibition traditions typical of many national museums (Carole 2012). However, at the NG, Munch was placed on a pedestal like no other Norwegian artist, and it has been argued that he has continued to reign over the rest of the collections since 1909 (Ustvedt 2004). As noted by Messel (2022), the director's active promotion of Munch at the NG is confirmed in his letter to the artist, in which he described plans for the rehanging of the painting galleries. Jens Thiis presented his intention for an 'elite room', essentially for Norwegian painters and in which, 'the best and finest wall', would be reserved exclusively for Munch's paintings.[13] Berman (2013) shows how Jens Thiis's critics were quick to have him publicly satirised for his explicit endorsement of Munch's art in Norway, both for artist's monumental paintings in the university's Aula and the Munch hanging at the NG. Thiis was caricaturised as a large sphinx, the emblem of the NG, breastfeeding the hungry infant figure of Munch (Berman 2013: 167) (Figure 02).

Munch's 1927 retrospective exhibition held in the NG (Thiis 1927), combined with a growth in the Munch collection to a total of 28 paintings, led to discussions for an improved and larger exhibition space for his art (Willoch 1937). Ten years later and in celebration of the NG's 100-year anniversary, the largest (162 m²) of the three newly built exhibition rooms was allocated solely for Munch's oeuvre (Messel 2012; Messel 2022). After years of persistent lobbying, Jens Thiis's dream for a permanent gallery dedicated to Munch was finally fully realised with the inauguration of the Munch Room in 1937 for the display of between 18 and 20 paintings (Willoch 1937) (Figure 01). Referred to in Norwegian as the *Munchsalen* or *Munchrommet,* this second-floor exhibition space has endured Jens Thiis's single-artist group display concept until the closure of the NG in 2019. In September 2021, the whole NM Munch collection was relocated to the new museum building on Oslo's quayside and the historical significance and display legacy of the original 1937 NG Munch Room was recreated. This new Munch Room is almost identical to the former one in terms of display format but has a slightly larger exhibition space (214 m²).

[13] Munch Museum: MM N 1182 (www.emunch.no).

Figure 02. 'The Sphinx of the National Gallery. Director Thiis breastfeeding Munch's art' (Korsaren, no.17, 24.04.1909, Nasjonalbiblioteket, Oslo., no-nb-sml_15841)

Despite the continuity in presentation of the NM Munch paintings, there exists surprisingly little research on the Munch Room as a concept and no overview of the shifts in the various display configurations.[14] Subtle changes in the choice of Munch paintings over time appear to have been influenced by later directors, curators, exhibitions, and loans. It is also worth noting, that both the old (NG) and new Munch rooms have had a limited space capacity in terms of a maximum of 18–20 paintings on display at any given time. This has resulted in a specific selection criterion and, according to Guleng (2013, 2022), the chosen core motifs essentially stem from Munch's *Frieze of Life* series which are meant to be viewed together. Munch's own comments regarding the importance of viewing his paintings as a group (Flaatten 2019)[15] may have also contributed to Jens Thiis's collective display approach. Lately, history, tradition and an engaged public opinion seem to have been the main factors which have shaped a post-Thiis Munch Room era (Haugstad 2005; Bjørkeng 2006; Malmanger 2006; Spigseth 2006; Grønvold

[14] Prior to this study, there has existed no systemised overview as to how many and which paintings were displayed in Jens Thiis's early Munch display configurations and in the Munch Room between 1909 and 2019.

[15] Munch Museum: MM N 46, 1930-34 (www.emunch.no).

2011; Borud 2015; Solhjell 2016; Skaug 2018)[16]. The current recreation of the new Munch Room in the new museum building could be perceived as essentially anachronistic in light of its approach to the exhibition of the paintings. However, the continuation of the Munch Room concept reflects its importance as an established part of Norwegian cultural heritage. Thus, this single-artist group display approach remains relevant to future conservation decision-making.

1.3 Varnishes: a brief overview

The etymology of the term 'varnish' for paintings can be traced back with certainty to the 12th-century French word '*vernis*' (Halleux 2007), derived from '*vernix'* (late medieval Latin) meaning fragrant resin.[17] Historically, varnishes have a dual purpose for easel paintings. They are utilised to unify and adjust the overall surface gloss through the saturation of the underlying paint (Rie 1987; Witte 1990; Berns and de la Rie 2003; Elias et al. 2006). In addition, the final transparent coating provides the paint surface with a physical protective layer from dirt and in some cases can serve as a form of filtration from the damaging effects of ultraviolet (UV) light (Theodorakopoulos and Zafiropulos 2009; Rie and McGlinchey 2014). For the artist, varnishing has been (Carlyle 2001: 239; Mayerne et al. 2001; Cennini and Broecke 2015) and still is, typically associated with the final and 'finishing phase' of an easel painting (Laurie 1988: 163; Mayer 1991: 209). Furthermore, it is also synonymous with the 'final phase' in conservation treatments (Goltz 2012; Massing 2012: 214). The optical properties of the varnish film(s) help create a uniform top layer which facilitates the control of the end visual effect (gloss and saturation) of a cleaned or restored painted surface (Phenix 1995) (Figure 03).

The history of various types of surface coatings (varnishes) used both by artists and conservators for paintings during the 19th century is a vast and complex topic (Carlyle 2001). For this study, a simplified and broad classification of the three main groups of natural picture varnishes (Phenix and Townsend 2012) is employed to describe the various types available during Munch's artistic period (1880–1944). The most common of them were the spirit varnishes, which consisted of a natural soft resin dissolved in a volatile solvent, either with an

[16] The references listed represent a selection of the main articles related to the Munch Room public debate between 2005 and 2018.

[17] https://www.etymonline.com/word/varnish.

alcohol or turpentine (Carlyle 2001: 73). The second category is comprised of the earlier oil-based resin varnishes. These were traditionally manufactured by colourmen as they involved the dangerous process of heating an often-harder natural resin before dissolving it in a drying oil (Gettens and Stout 1966: 73; Carlyle 2001: 57; Townsend 2010: 148). The third group encompasses the aqueous coatings such as egg white (glair), polysaccharide gums and animal glues (Carlyle 2001: 233; Massing 2012: 216). All three varnish types would have generally been known and accessible to artists such as Munch, both at home in Norway (Nicolaysen 1872: 33–37) and whilst painting abroad in France and Germany (Halleux 2007; Phenix and Townsend 2012).

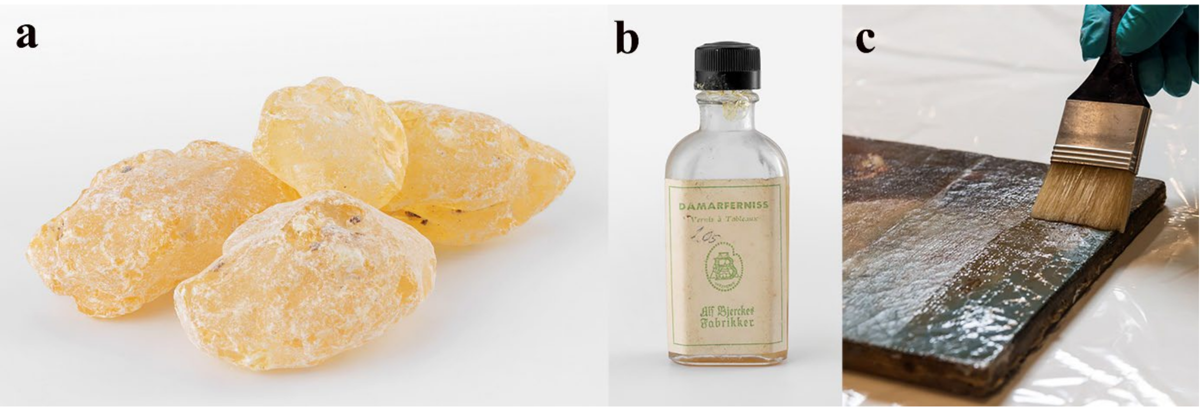

Figure 03. (a) Dammar resin, (b) Dammar picture varnish, Alf Bjercke, Oslo, (c) brush varnishing and saturation of paint layers (Nasjonalmuseet/Ford, 2022)

Given the vastness in the variations of recipes, mixtures, grades, additives and their range of use, the chemical classification of natural varnish resin types is best suited for their analysis (Mills and White 1994). The first chemical type consists of diterpenoid resins. These are exudates from a large variety of trees and plants, and include distillations from pine resins such as colophony, rosin and violin rosin, and balsams (Mills and White 1994). Some have been used more commonly as additives to varnish recipes such as Venice turpentine (from larch trees) and Strasbourg turpentine (*olio di Abezzo* from fir trees) (Mayer 1998: 22). Other relevant diterpenoid varnish resin mixtures include sandarac, copals and copaiba balsams, the latter having been used in early restoration treatments involving the removal or regeneration of old varnish layers (Berg 2003). The second chemical class of natural varnish types are the triterpenoid resins (Mills and White 1994). These are particularly relevant to this thesis as two of them, mastic, and dammar (Figure 03), were the most common of the late 19th and early 20th-century natural resins employed in picture varnish recipes by both artists and conservators

(Gettens and Stout 1966; Samet 1998). Dammar appears to have already been favoured as a picture varnish in Germany at the beginning of the 19th century and had gradually surpassed mastic by the middle of the 20th century (Mayer and Myers 2002; Phenix and Townsend 2012). Its increase in popularity and continued use by conservators, especially for darker paintings, is most probably due to its good optical and handling properties (Doelen 1999; Goltz 2012). Both mastic and dammar varnish recipes are documented as having been used by the NM's conservators during the first half of the 20th century (Rød 1993; Rød 1997).

The other miscellaneous natural resin groups and varnish additives related to the period of Munch's art and in context to this study, include fossil resins such as amber, insect resins such as shellac and the use of natural waxes (beeswax) (Mayer 1998).

At the beginning of the 20th century, some synthetic resins were initially developed as a more stable and refined alternative to the natural resins. However, synthetic resins used for picture varnishes and relevant to this study were not readily available to NM conservators until the middle of the 20th century (Feller et al. 1985; Epley 1998; Berg 2003). There exists a wealth of research devoted to the various types, use and suitability of synthetic picture varnish resins (Phenix 1995; Samet 1998) and the selection has been narrowed down in terms of relevance to this study. Those applicable to the NM's restoration varnishing period of Munch paintings (1871–1993) are essentially the low molecular weight polycyclohexanone ketone resins (Rie and Shedrinsky 1989; Cox 1998), commercially known as either, AW-2® (BASF), MS2® (Howards) and Laropal® K80 (Ketone N, BASF). During the 1960s, the availability of MS2A® and MS2B®, modified versions of the polycyclohexanone with a low residual ketone content, were developed and marketed specifically for works of art by Howards (Phenix 1995; Fisher 1998). Besides the ketone resins, the acrylic polymer Paraloid® B72 (ethyl methacrylate and methyl acrylate copolymer) (Buckley and Houp 1998) was also accessible to the NM's conservator-restorers by the late 1960s as an alternative synthetic varnish (Hanssen-Bauer 1990).

1.4 Munch and 19th-century varnish traditions

The background to the research concerns the NM's past application of non-original restoration varnishes to Munch's unvarnished painted surfaces (Stein and Rød 2015). As discussed in the previous section (sect. 1.3) the effect of a varnish coating to a paint surface essentially alters the optical properties by the saturation of the paint layers underneath. In addition, the ephemeral nature of varnish resins can create problems associated with their condition. This leads to questions concerning their removal and the effects of cleaning cycles (Feller et al. 1985; Rie 1988; Phenix and Townsend 2012). This is often due to the 'transitory' function (Feller et al. 1985: xv) of a picture varnish, resulting in loss of saturation and discoloration (yellowing) from the photo-oxidation of the resin polymer over time (Horie 2013: 41). Historically, the deep-rooted museum traditions of varnish removal (Weaver et al. 1950; Keck 1984), varnish regeneration methods (Duijn 2021b; Schmitt 2021) and the periodic revarnishing (Hellen 2014) of paintings have resulted in either controversy or critique. Consequently, the implications of varnishing paintings have been and still are widely debated. These include discussions regarding the practice of retaining the look of the historical 'patina' (Brandi 1996; Philippot 1996; Skaug 1996; Starn 2002) through to the condemnation of varnishing an unvarnished painted surface (Richardson 1983; Callen 1994).

In the case of the NM, Stein and Rød have documented two public episodes of criticisms concerning the controversial varnishing of Munch's paintings by conservators (Stein and Rød 2015). The first was in 1909 and promoted by the art critic Jappe Nilssen (1870–1931) in conjunction with the reopening of the National Gallery. Nilssen accused the NM of 'vandalism' with the varnishing of three new acquisitions, *Puberty* (Woll M 347), *The Day After* (Woll M 348) and *Ashes* (Woll M 378) (Nilssen 1909). The second accusation was made in 1980 by the head conservator of the Munch Museum (MM), Jan Thurmann-Moe (1927–2018), who condemned the NM for their overall 'mistreatment' of Munch's paintings through varnishing (Stein and Rød 2015: 258). Besides these moments of criticism, there remains an understudied 70-year gap of silence in which the practice of 'controversial varnishing' of the NM's Munch paintings essentially continued.

In general, the first coat of varnish is typically brushed over the entire painted surface once the paint film has dried thoroughly (Massing 2012: 214) (Figure 03c). However, during the 19th century, varnishing was not always undertaken by the artist given the often long drying period required for oil paint (Carlyle 2001: 239). Often, the process was carried out by the custodians of the painting, be it the owner, dealer or exhibiting institution (Swicklik 1993; Hellen 2014). It was also not uncommon for museum directors who were trained as painters to varnish and restore paintings in studios in the museum (Hendriks 2022). This openness for the division of labour might initially stem from the generic term, '*vernisseur*', which was employed in 18th-century French artist manuals to describe the professional practice of varnishers (Watin 1776).

Since the 1860s, the NM appears to have adopted a tradition of periodically varnishing its collection of paintings (Willoch 1937: 58). According to Rød, archival documentation describes plans for, and the implementation of, cleaning and revarnishing large sections of the NM's painting collections between 1864 and 1895 (Rød 1994). This approach resonates with the customary 'varnishing day' witnessed both in England and France, which often occurred before an exhibition opening (Hellen 2014; Étienne and Grevet 2017: 96). However, prior to the establishment of a formal conservator position at the NM, the recurrent practice of varnishing was initially entrusted to recognised painters on a freelance basis. In 1870, Christen Brun (1828–1905) became the first salaried NM museum conservator and received paid leave to undertake a nine-month apprenticeship abroad in Germany between 1875 and 1876 (Willoch 1937: 65; Rød 1994).

According to Stein and Rød (2015), surviving correspondence from Munch and the public perception, suggest a consensus that the artist did not favour the traditional application of a resin-based finishing coating applied to the entire painted surface. This fact is also supported by the numerous amounts of unvarnished Munch paintings in collections worldwide (Topalova-Casadiego 2008). From an early stage, Munch would have been subjected to the late 19th-century artists' political aversions to the academic traditions of varnishing through his travels to France between 1885 and 1892 (Langaard 1960; Biørnstad et al. 1991; Mørstad 2016). During this period, there was a search for new trends in the surface effects with unvarnished paintings (Swicklik 1993; Callen 1994; Mayer and Myers 2010). This was probably also influenced by a general awareness of the ephemerality of varnish coatings in terms of their degradation and discoloration over time. However, in the context of Munch's artistic career, his constant experimentation with different mediums, effects and types of supports makes it difficult to establish a 'fixed set of rules' regarding his painting technique (Plahter and Plahter 2015: 19). For example, there is some evidence to suggest from four paintings investigated (*The Sick Child*, Woll M 130; *Puberty*, Woll M 346 MM's version; *The Scream*, Woll M 333; *Evening on Karl Johan*, Woll M 290) that Munch experimented with locally applied varnishes, either mixed in with the paint or as a finishing effect (Aslaksby 2009; Topalova-Casadiego 2012;

Aslaksby 2015; Wardius 2015). The local use of partial varnishing or 'oiling out' (resaturation) of darker passages of paint was not uncommon practice (Phenix 1995) and was employed by some of his Norwegian contemporaries such as Harriet Backer (1845–1932) and Harald Sohlberg (1869–1935) (Lange 2003: 116; Ford 2018). Different regions in a painting could become matt and dull after drying and thus required more medium to achieve the desired final gloss effect. This phenomenon was often corrected using an interim, temporary varnish such as egg white (glair) or with a commercially available resin-based retouching varnish (Carlyle 2001). Van Gogh was an artist much admired by Munch and recent investigations into his studio practice have also revealed the artist's likely experimental use of partial and localised varnishes (Jooren 2013).

Hence, it is not without significance that six small varnish bottles, two of which are Vibert retouching varnishes, were discovered at Munch's Åsgårdstrand summer studio after his death (Gansum and Knudsen 2013).[18] Likewise, the diary entry from Munch's close relative and artist Ludvig O. Ravensberg (1871–1958) refers to a conversation in which Munch recommended the use of egg white as a preferable varnish 'sheen'.[19] This comment was made in reaction to the discoloured and altered surface effect created by the recent 'hard mastic' restoration varnish applied to his 1904 full-length portrait of *The Frenchman, Marcel Archinard* (Woll M 578) hanging in the NG.[20] However, as noted by Stein and Rød (2015), Munch's own attitude towards varnishes in terms of surface effects remains unclear. This is partly due to the ambiguity present in his surviving correspondence and texts in which there is also some evidence of his early purchases of varnish.[21]

Thus, the uncertainty surrounding Munch's use of varnish and early surface finishes deserves further investigation. This is especially relevant for the core of Munch paintings that belong to the NM, many of which are from an earlier period (1880–1900) in which the experimental use of varnish has already been identified and confirmed by analysis (Aslaksby 2009). In terms of future decision-making concerning the removal of non-original restoration varnishes, a more

[18] See also https://vestfoldmuseene.no/munchs-hus/ and Appendix 7.6.1.

[19] Munch Museum, LR 536, 27.12.1919.

[20] Munch Museum, LR 541, 02.09.1910.

[21] Letter to his aunt Karen Bjølstad dated, 1884. Munch Museum: MM N 732 (www.emunch.no).

in-depth analysis of each painting's entire paint surface is required to determine if original varnishes may be present. This process of investigation requires knowledge of both the NM Munch collection's restoration varnish history and Munch's experimental painting techniques.

1.5 Munch conservation past and present

The 2008 Munch catalogue raisonné of paintings (Woll 2008) and the 2013 conference proceedings organised by the university of Oslo, *Public Paintings by Edvard Munch and his Contemporaries: Change and Conservation Challenges* (Frøysaker et al. 2015), provide a comprehensive introduction and overview of Munch's paintings, painting technique and conservation-related issues. In addition, there exists a body of recent scientific and conservation-related research concerning specific issues and paintings.[22] Prior to the university's Munch Aula (MAP)[23] conservation project that started in 2005, Munch scholarly research (especially that undertaken in the past) has tended to employ a 'case study' approach rather than encompassing large groups and specific collections. The NM's 'soloist' conservation approach was confirmed by Leif Plahter's (head of conservation 1957–1999) reaction towards the varnish criticisms of 1980: 'Munch's paintings in the National Gallery are treated as all other paintings – that means individually' (Grøndahl 1980; Stein and Rød 2015).

The NM's earlier attitudes towards Munch restoration can be inferred through the biographical surveys of the first official conservators (Willoch 1937; Rød 1993; Rød 1997). Thereafter, Munch research history at the NM for the period 1970 to 2015 is neatly summarised by the joint essay written by the paintings conservator Leif Plahter and the conservation scientist Unn Plahter (Plahter and Plahter 2015). This overview confirms that only a handful of Munch paintings from the collection have been investigated, with in-depth scientific research carried out on only two of them: *The Sick Child* (Woll M 130, 1885–86) and *The Scream* (Woll M 333, 1893) (Aslaksby 2009; Plahter and Topalova-Casadiego 2011; Aslaksby 2015). Other past research on the NM Munch paintings has essentially concentrated on Munch's materials, techniques and compositional process rather than on conservation-related issues.

[22] Given the numerous studies on Munch, the publications relevant to this research are cited throughout the thesis rather than presented as a separate list.

[23] https://www.hf.uio.no/iakh/english/research/projects/aula-project/index.html.

The impact of past restorations, such as the application of non-original varnish layers, has not been prioritised by the museum. This topic was first addressed through the varnish surveys of both the NM and MM painting collections by Stein and Rød (2015). Their survey is based on 52 conservation reports which concluded that 37 of the NM Munch paintings had been registered as varnished by the museum. In addition, they documented the practice of varnishing Munch paintings as having spanned almost a century (1909–1993). This study represents the first group approach to studying the NM's 57 Munch paintings as a collection. While the research is based solely on documentary evidence, Stein and Rød's 2015 varnish survey marks a turning point in Munch research. It addresses the varnish practices of both the artist and the conservators across two similar public collections. Moreover, the overall findings recommend the necessity for further physical investigations, 'the best source for investigating Munch's varnishing practice is the paintings themselves' (Stein and Rød 2015: 267). Their proposal connects the conservation challenges of varnish degradation and removal with Munch's fragile and often problematic paint surfaces (Ormsby et al. 2015).

The historical controversy over Munch's intended surface effects and finishes, known as the 'kill or cure' method (*hestekuren*), has been recently re-evaluated and given a more nuanced interpretation (Liu et al. 2016; Stein 2017).[24] Likewise, ongoing research concerning the complexity of the unvarnished Aula paintings underlines the importance of understanding Munch's attitude to surface finishes in terms of future cleaning strategies (Stoveland et al. 2021). This recent research further emphasises the importance of assessing the historic and contemporary perception to Munch's paint surfaces collectively. Currently, there exists only one analytical study on the use of restoration varnishes on a group of Munch paintings (Storevik-Tveit et al. 2020). This research is based on microsamples of varnishes that were applied posthumously (1957–1980) to paintings in the MM collection. It provides an institutional overview of the ketone resins used and gives a good indication of the MM's varnishing practices. However, the comparatively different historical and display contexts between both museums present a more complex scenario for the NM's paintings. At the NM, several different types of varnishes appear to have been used in combination with multiple

[24] The term was initially coined by the Norwegian art collector – and Munch's patron, friend, and biographer – Rolf Stenersen (Stenersen 1945), who suggested that Munch deliberately exposed his paintings to the elements as part of his technique. It was further promoted by the chief conservator at the MM, Jan Thurmann-Moe (Thurmann-Moe et al. 1995).

revarnishings over a longer timeframe (1891–1993). Hence, there remains a need for the systemised documentation and research of the NM Munch collection; both in context to the challenges generated by past, present and future interpretations of Munch's surface finishes (Strand Ferrer et al. 2019), and as a group investigation related to the Munch Room display concept.

1.6 Research objectives

1.6.1 Unanswered questions

This research stems from the current lack of knowledge and overview of the NM Munch collection's varnish history, which can be summarised by the following unanswered questions.

Firstly, the issue of the non-original restoration varnishes and their past 'controversial' application to a large proportion of the paintings remains unclear. In addition, Munch's own use of varnish in terms of surface finishes is an aspect of his studio practice that is understudied and remains ambiguous. Despite the numerous documented problems associated with Munch's paint techniques, there exists comparatively limited scientific evidence of his use or the effect of varnish coatings to his paint surfaces (Topalova-Casadiego 2008; Ormsby et al. 2015; Storevik-Tveit et al. 2020).

Secondly, the entire NM Munch collection has never been assessed collectively in terms of its conservation historical context and has a largely unwritten conservation history. Moreover, past theories about the NM restoration varnishes (Stein and Rød 2015) are based solely on archival sources, without confirmation from physical surface examinations or scientific analysis. Furthermore, only a handful of the paintings have been technically investigated using microinvasive techniques. The 57 Munch paintings present a large and difficult collection to access due to sections of it being on permanent display and the high frequency of loans.

Consequently, there is a need for a revised understanding and survey of the varnished surfaces. The choice of practical methods used should facilitate the effective screening of varnishes over a large group of paintings. Moreover, the investigations should consider non-invasive alternatives to the NM's past micro-invasive research traditions.

1.6.2 Main research aims and hypothesis

The overarching objective of this thesis is how to best conserve the NM Munch collection. More specifically, the primary aim is to gain knowledge about the varnishes present in the NM Munch collection for future conservation decision-making. Common practice in conservation research recommends the use of an interdisciplinary perspective, which encompasses historical research combined with visual examinations, and technical and scientific analysis (Villers 2004; Scott 2008; Groen and Duijn 2014; Streeton 2017). Consequently, using such an interdisciplinary approach, the secondary aim of this thesis is to determine how the chosen methods employed to investigate the varnishes are feasible and useful.

The methodological approach chosen for the investigation consists of four steps: (1) a group case study and contextual overview of the conservation history, combined with (2) a non-invasive focus regarding the choice of technical surface investigations. The final stage of the research includes the creation (3) of a revised varnish survey and (4) the design for a decision-making model for the entire NM Munch collection. The theory of 'object itineraries'[25] (Joyce and Gillespie 2015) is employed throughout as a theoretical framework to trace and visually map the various trajectories and conservation narratives of the paintings over time.

To answer both the primary and secondary aims, a set of three research themes and a hypothesis was established and these correlate with the thesis's four interlinked studies presented in papers I–IV (sects. 3 and 6) (Figure 04).

1. Historical: To create a collective overview of the conservation history of the entire NM Munch collection between 1909 and 2019 as a group case study, providing the historical context for the restoration varnishes using object itineraries as a theoretical framework (Paper I).

[25] The theoretical concept of object itineraries is presented and discussed in the Methodology section 2.1.

2. Technical and scientific examinations: To physically identify the restoration varnishes in a subgroup of the NM Munch collection employing a non-invasive approach (Papers II and III).

3. Decision-making: To create a revised varnish survey and develop a suitable conservation decision-making model for the entire NM Munch collection using the theory of object itineraries to visually map shifts in the Munch Room display (Paper IV).

Hypothesis: Using the theory of object itineraries (mapping a painting's conservation history/narrative over time) a group case study approach and contextual conservation historical overview of the 57 paintings will together equip the conservator with a more realistic perception of the restoration varnish(es) present in each painting. It will also facilitate the decision-making process in relation to the historical Munch Room display legacy. New and portable non-invasive diagnostic techniques can be used as viable screening methods for the creation of a revised varnish survey in painting collections.

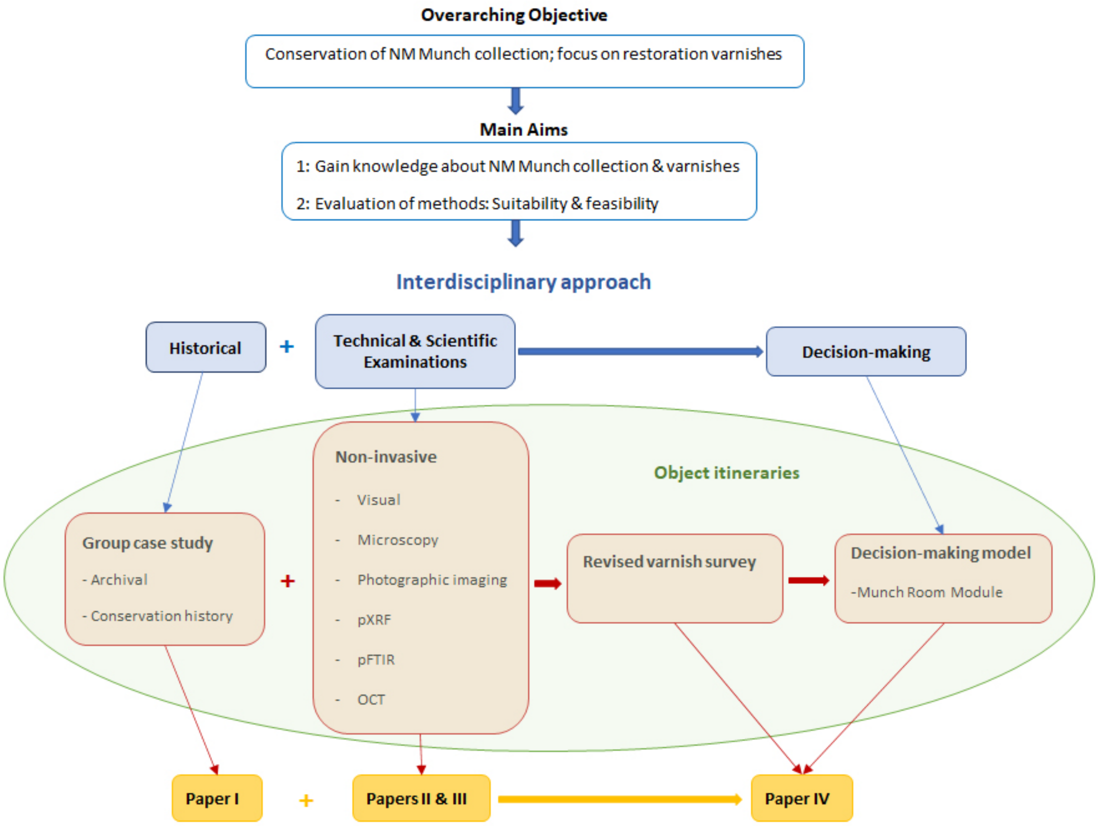

Figure 04. Schematic diagram of the thesis structure. Interdisciplinary approach (blue), research themes and methods (red), theoretical framework (green), and 4 interlinked papers (yellow) (Ford)

2. Methodology

Design

In the following sections, the broad interdisciplinary perspective and four-step methodological approach of the thesis are presented according to the workflow sequence of the research themes (sect. 1.6.2) and subsequent papers (sects. 3 and 6). In terms of research procedure, the author's own perspective as the museum conservator responsible for the NM Munch collection played a crucial part in the overall design. The design also follows the recommended sequential approach to conservation studies supported by a contemporary set of ethical standards (Sease 1998; Muñoz Viñas 2005; Appelbaum 2013; Muñoz Viñas 2020).[26] This starts with the study of historical documentation and visual observation of the paintings, followed by technical examinations and scientific analysis (proceeding from non-invasive to targeted microinvasive investigations). Lastly, the chosen methodology incorporates an overarching theoretical framework based on object itineraries (sect. 2.1) used to simultaneously map the conservation narratives of paintings and the collection, both over time and in relation to the Munch Room display.

Firstly, a group case study approach was implemented for the interpretation of the historical and archival documentation (sect. 2.2). The focus is on the collection's conservation history rather than individual case studies for each painting. The existing historical documentation represents a wide and complex repertoire of both written and photographic sources which had not yet been sorted into a coherent and systemised chronological history. However, a parallel art historical research of the entire NM Munch collection was also undertaken by the museum curators which gave collaborative support to the research. This has resulted in the revised

[26] The sequence of investigations and ethical approach was also guided by standards and principles outlined by a combination of professional bodies, namely the American Institute of Conservation (AIC) Code of Ethics (1994); https://www.culturalheritage.org/about-conservation/code-of-ethics; European Confederation of Conservator-Restorers' Organisations (ECCO) Professional Guidelines (II) Code of Ethics (2003), Microsoft Word - ECCO professional guidelines II.doc (ecco-eu.org).

edition of the NM's Munch catalogue with an additional summary of the collection's conservation history written by the author (Ford 2022).

Secondly, a predominantly non-invasive stance was favoured over microinvasive and sample-based methods for the technical and scientific analytical techniques (sect. 2.3). This approach was carefully orchestrated within a public museum context in terms of cost-related and ethical considerations for the varnish screening of a high-profile collection of paintings. The choice of investigative tools was also influenced by practical matters in terms of the collection's size, accessibility and feasibility within the runtime of the research project (2018–2021). Emphasis was placed on the advancement of viable, object-based conservation methods for conducting experiments with reproducible, reusable and easily interpretable data. These factors resulted in the testing of two non-invasive diagnostic techniques on smaller but representative subgroups of paintings. Portable Fourier transform infrared spectroscopy (pFTIR) (sect. 2.3.4) and optical coherence tomography (OCT) (sect. 2.3.5) were chosen as the preferred main techniques to detect and identify the restoration varnishes present. In all the investigative experiments, care was taken to ensure that the quality of measurements were made in a certified methodological manner involving standards and reference materials.

The findings from the interdisciplinary approach were then used to create a revised varnish survey (1909–2019) for the NM Munch collection, which feeds into the design of the fourth methodological step, the decision-making model (sect. 2.4).

2.1 Object itineraries

The theoretical framework is presented first given its overarching function in the methodological approach (Figure 04).

The object biographical framework has been successfully employed as a theoretical concept for conservation studies (Joy 2009; Appelbaum 2010; Vall et al. 2011; Ebert 2019; Pye 2019; Quabeck 2021). This theory initially stems from social anthropological and archaeological disciplines, and reflects an ontological shift towards tracing the life history of objects using biography as a metaphor (Appadurai 1986; Kopytoff 1986; Joyce and Gillespie 2015). In a museum context, the biographical concept could be applied to outline the historical timeline of a Munch painting regarding its date of production, early exhibition history, museum acquisition and current display. Furthermore, in an art historical context, a painting's path to an increased iconic status can also be represented, such as with *The Scream* (Woll M 333) and *Madonna* (Woll M 366). However, in terms of past conservation, the biography should also include the 'material aspects' of the artefact in flux (Pye 2019: 79). As argued by Pye (2019: 80), the 'physical life of artefacts' ('physical' referring to conservation history in terms of material changes) are often neglected or undercommunicated by museums, resulting in a purely cultural biographical representation of an artefact. Therefore, the engagement with the material biography (physical life) of a Munch painting is necessary if the historical context of the restoration varnish layers is to be understood. Painted surfaces are prone to physical and optical change over time whether through the effect of restoration treatments (such as the application of non-original varnishes) or the inherent degradation processes of the various original materials over time (Rie 1987; Rie 1988; Berns and de la Rie 2003; Elias et al. 2006; Delaney et al. 2008). Thus, the ongoing changes in the materiality of an artwork evokes a notion of flux and a painting's physical status remains neither fixed nor static when it enters a museum collection (Eggert 2019). Moreover, Eggert's concept of the 'ongoing life of a work', places the conservator at the centre of decision-making and the management of change, which can be likened to that of an editor (Eggert 2019: 75).

In addition to understanding the material biography of the Munch paintings, a theoretical framework was required to address their physical movements and interactions within and outside the institution. This was especially relevant to understand past transitory display stages and collective configurations of the Munch Room (sect. 1.2).

The object biography framework has been re-evaluated by Joyce and Gillespie (2015) to accommodate the 'mobility of things' using an 'object-itinerary' approach. *Things in Motion* explores the meanings behind an artefact's multiple interactions over time, mapped by the various routes or journeys described as 'itineraries' (Joyce and Gillespie 2015). The advantage of this theoretical concept is that it helps to build on the object's metaphorical biographical linear sequence, which according to Joyce (2015) has been restrictive insofar as assuming a singular path represented through an object's birth, life and death. Instead, the emphasis should be placed on the specificity of material mobility (Hahn and Weiss 2013) within a wider spatial and social arena (Joyce and Gillespie 2015). In the context of the Munch paintings, the object-itinerary framework allows for the meshwork of the various display trajectories, conservation interventions (varnishing) and art historical meanings to be simultaneously mapped. For example, a painting's set of individual institutional journeys and interactions, in terms of loans, exhibitions, display and iconic status, can be more readily traced and interpreted in a broader conservation-related historical context. Moreover, the 'collective aspect' of itineraries (Joyce and Gillespie 2015: 29) also facilitates the mapping of groups. This is particularly relevant for the NM Munch collection and proved useful in the design of the decision-making model (Paper IV). It helped to provide the structure for the visual mapping of paintings, in and out of the Munch Room over time.

By tracing the complex movement of the Munch paintings and their interactions over time, the comparative assessment between them creates multiple layers of meaning. These meanings required a framework for interpretation. Both the concepts of 'biography' and 'itinerary' imply the idea of an account and series of accounts, narratives (Joyce and Gillespie 2015). However, the 'object itinerary' provided the best connective foundation for the study of the NM Munch collection. It was therefore chosen as the overarching theoretical framework to bind together the various narratives for the interpretation of the group's conservation history.

2.2 A group case study approach

2.2.1 Archival sources

The archival material used in the research was acquired from primary and secondary sources. These were selected according to their relevance to the NM, the Munch paintings and the varnish history. The scope of the archival data ranges from surviving published and unpublished documents, photographic images, through to historic varnish samples. As is often the case with institutional archival material, it tends to be housed in separate locations (Blewett 2006; Wielocha 2021) and the aim was to integrate all the relevant sources into a more systemised and collective study. In addition, many of the sources, such as the historic photographs and varnish samples, were neither registered nor catalogued. The disparity and gaps within the different types of source material available influenced the concept of an integrated approach explored in the historical essay (Paper I).

The NG's documentation archive provided a variety of primary sources and ledgers related to the acquisition of the Munch paintings. In addition, the archive holds director Jens Thiis's correspondence, the NG's building history and documents concerning the WWII evacuations.[27] This information was also supplemented by the extensive newspaper clippings archive,[28] which includes relevant press references to individual paintings, exhibitions and the Munch collection in general. In terms of the NM's conservation history, there exists a separate, small archive with selective documentation compiled by the former NG paintings conservator, Johannes Rød.[29] This information is related to the general activities of the two pre-WWII conservators, Harald Brun (employed 1905–1921) and Ole Dørje Haug (employed 1921–1952) (Rød 1993; Rød 1997).

In addition to written sources, the NM houses a collection of historic printed photographs. These represent the earliest photographic references of the NM's Munch paintings and include important in-situ documentation of some of the historic Munch display configurations in the NG building. The archival material also consists of a set of undated glass dry plate positive lantern slides (82 × 82 mm), taken of individual Munch paintings within and outside the NM's collection. These are essentially reproductions of printed versions made from the original negatives and were most probably acquired by Jens Thiis for both documentary and educational purposes.[30] Many of the lantern slides stem from originals taken by Munch's main photographer Olav Væring (1837–1906). His studio was based in Kristiania (Oslo) and was taken over in 1906 by his nephew, Ragnvald (1884–1960), who continued to document Munch's art until his death (Jacobsen 2008: 205). The Væring archive holds approximately 2000 negatives of which several are glass plates.[31] However, the bulk of these original images remain undated resulting in a lack of systemised cataloguing. Despite this, both the digitalised original negatives and lantern slides provided some relevant historic rather than restoration information. Some of the

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[27] NM Archives: NMFK/NG-1000/D/Da/L0023 (1942), NMFK/NG-1000/D/Da/L0024 (1943-44), NMFK/NG-1000/D/Da/L0026 (1945-46), and NMFK/NG-0004 (1934-43).

[28] https://www.nasjonalmuseet.no/besok/bibliotek/dokumentasjonsarkivet/klipparkivet/.

[29] NM Archives: NMFK/NG-0007/E/L0002.

[30] The lantern slides are undated and were produced by the following photographers, Max Marschalk, Berlin (1863–1940), Ragnvald Væring, Kristiania/Oslo (1884-1960), Severin Worm-Petersen, Kristiania/Oslo (1857–1933) and publisher, Dr. Franz Stoedtner, Berlin (1870–1946).

[31] https://ovaering.no/.

photographs can be contextually dated according to a painting's earlier frame and their reproduction in an exhibition catalogue (Jacobsen 2008). The black and white scanned negatives and monochrome lantern slides were primarily useful in establishing visual historic timelines of the various paintings and groups of paintings regarding the Munch Room (Paper IV and Appendix 7.3). However, their function as evidence of individual past restorations is either impossible, especially regarding surface coatings, or limited in terms of other treatments.[32] Therefore a cautionary approach should be adopted for the use and interpretation of these digitalised images, especially when the date and/or condition of the scanned original negative is unknown.

Munch's own collection of writings and notes were also consulted in relation to correspondence concerning the paintings in the NG, the director Jens Thiis and references to varnish.[33] These were complemented by information obtained from the unpublished diaries of Munch's close relative and painter, Ludvig O. Ravensberg (1871–1958). Ravensberg does not appear to have had much contact with Munch before 1904–5.[34] However, between 1909 and 1910 and after Munch's return from his seven-month convalescence in Dr. Daniel Jacobsen's clinic, Ravensberg became closely involved with Munch and acted as his assistant with the sale of paintings (Flaatten 2019).[35] Both these written sources are available digitally and selected cited references relevant to the thesis are included in the thesis text.

2.2.2 Historic varnish samples and studio recipe books

The primary written sources associated with the restoration varnish types used at the NG consist of two studio recipe notebooks. The first belongs to the conservator, Harald Brun and essentially dates from his apprenticeships in Copenhagen and Berlin between 1906 and 1907 (Rød 1993).[36] The notebook includes several recipes for mastic-based picture varnishes (Appendix 7.5, Figure

[32] Stein has used and relied on Væring's photographs to document condition changes in some of the NG's Munch paintings. See unpublished report; Stein, Mille., 2020., Nasjonalgalleriet, Oslo. Registrering av 52 Munchmalerier med hensyn på opprinnelig tilstand.

[33] The collection of Munch's correspondence and texts are published on the digital archive www.emunch.no.

[34] Information supplied by the MM's research librarian, Lasse Jacobsen.

[35] The Ravensberg's diaries were examined for the years 1906–1938 (LR 157–LR 570). These are housed in the MM's library and transcribed by the librarian, Inger Engan.

[36] NM Archives: NMFK/NG-0007/E/L0002.

34). The second studio notebook dates from post-WWII and contains a compilation of handwritten and transcribed varnish recipes and notes from the paintings conservators, Ole Dørje Haug, Bjørn Kaland (1923–2013)[37] and Leif Plahter (employed 1956–1999). Both studio notebooks provided valuable information concerning the NG's historic use of restoration varnish resin types and mixtures (Appendix 7.5, Figure 35).

In addition to the written recipes, a collection of mainly historic dry varnish resin samples held in the former NG conservation studio was also incorporated into the study. This assortment consists essentially of the later synthetic resins (Paper II). Nevertheless, it was possible to correlate historic recipe notes with the existing dry resin and liquid mixtures for analytical purposes. The NG's restoration varnishes provided a useful basis for the creation of standards used in the diagnostic testing methods explored in Papers II and III.

Three historic varnish types belonging to Munch's summer house in Åsgårdstrand were also analysed. These comprised microsamples taken from late 19th and early 20th-century commercial varnish bottles (Appendix 7.6.1).[38]

2.2.3 Conservation dossiers

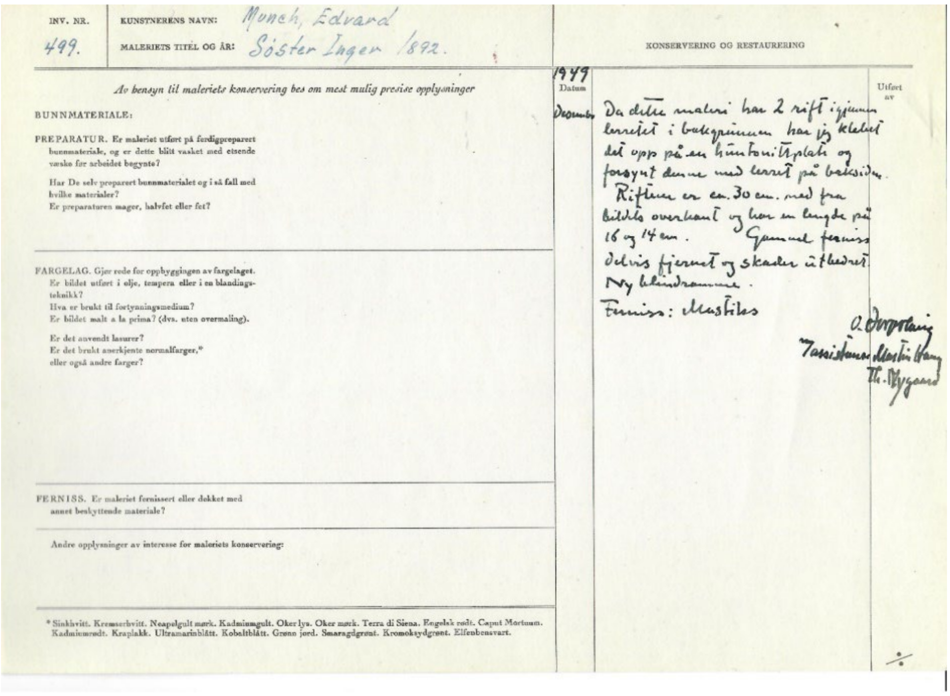
Written records and reports used for the conservation documentation of paintings at the NM, appear to have only become part of an established work practice, post-WWII. The earliest record for a Munch painting is dated 1949 (*Inger in Black & Violet*, Woll M 294; Figure 05) and there is evidence to suggest that some of the paintings' conservation dossiers are incomplete with early records missing. This lack of a standard condition report during the first half of the 20th century is not uncommon for most western museum institutions (Blewett 2012). The NM's early records tend to passively describe the restoration treatment undertaken rather than describing the pretreatment condition of the painting, let alone the considerations behind the chosen treatment. These are sometimes annotated by black and white photographs and a basic

[37] Between 1947 and 1951, Bjørn Kaland undertook some of his conservation training at the NG under Ole Dørje Haug although the length of time spent there and specific dates are unknown. In 1951 he established a private conservation studio in Bergen working with the Rasmus Meyer collection, and a year later was allocated supervision of his first conservator student, Leif Plahter (Skaug 1999).

[38] Samples were taken in October 2018 with the kind permission of Solfrid Sakkariassen, Vestfold Museums IKS (www.munchhus.no).

description of conservation materials, such as the name of the varnish resin used. Over time, the progression of the NM's conservation dossiers reflects a gradual shift in focus towards the current documentation of a painting's condition (as a condition report), often in connection to an exhibition or loan. From the 1990s, the reports were filed electronically in a makeshift paintings conservation database separate from the NG's two earlier collection databases.[39] In February 2019, the NM introduced the first collective and web-based collection management system with an integrated conservation module.[40]

Despite the variations, subjectivity and inconsistencies noted in the NM's conservation records and reports, much of the information sourced provided the basis for establishing the first overview of the entire NM Munch collection in relation to varnish and varnishing (Appendix 7.1). The collation and presentation of information together with the visual examination of 56 paintings, represents one of the major time factors of the research.



INV. NR. 499.

KUNSTNERENS NAVN: Munch, Edvard

MALERIETS TITEL OG ÅR: Söster Inger 1892.

Av hensyn til maleriets konservering bes om mest mulig presise opplysninger

BUNNMATERIALE:

PREPARATUR. Er maleriet utført på ferdigpreparert bunnmateriale, og er dette blitt vasket med etsende væske før arbeidet begynte?

Har De selv preparert bunnmaterialet og i så fall med hvilke materialer?
Er preparaturen mager, halvfet eller fet?

FARGELAG. Gjør rede for oppbyggingen av fargelaget.
Er bildet utført i olje, tempera eller i en blandingsteknikk?
Hva er brukt til fortynningsmedium?
Er bildet malt a la prima? (dvs. uten overmaling).

Er det anvendt lasurer?
Er det brukt anerkjente normalfarger,*
eller også andre farger?

FERNISS. Er maleriet fernissert eller dekket med annet beskyttende materiale?

Andre opplysninger av interesse for maleriets konservering:

* Sinkhvitt. Kremserhvitt. Neapelgult mørk. Kadmiumgult. Oker lys. Oker mørk. Terra di Siena. Engelsk rødt. Caput Mortuum. Kadmiumrødt. Kraplakk. Ultramarinblått. Kobaltblått. Grønn jord. Smaragdgrønt. Kromoksydgrønt. Elfenbensvart.

KONSERVERING OG RESTAURERING

Datum		Utført av
1949 Desember	Da dette maleri har 2 rift igjennom lerretet i bakgrunnen har jeg klebet det opp på en kuntonittplate og forsynt denne med lerret på baksiden. Riftene er ca. 30 cm. ned fra bildets overkant og har en lengde på 16 og 14 cm. Gammel ferniss delvis fjernet og skader utbedret. Ny blindramme. Ferniss: Mastiks	[illegible]

Figure 05. Example of NM treatment report, NG.M.00499,
Inger in Black & Violet, December 1949.

[39] The NG's first two collection management databases were Imago (mid-1990s–2008) and Primus, KulturIT, Norway (2008–2019). The separate paintings conservation database included the options for basic condition (loan) and treatment reports with annotated digital photographs.

[40] MuseumPlus Zetcom Ag, Bern, Switzerland: https://www.zetcom.com/en/museumplus-en/.

2.2.4 Conservation history: building a collective narrative

A key aspect of this research was to trace and understand the conservation history of the NM Munch paintings as a collection. Although each painting possesses a unique narrative in terms of past conservation treatments, the focus is on the collective narrative of the NM's conservation history. The aim was to gain an overview and broad understanding of the historical context behind the 'controversial' varnish practice at the NM.

Over the last few decades there has been revived interest in tracing and recounting institutions' conservation histories (Blewett 2006; Blewett 2016; Aronson et al. 2017; Streeton 2017; Duijn and Noble 2021; Pinto 2021; Sperber and Burnstock 2021). Some of these have also focused on the historical emergence, establishment and development of conservation as a discipline and professional sector within the various institutions (Burnstock 2017). Concurrently, certain studies have outlined the historical progression in terms of the changes in conservation approach and treatments over time for a specific artist or collection (Solheim 2019; Duijn 2021a; Hendriks 2022). Both types of histories enrich our contextual understanding of the artworks in their respective sociohistorical environments. However, the way in which these historical accounts are presented requires a format.

In the field of paintings conservation, the term 'conservation narrative' can be employed to describe an artefact's conservation history. The dictionary definition of a *narrative* is, 'a way of presenting or understanding a situation or series of events that reflects and promotes a particular point of view or set of values'.[41] It is essentially a written account of connected events (timeline) which has been used in a conservation context to both describe and map the treatment history of paintings (Bomford 2003; McClure 2009; Appelbaum 2010; Seymour and Sawicki 2012; Albendea et al. 2015; Hendriks et al. 2019).

In the field of architectural conservation, the term 'conservation narrative' has been explored and adopted as a specific theory (Walter 2014; Walter 2020). Historic buildings and their conservation are seen as being in constant flux as 'living buildings' which continue to interact with their environments (Walter 2020: 3). The dilemma of striving for permanence whilst also accepting change, which is often faced in conservation decision-making, can be presented and

[41] https://www.merriam-webster.com/dictionary/narrative (accessed 06.12.2021).

assessed through the building's intrinsic conservation narrative over time. Walter uses the narrative approach to 'provide a means for accounting for change' whilst also 'acknowledging the interpretative nature of conservation decision-making' (Walter 2020: 169). These principles are equally relevant for other historical artefacts such as paintings and crucial to understanding an object's past conservation trajectory and its future management in terms of change (Hölling 2016).

In the case of the NM Munch paintings, the collection's historicity in terms of display (the Munch Room), the significance of the NM's role as the first national arena for Munch's art, and its institutional impact on the conservation profession in Norway, are all key contextual factors. These factors are all interlinked with each painting's individual conservation narratives. Conservation histories also help to uncover the controversies in the field and shifts in tastes and notions of how particular works by a certain artist should look. This can influence the way in which artworks have been restored across time. What can appear as definite knowledge at a given point in time often comes under revision later (Hendriks et al. 2019; Duijn 2021a; Duijn and Noble 2021; Neidhardt and Schoelzel 2021; Hendriks 2022). Thus, the conservation narrative of the NM Munch collection is an important asset to understanding the broader historical context of the past varnish practice.

2.3 A non-invasive approach

The basic 'anatomy' (Ruhemann and Plesters 1968: 99) and layered structure of 19th and early 20th-century easel paintings traditionally consist of a secondary support (stretcher or rigid base), a primary support (canvas, wood, cardboard or paper), ground, paint and varnish layers (Pinna et al. 2009; Bucklow 2013) (Figure 06).

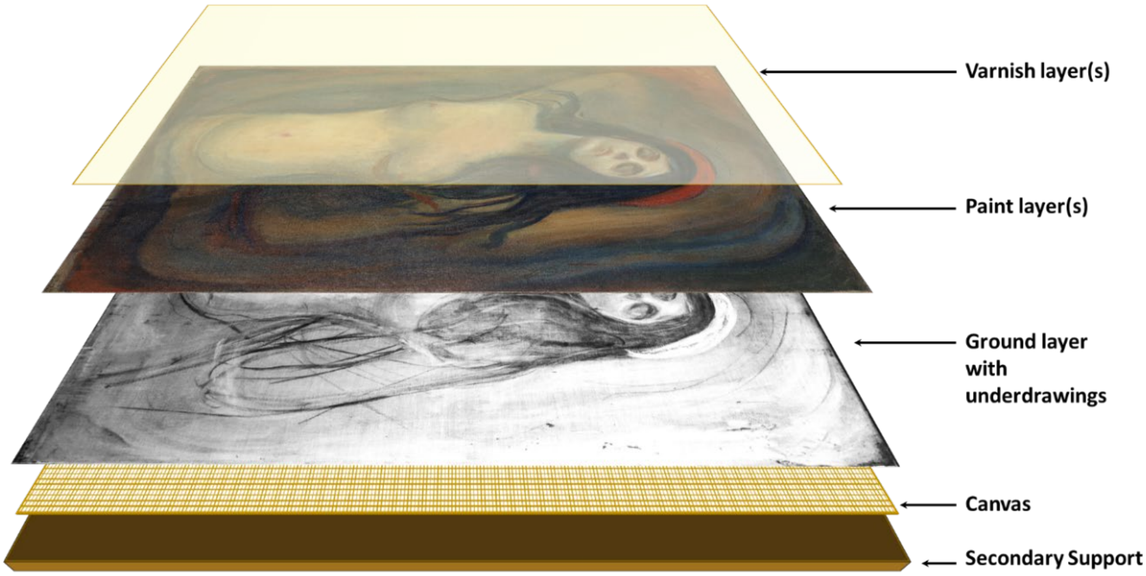


Figure 06. Typical layered structure ('anatomy') of easel paintings (Ford)

These generic subdivisions are employed as a guide for the systemised documentation and study of paintings. Nevertheless, there exist multiple variations to this basic structure. In terms of material analysis, paintings often present a more complex and heterogeneous composition. Munch's experimental painting techniques are no exception to this structural diversity with the examples of unconventional supports, lack of ground layers and unvarnished surfaces (Topalova-Casadiego 2008; Singer et al. 2013; Frøysaker et al. 2015; Tveit and Ferrer 2016; Stoveland et al. 2021). Furthermore, the notion of distinct layers may change with time. For example, a varnish layer may have sunk and no longer appear segregated from the paint 'layer(s)' underneath (Townsend 2010). This study's material analyses have focused on a painting's uppermost region regarding the chemical identification and spatial location of either superficial varnish (original and non-original), glazes and/or finishing layers.

The field of cultural heritage conservation and research has, over the last two decades, witnessed a growing interest in the development and use of in-situ non-invasive analytical techniques (Miliani et al. 2010; Alfeld et al. 2011; Brunetti et al. 2016; Pozzi et al. 2021). This has led to a gradual methodological shift in the examination of paintings with the possibility of both new and established laboratory-based benchtop methods being brought to the artworks in the field (Miliani et al. 2007; Nevin and Doherty 2016; Burnstock 2017). The advantage of in-situ methods is that they open up interdisciplinary discussions in front of the artwork, allowing for adaptive decision-making when gathering data (Hendriks and Miliani 2019; Sabbatini and van der Werf 2020). In general, the focus of employing non-invasive techniques falls into two broad categories: firstly, it can be used for the documentation of art technological aspects and the artist's creative/compositional process and, secondly, for the identification and assessment of materials concerning condition and preservation issues. This research addresses both categories.

Until now, the non-invasive approach has rarely been implemented in the previous research campaigns carried out on the NM's Munch paintings due to the limited availability of such techniques (Aslaksby 2009; Singer et al. 2013; Aslaksby 2015) (see also sect. 1.5). However, recent examples of other Munch conservation research (MAP and TECH-SCREAM-TECH)[42] have shown the benefits of using in-situ and non-invasive techniques (Frøysaker et al. 2010; Cutajar et al. 2020; Monico et al. 2020). These studies influenced a revision in the NM's methods with the endorsement of a more non-invasive analytical policy to conservation research. Consequently, this study has limited the amount of physical microsampling.

A non-invasive approach was therefore favoured for the characterisation and mapping of the superficial varnish layers, based on the following set of reasons:

1) The testing and use of novel, portable and non-invasive diagnostic techniques as viable screening methods for varnish layers present across a large collection of paintings.
2) The employment of methods and techniques which are accessible, user friendly and can be operated by museum staff (conservators).
3) Repeatability of measurements and accessibility to the same examination spot for future comparative research.
4) The possibility of data fusion and comparison generated by the different analytical techniques used.
5) The implementation of a more critical approach to and limitation of physical microsamples taken from high-profile paintings in the NM collections.

[42] Munch Aula Project (MAP): https://www.hf.uio.no/iakh/english/research/projects/aula-project/ and the Munch Museum's TECH-SCREAM-TECH project: http://www.iperionch.eu/project/tech_scream_tech-technical-study-of-core-art-materials-techniques-of-scream-versions/.

2.3.1 Selection criteria for paintings investigated

The collection of all scientific data was acquired within a four-year period (January 2018–June 2021) and made feasible by the author's permanent position as a paintings conservator at the NM. The physical 'revisiting the surface' consisted of the simultaneous visual inspection and renewed documentation of each painting's condition. This coincided with the NM's photographic campaign of the whole Munch collection prior to its relocation to the new museum building with illustrations to feature in the new and updated Munch catalogue (Ustvedt and Yvenes 2022). All the paintings with the exemption of two, were examined unframed in the conservation studios of the NG.[43] Given the size of the NM's Munch collection, issues of accessibility,[44] and the scope and timeframe of the study, a selection of paintings was required for the in-depth investigations. The purpose of the first scientific study (Paper II) was methodological and restricted to the pFTIR investigation of three paintings, due to the limitations of the journal publication. This total was increased to 13 for the second campaign of investigations using OCT (Paper III).[45] The selection criteria for the paintings are summarised below and listed in both diagnostic studies (sects. 6.2 and 6.3).

1) Accessibility, size, and painting technique[46]
2) Early works dating between 1884 and 1900 and including motifs from Munch's *Frieze of Life.*
3) Paintings with an uncomplicated provenance history.
4) Varnished paintings mentioned in texts and diaries.
5) Paintings with a documented varnish either as single, multiple or mixed (natural and synthetic) restoration varnish layers.
6) Untreated and unvarnished surfaces.

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[43] The two artworks not examined include (1) the small portrait study of *Betzy Nilsen* (Woll M 144) which was stolen on 20 August 1993 and is still missing, and (2) Munch's 1905 *Self Portrait* painted with watercolours/pastel/gouache on a paper support (Woll M 649). Both artworks are formally catalogued as part the NM's collection of 57 Munch paintings (Ustvedt and Yvenes 2022).

[44] Issues concerning accessibility to the paintings during the 4-year period are discussed in section 4.4, Limitations.

[45] A forthcoming study is planned with the presentation of the pFTIR results for the remaining 10 paintings in relation to the OCT results. This paper is envisaged as a continuation of the study (see sect. 4.5, Future perspectives).

[46] Paintings that were not considered in the selection process include the stolen painting, *Betzy Nilsen* (Woll M 144); *Self-portrait* (Woll M 649) painted on paper support; those on long-term loan, *Mrs Schwarz* (Woll M 698) and *Workers Returning Home* (Woll M 1361); and *Spring* (Woll M 173), due to practicalities concerning its size and inaccessible location in the NG's main staircase.

The focus dates 1884–1900 are based on the bulk of the NM's collection consisting of paintings from Munch's earlier years (Bjerke 2008; Mørstad 2016; Messel 2022). The term 'uncomplicated provenance history' refers to paintings acquired either directly from Munch himself or from early exhibitions and with few previous owners (Table (i)).

2.3.2 Imaging techniques

The paintings were photographed unframed using standard conservation photographic and imaging techniques based on the CHARISMA standards (Dyer et al. 2013). These were employed to both investigate and capture the varnished and unvarnished paint surfaces. An overview of the various imaging methods is tabulated below (Table (ii)) and details concerning their relationship to the diagnostic analyses is described further in the methodology sections of the two associated studies (Papers II and III). Where relevant, previously scanned X-radiographs were consulted.[47] Annotations made to the photographs (VIS and UVA) refer to the spot examination locations for the pFTIR and OCT readings. The key refers to the main colour from the examination spot followed by the examination sample number (Table (iii) and Figure 07).

2.3.3 Microscopy

The visual examinations were complemented using the combination of optical and digital microscopy coupled with photographic documentation for the 13 selected paintings, The paint surfaces, varnish coatings and their condition were first examined and documented through a Leica Wild M8 stereomicroscope (5–50× magnification range, Ortomedic AS, Lysaker, Norway). The NM's purchase of a Hirox RH-2000-3D digital microscope (Full HD 20–160× zoom lens, Hirox Europe, Limonest, France) during the study's timeframe allowed for a more in-depth examination and documentation of the surface topographies.[48] Information and images produced from both microscopic techniques assisted the selection of the spot locations for the pFTIR and OCT examinations.

[47] New X-rays could not be taken due to the delayed installation (October 2021) of the NM's new digital X-ray system.

[48] The Hirox microscope was acquired by the NM in 2020.

Table (i). Paintings selected for pFTIR and OCT analysis.

	Woll cat. no. **NM Inventory no.** **Title**	**Medium** **Dimensions (cm)**	**Painting date**	**Acquisition date** **P = Purchased,** **D = Donation**	**pFTIR** **Date of examination**	**OCT** **Date of examination**
	Woll M 113 (NG.M.01862) *Inger in Black*	Oil on canvas (97 × 67)	1884	D-1937	-	03.07.2019
	Woll M 130 (NG.M.00839) *The Sick Child*	Oil on canvas (120 × 118.5)	1885–86	D-1931	-	05.07.2019
	Woll M 133 (NG.M.01915) *Self-portrait*	Oil on canvas (33 × 24.5)	1886	P-1938	-	01.07.2019
	Woll M 148 (NG.M.01235b) *Flowery Meadow at Veierland*	Oil on canvas on cardboard (66.5 × 44)	1887	D-1921	11.09.2018	01.07.2019
	Woll M 174 (NG.M.00485) *Hans Jæger*	Oil on canvas (109 × 84)	1889	P-1897 From Munch	08.11.2018	03.07.2019
	Woll M 224 (NG.M.00394) *Night in Nice*	Oil on canvas (48 × 54)	1891	P-1891	09.11.2018	02.07.2019

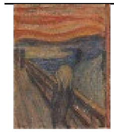	Woll M 333 (NG.M.00939) *The Scream*	Tempera/casein/ egg/oil/wax crayon on cardboard (91 × 73.5)	1893	D-1910	-	05.07.2019
	Woll M 347 (NG.M.00807) *Puberty*	Oil on canvas (151.5 × 110)	1894–95	P-1909	-	04–05.07.2019
	Woll M 348 (NG.M.00808) *The Day After*	Oil on canvas (115 × 152)	1894	P-1909	-	03–04.07.2019
	Woll M 366 (NG.M.00841) *Madonna*	Oil on canvas (90.5 × 70.5)	1894–95	D-1909	-	02.07.2019
	Woll M 382 (NG.M.00470) *Self-portrait Cigarette*	Oil on canvas (120.5 × 141)	1895	P-1895 From Munch	-	01.07.2019
	Woll M 445 (NG.M.00570) *Winter in the Woods*	Oil on cardboard/ wooden board (60.5 × 90)	1899	P-1901	-	05.07.2019
	Woll M 464 (NG.M.00941) *The Dance of Life*	Oil and crayon on canvas (125 × 191)	1899–1900	D-1910	-	02.07.2019

Table (ii). Overview of imaging techniques

Photographic/Imaging Technique	Equipment	Purpose
Visible reflected/normal light (VIS)	•Hasselblad H6D-400C MS digital camera (Interfoto AS, Oslo, Norway). •Broncolor Pulso G Halogen flash lamps (Fotocare AS, Oslo, Norway). •Color Checker Classic X-Rite patch (Xrite Europe GmbH, Regensdorf, Switzerland).	High resolution colour image documentation.
Induced/reflected light	•Hasselblad H6D-400C MS digital camera (Interfoto AS, Oslo, Norway). •Broncolor Pulso G Halogen flash lamps (Fotocare AS, Oslo, Norway).	False colour reflection captured from surface gloss (varnish). The image provides an approximate indication of the distribution of varnish over the paint surface.
Raking light	•Hasselblad H6D-400C MS digital camera (Interfoto AS, Oslo, Norway). •Broncolor Pulsospot 4 Halogen lamp (Fotocare AS, Oslo, Norway).	False colour photograph from single light source at oblique angle to the paint surface. Accentuation and documentation of surface topography.
UVA-induced fluorescence photography	•Hasselblad H6D-400C MS digital camera (Interfoto AS, Oslo, Norway). •Baader UV/IR Cut/L-Filter (Baader Planetarium, Mammendorf, Germany). •Target-UV^{TM} calibration reference patch (UV Innovations, USA). •Two UVA luminaires placed at equal distance, on either side of the painting, with three 40 W UVA fluorescent tubes per luminaire, radiating in the 355–360 nm region.	Documentation of fluorescing uppermost layers and/or pigments. Distribution and location of upper varnish layer(s). Used as a guide for the selection of areas relevant for pFTIR and OCT spots.

Infrared reflectography (IRR) with false colour	•ARTIST camera (former Dutch company ART Innovation). •Operational IR spectral wavelength range 700–1100 nm.	Documentation of underdrawings and artist's alterations. Characterise the distribution of possible infrared transparent pigments. Used as a guide for the selection of areas relevant for pFTIR and OCT spots.
Infrared reflectography (IRR)[49]	Apollo digital scanning InGaAs IRR camera (Opus Instruments, Norwich, UK). Operation IR spectral wavelength range 900–1700 nm.	Higher image resolution and longer wavelength. Documentation of underdrawings and artist's alterations. Used as a guide for the selection of areas relevant for pFTIR and OCT spots.

[49] Acquired by the NM in January 2020.

Table (iii). Key to annotations of spot examination locations in VIS and UVA photographs

Main colour in spot examination location	**Spot examination location code (pFTIR, OCT & pXRF)**
Blue	Bl
Black	Bk
Brown	Br
Flesh/carnation	Fl
Green	Gr
Ground	Gd
Red	R
Violet	V
White	W
Yellow	Y

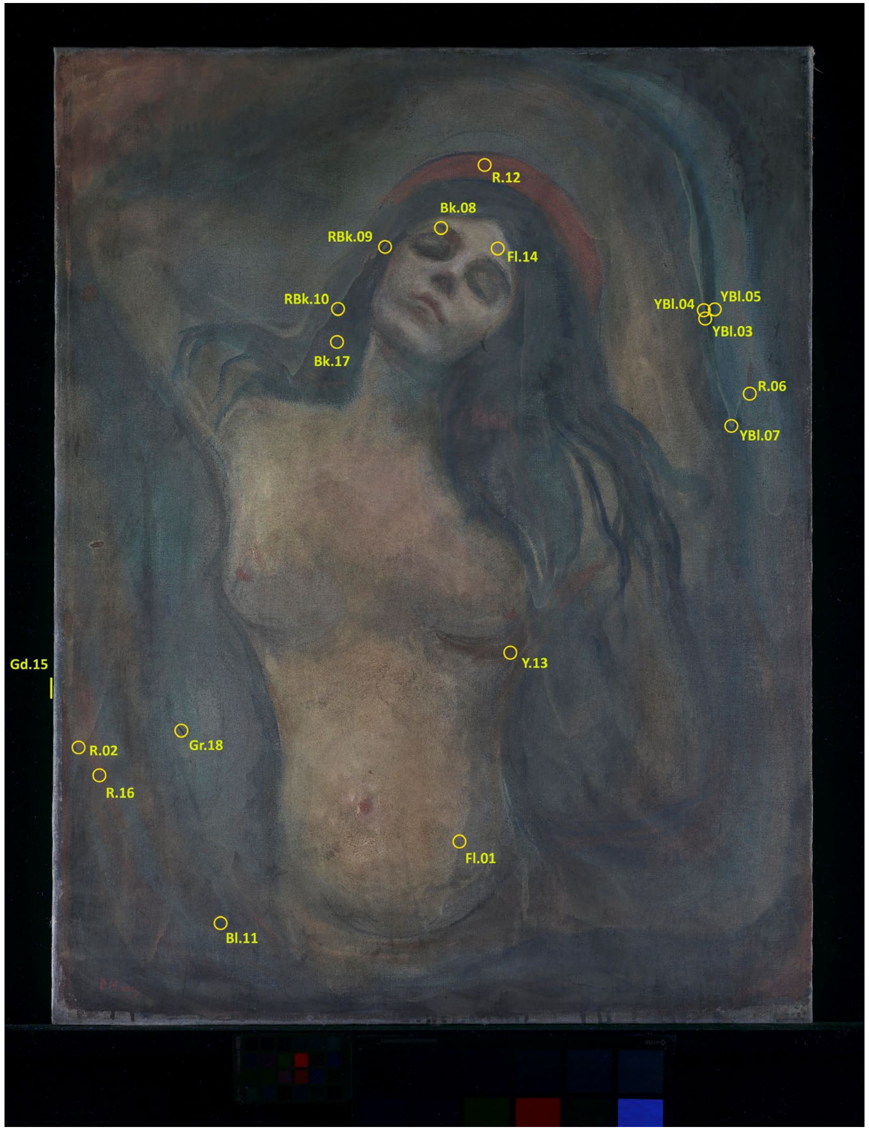

Figure 07. UVA photograph *Madonna* (Woll M 366) showing location and labelling of examination spots

2.3.4 Portable Fourier transform infrared spectroscopy (pFTIR)

Fourier transform infrared (FTIR) spectroscopy is a well-established analytical method for the molecular characterisation of inorganic and organic compounds (Stuart 2004; Robinson et al. 2017; Arana and Madariaga 2021; Madariaga 2021). Over the previous four decades, its successful application to the field of cultural heritage research for the identification of binding media, varnishes, adhesives and varnish resins has resulted in it becoming a routine investigative technique used for the material study of paintings (Derrick et al. 1999; Weerd et al. 2002; Galeotti et al. 2009; Prati et al. 2016; Rosi et al. 2019; Arana and Madariaga 2021).[50]

FTIR was chosen as one of the two main diagnostic techniques in a non-invasive capacity for the overview of the various surface finishes and non-original restoration varnishes present on the Munch paintings (Paper II). The main aim was to correlate information gathered from documentary sources (archives and conservation reports; sect. 2.2) with the investigation and identification of varnishes present. It was also felt that the results gained from the scientific analyses would greatly enhance later conservation decision-making strategies in context to the conservation history. This ties in with the study's three main research themes (sect. 1.6.2). In terms of the equipment, methodology and interpretation, emphasis was placed on finding the best practical solutions that would be both accessible, beneficial and comprehensible for museum conservators. The choice of portable instrumentation was governed by the availability of the NM's own equipment (4300 handheld Agilent Spectrometer) (Figure 08) which had been acquired for another research project concerning the identification of plastics.[51] This factor coupled with the general trend towards portable spectroscopy for cultural heritage research (Pozzi et al. 2021) influenced the author's decision, as a conservator, to test the NM's available spectrometer for varnish identification. FTIR is an established analytical technique used for varnish identification in paintings, but the employment of FTIR used with the specific portable Agilent spectrometer had not been previously used for the surface identification of varnishes in a collection of (Munch) paintings. Portable/handheld FTIR (pFTIR) spectroscopy

[50] The citations represent a selection of the most relevant references to the research.

[51] The pFTIR instrument was acquired by the NM for the collaborative research project, Reduced Ageing and Active Preservation of Plastic Items Stored in Museums and Art Collections (2017–2020). https://www.norner.no/funding-research-project-overview/rapmus, and https://www.nasjonalmuseet.no/om-nasjonalmuseet/forskning-og-utvikling/forsknings--og-utviklingsprosjekter/2019/lenge-leve-plasten-konservering-av-plast-i-museum/.

was used in an experimental capacity for the screening of restoration varnishes in three Munch paintings (Paper II).

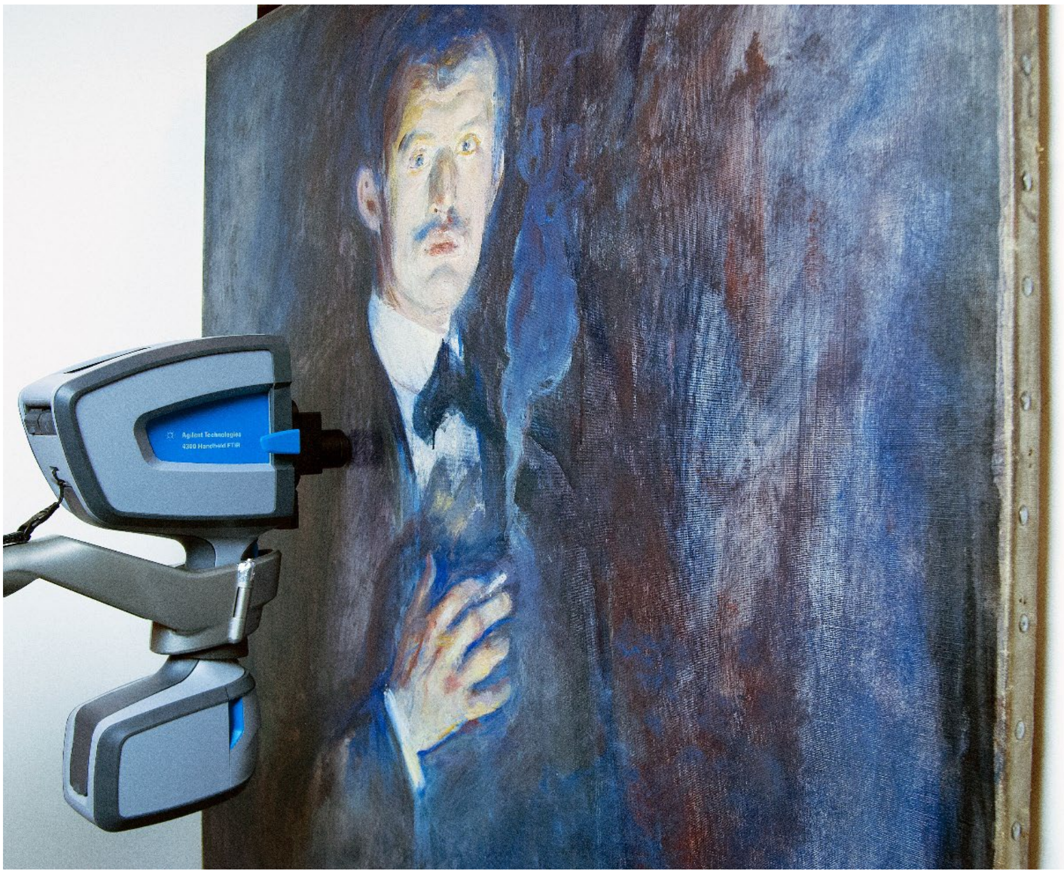

Figure 08. The NM's Agilent 4300 FTIR spectrometer (Matriks AS, Oslo, Norway) used on *Self-portrait with Cigarette* (Woll M 382) (2019, Ford)

FTIR Spectroscopy

The basic principles of FTIR[52] consist of absorption and scattering when a sample is irradiated with infrared (IR) light. The spectral range which has been commonly used for

[52] FTIR is now the most common of IR spectroscopic methods applied to cultural heritage research. It uses a broadband light (full IR spectrum) which is both emitted by and reaches the detector simultaneously. This is achieved through a Michelson interferometer which splits the IR beam (beam splitter) in two and remerges them into one creating interference as a pulsating beam which mimics the different pattern of frequencies in the IR beam. The beam is then directed onto the sample, and the frequencies and intensities absorbed or transmitted by the sample from the radiation pulses are obtained via an interferogram (time-domain spectrum). Fourier transform (FT) refers to the mathematical transformation (calculation). This determines what frequencies and intensities are present in the signal and converts the interferogram's raw data into a usable spectrum (frequency domain spectrum). The outcome is compared to a background spectrum (reference spectrum measured without the sample) to obtain the final absorbance or transmittance spectrum (Stuart 2004; Robinson et al. 2017; Arana and Madariaga 2021).

varnish identification (Derrick 1989; Doménech-Carbó et al. 2001; Popescu et al. 2012; Invernizzi et al. 2018; Martín-Ramos et al. 2018) is in the mid-IR (MIR) region, expressed either in wavenumbers, 4000–400 cm^{-1} or wavelengths, 2.5–25 µm.[53] As the IR radiation is passed through a sample, some of it is absorbed (retained), some passes straight through (transmission) and some light can also be reflected back to the source. IR spectroscopy is a vibrational methodology based upon the absorption of IR energy by a molecule which results in a characteristic physical motion known as vibrational modes (Derrick et al. 1999: 8; Stuart 2004: 7). According to its molecular structure, a molecule will only absorb radiation when the frequency of the source (IR) matches its own natural frequency of vibration (Stuart 2004: 8; Arana and Madariaga 2021: 102). This is because a molecule can only absorb IR radiation when there is a change in the permanent dipole moment caused by the alternating electrical field (oscillating electromagnetic field) of the IR radiation (Derrick et al. 1999: 11). If the IR radiation interacts with the fluctuations between the positive and negative electric charges on the atoms of the molecule, it will create motion in the bonds between atoms and groups of atoms, which is unique to the molecule(s) present within a given sample (Derrick et al. 1999: 11). The different types of motions produced are classified according to their movements in the x, y and z axes. These are described as translational, rotational and vibrational, with the latter being the most relevant for this study's MIR spectroscopical interpretation (Derrick et al. 1999: 10).

In visual terms, molecules can be likened to a three-dimensional structure in which the atoms are circular weights joined together by springs representing the bonds (Robinson et al. 2017: 70). The various movements of the springs (bonds) will therefore cause the circular weights (atoms) to oscillate in different ways. There are two main types of IR-induced vibrational modes: stretching (changes in bond length between two atoms) and bending (changes in bond angle between two atoms) (Stuart 2004: 6; Robinson et al. 2017: 166; Arana and Madariaga 2021: 102). The stretching vibrational modes between two atoms can either be symmetric (movement in the same direction) or asymmetric (movement in different directions) (Stuart 2004: 8). For the bending vibrations, which require less energy (Arana and Madariaga 2021:

[53] The IR region of the electromagnetic spectrum is divided into three zones: near-IR (NIR, 0.7-2.5 µm or 14000–4000 cm^{-1}), mid-IR (MIR, 2.5–25 µm or 4000–400 cm^{-1}) and far-IR (FIR, 25–300 µm or 400–10 cm^{-1}) (Stuart 2004: 24).

102), the atoms have four modes: rocking and scissoring which are in-plane vibrations, and wagging and twisting which are out-of-plane vibrations (Stuart 2004: 9).
The IR energy required to initiate the various molecular vibrations within a given sample is dependent on the masses of the atoms present, the strength of the covalent bonds, and the geometry of the molecule(s) (Stuart 2004; Robinson et al. 2017). The number and specific way in which these vibration modes occur can be specified for known simple diatomic and triatomic molecules (Robinson et al. 2017: 166). This is known as a molecule's 'degrees of freedom' which describes the maximum number of movements/transitions along x, y z axes (3) for each atom (N), represented as 3N (Derrick et al. 1999: 8; Robinson et al. 2017: 167). In addition, the fundamental (first order/normal) vibrational modes having the strongest energy absorption can also be predicted and are represented as 3N – 6 for non-linear molecules or 3N – 5 for linear molecules.[54] It is these specific interactions (or their absence), related to the frequency of IR radiation absorbed or transmitted (the characteristic vibrational modes), which provide information about the molecular structure of sample.

However, molecular structures of varnishes can be complex to identify depending on the mixtures and if a sample is contaminated. The technique's ability to identify combinations of atoms (functional groups) facilitates this by producing unique group vibrational frequencies independent to the remaining structure (Derrick et al. 1999: 12). For example, a carbonyl group which is typically present in varnish resins, will produce distinctive stretches occurring between 1650 and 1750 cm^{-1} and can help to give a first indication of the molecular structure's backbone and ageing, based on its shape (Derrick 1989: 4). Caution is nevertheless required, as in some instances, a functional group's vibrational frequencies can be influenced by neighbouring atoms which might cause slight changes in the typical intensity and position of the bands (Derrick 1999: 11). Likewise, overlapping bands from pigments and binding media (contaminants) might affect the overall interpretation (Mazzeo et al. 2008). Nevertheless, the identification of multiple and known functional groups help to guide and provide a general first interpretation of the sample in question.

[54] In a linear molecule the atoms are arranged along a single, straight line and hence only two rotational axes are possible resulting in a total of 2 (rotational) + 3 (translational) = 5 'degrees of freedom' (Derrick et al. 1999: 9; Robinson et al. 2017: 167).

Spectra and spectral modes

The instrument's output produces an IR spectrum which provides energy/frequency information about the IR radiation absorbed or transmitted from each reading. In this study, the intensity was plotted in pseudo-absorbance (y-axis = log(1/R), where R is the reflectance) against the IR frequency (x-axis, wavenumber cm^{-1}) to improve visualisation and interpretation of the functional groups (Angelin et al. 2021: 5) (Figure 09 and Appendix 7.6.2). The spectrum reveals the position or *frequency* (dependent on the atom-to-atom vibrational bond energies, *degrees of freedom*), the *intensity* (band height, related to the extent of changes of the dipole moment during vibration) and the *band shape* (influenced by the different chemical environments and intermolecular interactions) (Varella 2013: 68).

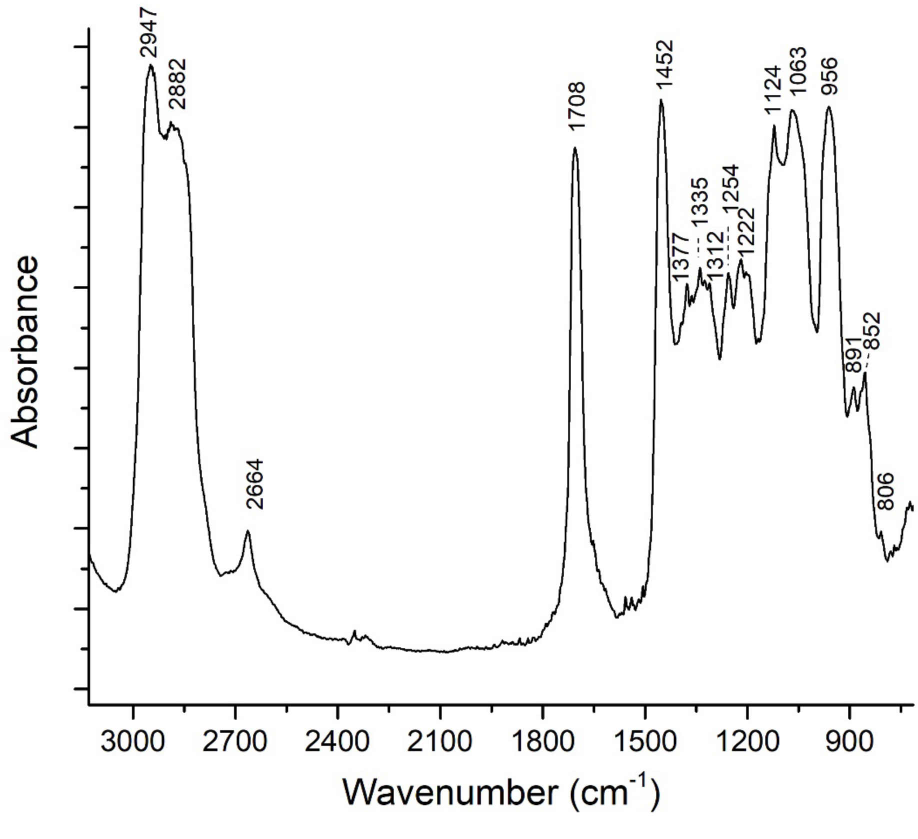

Figure 09. Example of a pFTIR DRIFT spectrum plotted in pseudo-absorbance and annotated peaks for Laropal K 80 (ketone) – standard varnish solution, MirrIR.08

The NM's Agilent 4300 FTIR spectrometer (Matriks AS, Oslo, Norway) was employed for all the non-invasive tests and measurements undertaken in the research (Paper II) (Figure 08). The pFTIR was essentially used as a surface analytical technique, restricted to the detection of the upper and thicker varnish or finishing layers present in the Munch paintings. This approach affected choice for the mode of operation used to acquire the spectra. The Agilent spectrometer is designed for reflectance spectroscopy and three different probes were available. These relate to the three main modes of FTIR reflectance spectroscopy: attenuated total reflectance (ATR), specular reflectance (external reflectance, ER) and diffuse reflectance spectroscopy (DR or DRIFTS) (Figure 10).

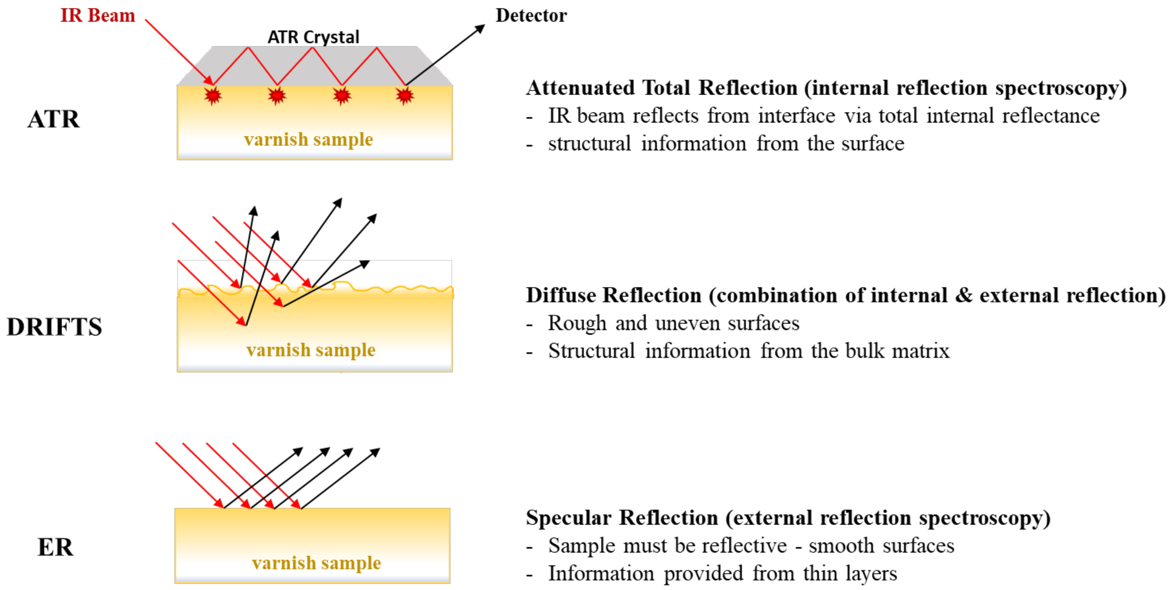

Figure 10. Schematic diagram showing three main modes of FTIR reflectance spectroscopy (Ford)

ATR is one of the preferred modes of FTIR reflectance spectroscopy in cultural heritage research and is used both in portable set-ups as well as with benchtop instruments (Mazzeo et al. 2008; Prati et al. 2010). The latter are equipped with FTIR microscopes as micro-ATR-FTIR to study a variety of material samples in cultural heritage research. However, when used in a portable set-up, there is a practical disadvantage as the ATR crystal requires direct contact with the sample. Experimentation with the technique on a series of test canvases quickly revealed that the exerted pressure required to obtain a good IR signal created permanent indentations to the paint surface.[55] The use of ATR as an IR spectral reflectance mode was thus reserved for the laboratory-based analyses of microsamples (sect. 2.5) and was not employed in the portable manner. Similar tests were conducted with the ER probe for the specular reflectance mode.

[55] Numerous trials were first undertaken on variety of varnished and unvarnished test paintings.

Hypothetically, specular reflectance should be more suited as an analytical mode for more reflective surfaces (Stuart 2004: 35), such as the glossy varnishes applied over thinly painted smooth panel supports (*Young Woman Washing Herself*, Woll M 387). However, the importance of applying no pressure to the painted surfaces, the sensitivity of the detector, and the topographical irregularity of the paint and varnish surfaces (at microscopic level), created a poor and noisy signal in the ER mode. In contrast, the instrument's DRIFTS mode produced an exciting set of initial test spectra acquired with minimal contact to the painted surface. This success led to the pFTIR technique being used as an experimental non-invasive screening technique for the characterisation of varnishes in the Munch paintings (Paper II). Moreover, the benefits of employing the DRIFTS mode for in-situ analyses of cultural heritage artefacts is supported by earlier research using similar portable instrumentation (Arrizabalaga et al. 2014).

Equipment and set-up

The compact size and ergonomic design of the Agilent instrument is suggestive of an equipment format that is suitable for handheld measurements. Nevertheless, given the nature of the study and the artefacts examined, extra practical and safety issues had to be implemented. These included the attachment of the instrument to the same movable counterweight stand as used for the pXRF (Figure 11). Safe practical working conditions were not only ensured but the stand also facilitated the precise location of the spot measurements and provided extra stability for the acquisition time needed (number of scans). The best data sets were generated with a high signal to noise ratio configuration using 256 scans[56] (with 8 background scans), acquired between 650 and 4000 cm^{-1} at a resolution of 4 cm^{-1}. The DR probe's spot size measures 6 mm in diameter. Areas of analysis were chosen based on information previously gathered through various imaging techniques used to document the painting's surface topography (raking light), thickness and the distribution of the varnish layers present (microscopy and UVA). The spot location measurements for each painting are classified according to their main colour and/or colour mixture and marked on the VIS and UVA photographs (sect. 2.3.2, Table (iii), Figure 06). Their coordinates (x, y) are calculated from left and bottom edges of the paintings. Nitrile gloves were used for handling and the probe's protective rubber ring was wiped with isopropanol between measurements at each spot location to reduce the risk of external

[56] Tests were undertaken using 32, 64, 128, 256 and 512 scans. The best signal was recorded at 128 and cleanest readings at 512: 256 scans were therefore chosen as the intermediate parameter.

contamination. All the in-situ scans on the paintings were performed perpendicular to the painted surfaces with artworks secured to an easel. Multiple scans were acquired at each location spot. The interpretations of the DRIFTS spectra were processed with OMNIC Spectra software (version 7.2 by Thermo Fischer Scientific, Oslo, Norway). In 2020 the NM purchased Agilent's MicroLab expert software (version 1.1.0.1, Matriks AS, Oslo, Norway) which greatly facilitated the data processing and comparative interpretations. All the spectra presented are without the use of correction algorithms. A detailed summary of the studio equipment set-up and the pFTIR parameters is also outlined in Paper II.

Figure 11. pFTIR (DRIFT) varnish library tests. Dry resin sample, recipe solutions, MirrIR low-e microscope slides and tripod set-up (2022/2018, Nasjonalmuseet/Ford)

Varnish reference library

Although pFTIR is a powerful tool for the detection of molecular structures on a surface, the limitations of reflectance modes (Miliani et al. 2007; Miliani et al. 2010; Miliani et al. 2012) and the complex and heterogeneous nature of painted surfaces (Brunetti et al. 2016: 3) are known to influence the approach and methods of interpretation. Unlike a pure varnish sample, the complex composition of subsurface layers present in a varnished painted surface might contribute bands in the IR spectrum when an in-situ examination is performed non-invasively. The possibility that absorption bands would either overlap those belonging to the varnish or be assigned to other components such as pigments and the binding medium (drying oil) was considered (Miliani et al. 2012: 305). Consequently, three aspects were implemented into the methodology concerning the IR interpretation of the surface morphology of the spot locations: a reference library of spectra, the depth of penetration of the instrument and the influence of a glossy/non-glossy surface. All three are described in detail in the methodology section of Paper II (see also Appendix 7.6). Despite the accessibility and usefulness of existing reference libraries such as IRUG,[57] it was important to create a specific reference library from the NM's known and historic varnish recipes analysed by the Agilent instrument as DRIFT spectra.[58]

2.3.5 Optical coherence tomography (OCT)

Like pFTIR, optical coherence tomography (OCT) is an interferometric technique which also employs broadband infrared radiation. However, OCT utilises light of low intensity with a more limited spectral range than FTIR to determine the distances within structures and layers that either scatter or absorb the IR radiation (Drexler and Fujimoto 2015).[59] The method is employed to provide high resolution virtual cross-sectional and three-dimensional volumetric imaging (tomograms) of superficial surfaces and layers (Drexler and Fujimoto 2015). It is both non-invasive and non-contact and its origins stem from the medical field (Huang et al. 1991). Since its invention during the mid-1990s, it has become a well-established optical diagnostic method, especially in ophthalmology, where it is used for the in-vivo imaging of retina tissue layers in the human eye through the iris (Drexler and Fujimoto 2015: ch. 56).

The wide application of OCT to the field of cultural heritage research has greatly enhanced the conservator's repertoire of non-invasive diagnostic options for the study of historical artefacts (Targowski et al. 2004; Liang et al. 2005; Targowski and Iwanicka 2012; Targowski et al. 2020).[60] A large body of research has shown the diagnostic suitability of OCT for the inspection of transparent and semi-transparent surface and subsurface layers in paintings, namely the

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[57] Infrared & Raman Users Group. http://www.irug.org/.

[58] At the time of the study, no reference DRIFT spectra existed for varnish resins or varnished painted surfaces acquired with a pFTIR 4300 Agilent spectrometer.

[59] In comparison to the MIR of pFTIR, the OCT's IR spectral range (used in this study) is in the NIR between 750 and 950 nm.

[60] For a complete literary overview of OCT applications to cultural heritage, see also, http://www.oct4art.eu/.

spatial distribution, layer identification and thickness of historic varnish (surface) layers present (Targowski et al. 2010; DeCruz et al. 2016). Furthermore, the technique has been employed to detect artist's alterations and/or restorations, and to monitor cleaning strategies (Fontana et al. 2015; Iwanicka et al. 2018; Berg et al. 2019). In addition, OCT has similar benefits to pFTIR whereby the surface examination is fast and does not require any preparation of the painting prior to examination. From a conservator's and practical perspective, these factors influenced my decision to adopt it as one of the two main diagnostic techniques for the screening of restoration varnish layers in the NM Munch collection. Moreover, it provided supplementary visual stratigraphical information to the chemical characterisation of the varnishes from the pFTIR spectra. The aim of combining both these non-invasive techniques was to obtain a more comprehensive understanding of the varnish layers with in-situ measurements collected from the same examination spot (Iwanicka et al. 2018).

Technique and instrumentation

A high-resolution portable SdOCT (spectral domain OCT) instrument was used in this study with a broadband super-luminescent light source (M-T-850-HP broadlighter, Superlum, Ireland). The IR light with a spectral range 750–950 nm, high spatial but low temporal coherence with a maximum power of 800 μW was used for the examination.[61]

The technique employs the principles of the Michelson interferometer in which the incoming beam of light is split. Half is directed to a reference mirror and reflected back, and the other half is formed into a narrow beam directed towards the paint surface and also reflected/scattered back. In SdOCT the reference arm has a fixed optical path length (Drexler and Fujimoto 2015: 36). Both reflected light beams meet in the instrument spectrometer. The delay of the reflected/scattered light beam imposed by its interaction with the painting is dependent on the refractive index and thickness of the various transparent and semi-transparent (varnish) layers present. These delays can be revealed by means of the interference with the reference beam and thus precisely measured. The interference pattern is detected by the charge-coupled (CCD) camera of the spectrograph and analysed via Fourier transformation, grated into its frequency components (Podoleanu 2012: 3). Each frequency relates to a specific depth along the probing beam (A-scan) and enables the reflective/scattering structures to be visualised simultaneously

[61] A detailed summary of the equipment and set-up is also outlined in the methodology section of Paper III.

(Targowski et al. 2010; Drexler and Fujimoto 2015). A set of parallel penetration A scans can then be taken along a specified horizontal axis which builds the virtual cross-sectional image (OCT tomogram, B-scan) (Figures 12, 13 and 14). This stratigraphical image is defined by the reflective/scattering properties of the various varnish layers (and/or glazes) present and allows for their precise measurement in terms of position and thickness. The absorption properties of these layers define the depth of penetration of the probing light and thus the range of in-depth imaging (Targowski et al. 2010).

The prototype SdOCT instrument, which was designed and built under the EU FP7 CHARISMA and H2020 IPERION CH programs, was borrowed by the NM with the assistance of two experts from the Nicolaus Copernicus University, Toruń, Poland. It was used to examine the surfaces of 13 Munch paintings (Paper III) and the scanning was carried out horizontally at a 43 mm distance from the instrument to the paint surface (Figure 12). Ideally, the OCT examinations should have been undertaken prior to the pFTIR investigations facilitating a more targeted analysis. UVA photography was used as a guide for the selection of matching and additional areas of interest. The OCT tomograms were acquired with a lateral resolution of 15 μm and 2.2 μm axial resolution in the varnish. For every examination spot, 150 parallel 2D slices were acquired from a 12×12 mm^2 area. Post-processing of data and correction of the OCT tomograms was undertaken by the Nicolaus Copernicus University. This included the common value $n_R = 1{,}5$ for the correction of light refraction and false colour scale presentation for interpretation (Figure 14). Given the macroscopic nature of the technique, some of the OCT data were presented as a composite panel which includes the whole cross-section (12×0.89 mm^2) complemented by an IR reflectogram and two macrographs of the scanned area showing the precise location of the scan line (see Paper III). This additional visual information generated by the OCT software was esteemed useful for both the interpretation and presentation of the findings.

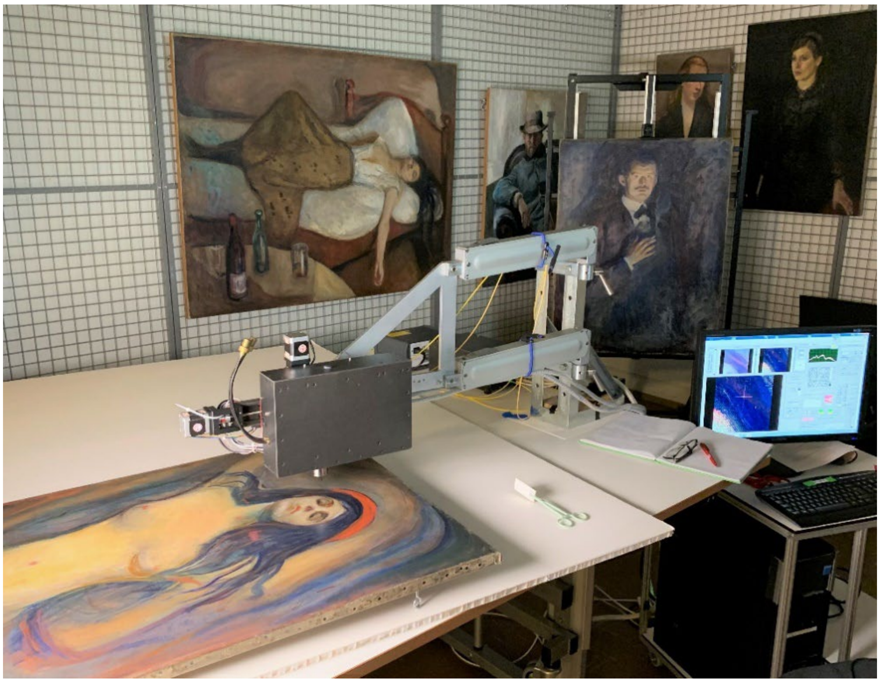

Figure 12. sdOCT scanning of *Madonna* (Woll M 366) at NM (July 2019, Ford)

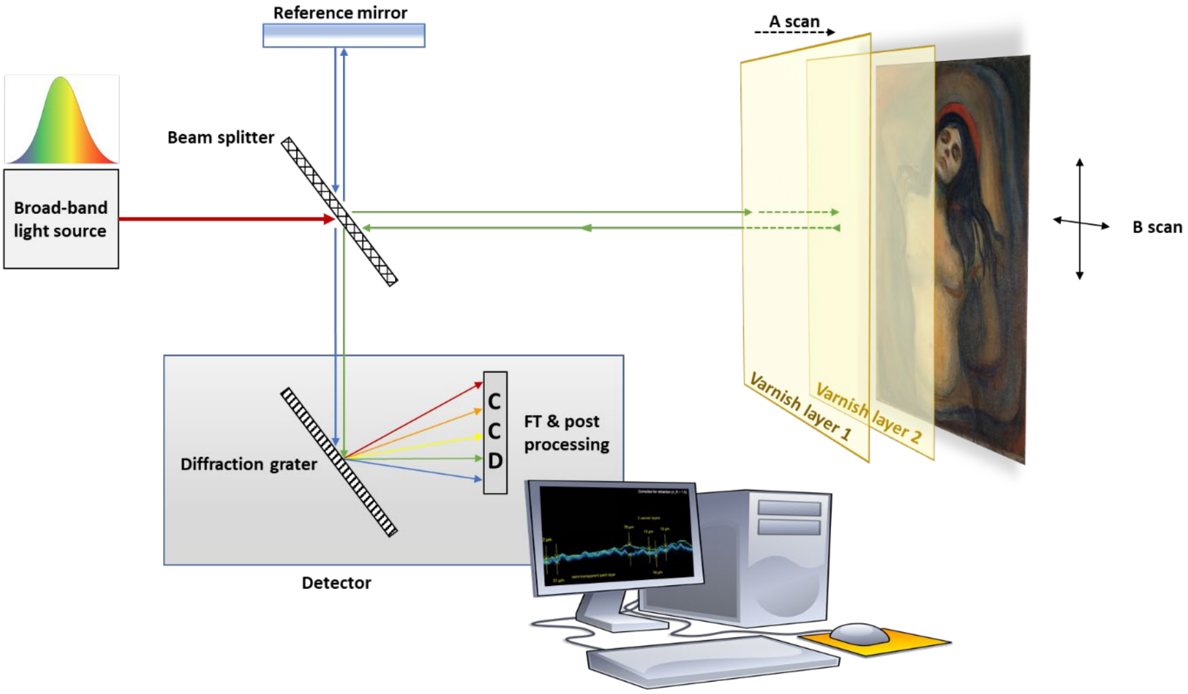

Figure 13. Schematic diagram of sdOCT scanning technique (Ford)

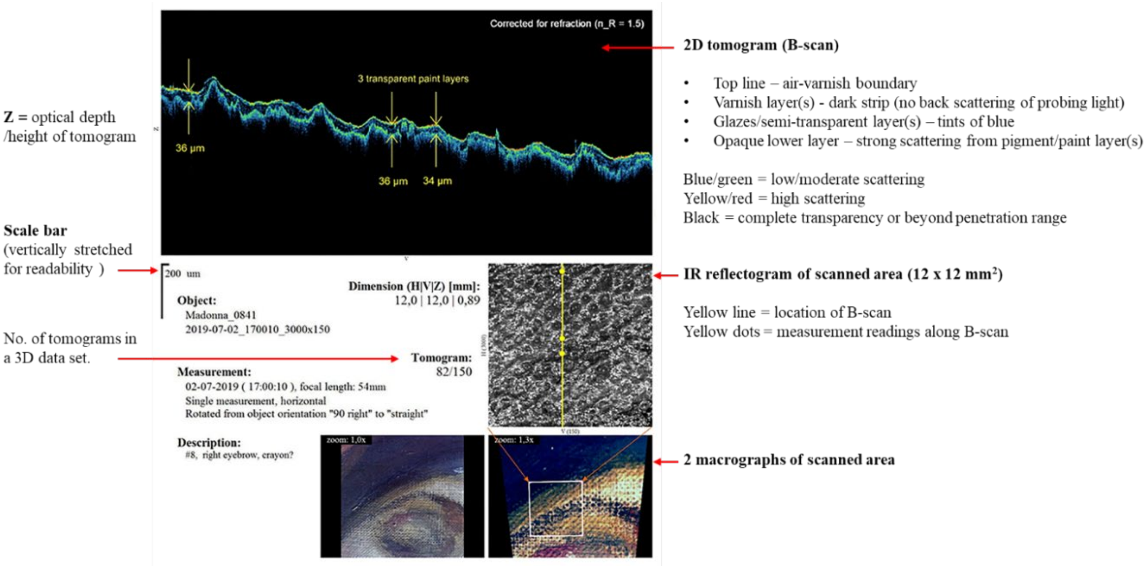

Figure 14. Example of OCT results panel: *Madonna* (Woll M 366), for examination spot Bk.08 (Targowski)

2.3.6 Portable X-ray fluorescence spectroscopy (pXRF)

Portable X-ray fluorescence spectroscopy (pXRF) is a non-invasive, close-contact, analytical technique which has become a well-established and standard practice in the field of cultural heritage research (Janssens and Grieken 2004; Shugar and Mass 2012; Janssens et al. 2016). It is an ionising technique which uses X-rays to irradiate an artefact's surface or microsample which can produce qualitative and/or semi-quantitative elemental data (Acquafredda 2020: 31; Bezur et al. 2020: 18). The X-ray tube generates a broad and continuous beam of high energy X-ray photons which interact with the various elements present in the artefact/sample. The absorption of higher energy causes the expulsion and displacement of electrons from the shells of an atom and consequently, the re-emission of a lower-energy radiation (fluorescence) produced by the ejection of electrons can be detected (Bezur et al. 2020: 17). The fluorescent radiation emitted by an ionised atom contains specific information which is characteristic to the irradiated element (Acquafredda 2020: 34). As a non-invasive screening technique for the identification of elements present in a sample, pXRF can be useful to gain a preliminary indication of possible pigment or general pigment compositions present in a paint surface (Rosi et al. 2009; McGlinchey 2013: 131). However, the complex stratigraphy and heterogeneity of paint surfaces can often limit the capability of the technique in providing a precise and complete overview of all the pigments present. The technique is not layer specific and the mixed and complex paint layer structure can result in ambiguous readings from matrix effects on X-ray intensity and absorption causing secondary radiation in addition to elemental peak overlaps (McGlinchey 2013: 136; Bezur et al. 2020: 21).

In the context of this study, pXRF was employed for the elemental characterisation of pigments present in the paintings. The XRF data provided complementary elemental information for the two main diagnostic techniques (pFTIR and OCT). Regarding the pFTIR investigations, it was utilised to help interpret possible pigment interference present in the FTIR spectral results (Paper II). With OCT, pXRF was employed to help clarify the possible presence of pigments located in semi-transparent layers (Paper III). Although it was not the focus of the research, the additional elemental data collected from the pXRF readings was seen as an important subsidiary contribution to the general knowledge base of Munch's use of pigments between 1884 and 1900.

A Thermo Niton XL3t 900 energy dispersive pXRF spectrometer (Thermo Scientific, Holger Hartmann, Oslo, Norway) with a Si-drift detector (GOLDD – Geometrically Optimized Large Drift Detector) was used. Measurements were taken directly from the paint surfaces with the pXRF securely attached to a tripod. This provided extra security against the risk of damage to the paint surface whilst also increasing the stability of the instrument for the acquisition of data. In each case, a set of multiple readings with 3 mm and 8 mm spot sizes were taken from the same analysed areas as pFTIR and OCT. Where this was not possible, adjacent passages with dominant primary, secondary, black and white colours were used. A system check was performed at the beginning of each session and background spectra were collected from a sheet of plexiglass (McGlinchey 2013: 147). The instrument's default 'Mining Cu/Zn Testing Mode' was chosen and provided the setting for the largest range of elements. Spectra acquisition time was 60 seconds for each sampled area and the pXRF switched automatically from main (Al/Fe filter, potential: 50 kV, maximum current: 40 μA) to low (Cu filter, potential: 20 kV, maximum current: 100 μA), high (Mo filter, potential: 50 kV, maximum current: 40 μA) and light range filters. Spectral data were analysed with the Thermo Niton NDT software (version NDT 8.5.1).

2.4 Conservation decision-making tools and strategies

A revised and updated varnish survey of the NM Munch collection was created through the systemised examination of 56[62] paintings undertaken between January 2018 and June 2021 (Paper IV). The relevant information was gathered from the main overview of the entire NM Munch collection which represents the backbone of the thesis (Appendix 7.1).

Conservation decision-making is embedded in the ‘paradigmatic triangle model’ of art history (conservation) science and conservation practice (Hummelen et al. 2008: 1045). There exists a twin interest and dialogue between ethical codes and principles pertaining to the permanence of artworks (in terms of preservation) and with those of change (Ashley-Smith 2017). This often involves compromise decisions, based on weighing what is an achievable and desirable outcome of conservation measures. Change, or the ‘management of change’ (Vall et al. 2011; Hölling 2016) represents not only the chemical- and biological-induced alterations in an artefact (processes of material degradation) – it equally embodies physical changes related to its social and historical context intertwined with changes in meaning (Hummelen et al. 2008; Streeton 2017; Wharton 2018).

Given the historical diversity of the non-original restoration varnishes applied to the Munch collection, a flexible and ‘bespoke’ decision-making strategy was considered (Ashley-Smith 2017; Wharton 2018). However, it was important to adopt a framework based on existing and processed decision-making systems (Laurenson 2004; Scholte and Wharton 2011; Marçal et al. 2013; Saaze 2013; Henderson and Nakamoto 2016; Henderson and Waller 2016; Marchesi 2017). The chosen model was based on a flow diagram designed for contemporary art (Giebeler et al. 2021) but adopted for and tailored to the requirements of the NM and for the Munch collection. Elements of the structure initially stem from Van der Wetering’s original theoretical wheel of conservation (Wetering and Wegen 1987) and aim to address the requirements of more traditional and historical collections. The details and presentation of the Munch decision model form part of the fourth article, Paper IV.

[62] Past documentation of the restoration varnish applied to the small portrait study of *Betzy Nilsen* (Woll M 144), stolen on 20 August 1993, was included in the survey but the painting could not be re-examined.

2.5 Supplementary microinvasive analytical methods

Despite the non-invasive stance of the research (sect. 2.3), a limited amount of microinvasive analysis was deemed relevant for comparative purposes and in conjunction with the further validation of some of the pFTIR and OCT results (Papers II and III). When necessary, microsampling was carried out as the last leg in the chronology of analytical techniques and functioned as a justified complementary and/or supplementary scientific method. A strict and minimal physical interventive approach was adopted in line with the established codes of ethics and guidelines.[63] The removal and amount of material taken from each painting was assessed case by case and followed common methodologies for the removal of material from paintings for analysis (Khandekar 2003). Permission for sampling and discussions pertaining to the quantity, type and suitable areas were sought from and discussed with the author's superiors at the NM.

The main bulk of the physical sampling consisted of micro-scrapings taken from the upper restoration varnish layers. Where possible, samples were sourced from the pFTIR examination spot locations or from an adjacent area. For the stratigraphical comparisons with OCT, microscopic flakes were embedded in a light-curing acrylic resin and polished perpendicular to the surface with an ultra-fine Micromesh paper to obtain a cross-section of the layers.

Layers in cross-section were first analysed using attenuated total reflection FTIR (ATR-FTIR). This technique was used essentially as a means to validate the results from the pFTIR spectra. In addition, it provided a useful comparative spectral overview of the NM's historical dry resin samples. Raman microspectroscopy was also performed on the samples from *Night in Nice* (Woll M 224) (Paper II) to support the pigment identification from the pXRF results (Casadio et al. 2016).

Additional, micro-destructive tests were performed on four samples for further clarification of the chemical composition of varnish resins (Paper II). Thermally assisted hydrolysis and methylation-gas chromatography coupled with mass spectrometry (THM-GC-MS) was used. This analytical technique provides a precise molecular breakdown of the organic varnish

[63] European standards (CEN), BS EN 16085:2012 Conservation of Cultural property. Methodology for sampling from materials of cultural property. General rules English PDF.

polymers in the sample through separation and thus facilitates the identification of both polar and non-polar components and polymer fragments present (Challinor 2001; Shadkami and Helleur 2010).

All microanalytical tests were carried out at the scientific department of the Metropolitan Museum of Art (New York, USA) by the conservation scientist Adriana Rizzo. The instrumental set-ups, equipment and conditions are summarised in the following table (Table (iv)) and described in the Methodology section of Paper II.

Table (iv). Overview of supplementary microinvasive and micro-destructive techniques

Analytical technique	Equipment and methods	Purpose
FTIR, of varnish layers embedded in cross-section	• Microscopic flakes embedded in the light-curing acrylic resin Technovit 2000 LC. • Cured under blue light – Technotray CU (both Heraeus Kulzer, Germany). • Polished using Micromesh (1,200 to 12,000 grit) (Micro-Surface Finishing Products, USA). • Examination using 20× ATR germanium-crystal objective of a Hyperion 3000 microscope, featuring a liquid nitrogen-cooled mercury cadmium telluride detector, and interfaced to a Tensor 27 spectrometer (both instruments by Bruker Optics, Billerica, MA, USA). • The spectra were acquired as an average of 64 scans in the range from 600 to 4000 cm^{-1} at a resolution of 4 cm^{-1}	Confirmation of resin type in varnish samples
FTIR, Varnish scrapings	• Samples were crushed in a diamond micro compression cell (Spectra-Tech, Inc., Oak Ridge, TN, USA). • Samples were analysed using a 15× FTIR objective using the same instrumental set-up and acquisition conditions for embedded cross-sections (above).	Confirmation of resin type in varnish samples
Raman microspectroscopy of varnish layers embedded in cross-section	• Raman microscopy performed on single particles in cross-sections using a Bruker Senterra ™ dispersive Raman microscope system (Bruker Optics) with a 1,200 l/mm holographic grating and a CCD detector. • A 785 nm excitation with 20× or 50× objectives and 30–60 s total acquisition time were used, with laser power ranging between 1 and 10 mW; resolution was in the range of 3–5 cm^{-1}.	Pigment identification

THM-GC/MS Microsamples	• Microsamples with a mass between 15 and 30 µg were accurately weighed on an Ultramicrobalance UMX2 (Mettler Toledo, Columbus, OH, USA) in the pyrolysis cup (Eco-cup, Frontier lab, Fukushima, Japan). 3 µL of TMAH solution ((tetramethyl)ammonium hydroxide 25% (w/w) in methanol) were added to the sample prior to pyrolysis at 550 °C in the vertical micro-furnace of the double-shot 2020iD pyrolyser (also from Frontier lab). • The micro-furnace is interfaced to the gas chromatograph Agilent 6890 coupled with the Agilent 5973 Network Mass Selective Detector (Agilent Technologies, Inc., Santa Clara, CA, USA). • The analysis was carried out in split mode at a split ratio 15:1. An Agilent J&W DB-5ms capillary column (30 m × 0.25 mm × 0.25 µm) was used. • The inlet and the MS transfer line were kept at 320 °C. Helium was used as the carrier gas at a constant flow of 1 mL/min. • The GC oven temperature program was: 40 °C for 2 min, up to 320 °C with a rate increase of 6 °C/min, followed by 10 min of isothermal conditions. • Analysis was conducted in full scan mode (35–600 m/z). Temperature at the MS source was 230 °C and at the quadrupole 150 °C. A solvent delay of 2 min was used.	Confirmation of resin type and other organic components in varnish samples

2.6 Data management

Given the variety of data types and formats collated from this research, a data management plan was created following the 2016 FAIR standards and principles. These guidelines recommend four main principles: findability, accessibility, interoperability and reuse of digital assets.[64]

2.6.1 Photography

All, VIS, raking light, UVA and IRR photographic files are catalogued under the painting's NM inventory number (NG.M.0xxxx) stored in the museum's digital online repository.[65]

2.6.2 pFTIR data

Data folders for each painting are temporarily housed on the museum's conservation server awaiting the NM's collection management database's forthcoming scientific module. These are filed under the painting's NM inventory number (NG.M.0xxxx). Raw spectral data for each pFTIR scan is stored as a SPC digital file format with the following sequence.

Example: Woll M 224, *Night in Nice* (NG.M.00394):
NM inventory no. + examination spot colour & no. + reflectance mode/scans + date[66]

0394_BI01_DR256_2018-09-11T00-17-42.spc

2.6.3 OCT data

The OCT result panels are housed in separate folders under the painting's NM inventory number and stored both at the NM and Nicolaus Copernicus University, Toruń, Poland. The file naming follows the main object field (date and time) and number from the results panel (Figure 14).

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[64] https://www.go-fair.org/fair-principles./

[65] https://images.nasjonalmuseet.no/fotoweb/

[66] The last letter and 6 digits are automatically assigned by the Agilent software.

Example: data from examination spot Bk.08 in the painting Woll 366 *Madonna* (NG.M.00841), is stored in the folder 2019-07-02_170010_3000x150. The data is composed of 150 B-scans comprised of 3000 A-scans per B-scan. Therefore, the file for the 82nd B-scan from this spot location is named:

2019-07-02_170010_3000x150_00082.jpg

2.6.3 Conservation-related data

All remaining conservation-related data, condition reports, annotated photos, microscope photographs, pXRF spectra and records of sampling are stored in the NM's collection management database under the painting's NM inventory number.

3. Summary of papers and main findings

The article-based thesis consists of four interlinked studies, all of which are designed and written by the author, and three of which are co-authored. The author's personal experience as a paintings conservator was a major incentive behind the search for practical solutions to the research process. Hence, the conservator's perspective has functioned as one of the central overarching requirements which has helped to guide and underpin the format of the four studies. The papers are arranged chronologically linked to the three main research themes (sect. 1.6.2) with an intended methodological progression. The sequence begins with a historical overview (Paper I) followed by two studies concerning the identification of varnish types (Paper II) and varnish layers (Paper III). Paper IV presents the combined results from papers I–III in a revised varnish survey and feeds into the design for a decision-making model for the NM Munch collection (Figure 04). The common dissemination aim of all four papers is to address a wider cultural heritage community through a varied platform of themes, content and journal publications.

Author contributions are listed at the end of each paper and their participation to the experiments is also documented in the Methodology sections (sects. 2.3.5 and 2.5).

3.1 Summary of Paper I

An integrated conservation approach to a historic collection: the controversial varnishing of Munch's paintings
Ford, T. 2021. In Transcending Boundaries: Integrated Approaches to Conservation. ICOM-CC 19th Triennial Conference Preprints, 17–21 May 2021, Beijing, ed. J. Bridgland. Paris, International Council of Museums.

The first paper is written as a critical, historical conservation overview of the NM Munch collection between 1909 and 2019. The aim of the study is the application of a collective and integrated methodological approach (group case study) for the examination of a single-artist collection of paintings assessed in their historical context. Firstly, it addresses the largely unwritten research status of the NM Munch collection in terms of past 'controversial' varnishing traditions. Secondly, the collective art historical and curatorial display traditions are also contextualised.

Methods of examination include a critical review of a variety of existing archival sources from the 110-year period using an 'object itinerary' theoretical approach. The combined information presents the first systematic and biographical mapping of the NM Munch collection's conservation history. The period 1909–2019 is divided into three sub-periods: Phase 1 Acquisition and display (1909–1944), Phase 2 Post-war restorations (1945–1965) and Phase 3 Conservation and research (1967–2019). The complexity of the non-original restoration varnish layers is discussed in relation to their specific timeframed historical context and the general national context of Munch conservation history. Besides ethical considerations, the high-profile nature of the paintings, the size of the collection and practical aspects concerning accessibility are presented as arguments for choosing non-invasive methods for the identification of varnishes. Emphasis is placed on the importance of incorporating collective conservation histories with future analytical investigations. The group case study approach provides the background and point of departure for the thesis including the three subsequent papers.

The paper was written parallel to the scientific studies (Papers II and III). Its presentation at the ICOM-CC conference (Theory, History, and Ethics working group) was chosen to target a broader professional museum audience dealing with historic painting collections.

3.2 Summary of Paper II

A non-invasive screening study of varnishes applied to three paintings by Edvard Munch using portable diffuse reflectance infrared Fourier transform spectroscopy (DRIFTS)
Ford, T., Rizzo, A., Hendriks, E., Frøysaker, T., and Caruso, F., *Heritage Science* 7, 84 (2019).
https://doi.org/10.1186/s40494-019-0327-1

Paper II is the first of the two empirical scientific studies featured in the thesis. It explores the suitability of using portable infrared Fourier transform spectroscopy (pFTIR) as a screening method for the identification of the restoration varnishes applied to the NM Munch collection. Given the size of the collection, emphasis is placed on the evaluation of non-invasive analytical methods. Although FTIR is a well-established benchtop technique used in conservation, its employment in the field with new portable devices still requires scientific evaluation, namely in the form of in-situ case study examples for the chemical characterisation of varnishes in paintings. The experimental study tested the NM's Agilent 4300 pFTIR spectrometer (Matriks AS, Oslo, Norway) in DR mode (DRIFTS) on three Munch paintings with different varnish histories: *Night in Nice* (Woll M 224), *Flower Meadow Field* (Woll M 148) and *Hans Jæger* (Woll M 174). Spectral data are compared with a reference library of standards created from the museum's past historic restoration varnish recipes.

The research presents the first coordinated varnish analysis of the NM Munch collection, and the paper concludes with an assessment of the practical benefits and limitations of the instrument and technique. The relevance of the findings contributes to current discussions concerning the feasibility of using non-invasive tools for the examination of easel paintings.

Paper II was presented at the 2018 IRUG (Infrared & Raman Users Group) 13 conference in Sydney and published as part of the conference special issue in the *Heritage Science* open access journal. One of the overarching aims of the study was to engage both the scientific and conservation communities in discussions concerning the conservator user-friendly aspect of novel, non-invasive types of analytical equipment.

3.3 Summary of Paper III

Munch and optical coherence tomography: unravelling historical and artist applied varnish layers in painting collections

Ford, T., Iwanicka, M., Platania, E., Targowski, P., and Hendriks, E., *The European Physical Journal Plus* 136, 899 (2021). https://doi.org/10.1140/epjp/s13360-021-01758-5

This paper represents the second non-invasive scientific study and concerns the identification of varnish layers in the Munch collection. In contrast to Paper II, 13 paintings were examined, and optical coherence tomography (OCT) was used as the diagnostic tool for the visualisation and spatial location of the semi-transparent and transparent layers (varnishes). The study represents the first of its kind in terms of employing OCT on a collection of Munch paintings dated between 1884 and 1900. OCT scans are used to provide virtual cross-sections of the varnish layers and some of the results are also assessed in combination with pigment identification from the same locations using pXRF.

The aim of this study was to build on, and incorporate, information acquired from archival and scientific data discussed in the previous two papers. The selection of paintings mirrors the collection's complex conservation history in terms of different types of restoration varnishes and changes to original surface finishes. Three categories were established in terms of Munch's painting style and technique and examples of paintings with Munch's own use of varnish were included (*The Sick Child*, Woll M 130). In addition, the OCT scan results from the varnished surfaces were compared with two unvarnished and unrestored paintings (*Self-portrait with Cigarette*, Woll M 382 and *The Scream*, Woll M 333). This study also employs a group case study approach. This collective perspective is assessed in relation to the collection's art historical and display context in terms of The Munch Room.

OCT as a non-invasive diagnostic method is critically reviewed in the paper and the study contributes to the existing body of OCT research in terms of its relevance and application to the field of conservation. The research was published as part of the inArt 2020 conference special issue. Findings from four of the paintings were used in the testing of the decision-making model discussed in Paper IV.

3.4 Summary of Paper IV

Bridging the gap between the Munch Room display and the conservation narrative: a decision-making model

Ford, T., Frøysaker, T., and Hendriks, E.
https://www.ijcs.ro/public/Munch2022_Book_of_Abstracts.pdf

The fourth paper draws on the documentation and findings assimilated from the first three papers. The study has a dual aim: firstly, the creation of an updated and revised varnish survey of the entire NM Munch collection and secondly, the design for a conservation decision-making model. The non-original restoration varnish layers are discussed in context to the NM's Munch Room display traditions and its recreation in the new museum building, opening 11 June 2022.

This paper explores the suitability of using current model systems designed for contemporary art and adapting them to fit more traditional and historic collections. The proposed design for the Munch collection incorporates a revised version of a recent flowchart model presented by the Cologne Institute of Conservation Sciences in 2019. The study also discusses the challenges of creating a framework relevant for individual paintings in terms of their collective display context, manifest in the Munch Room.

The theory based on 'object itineraries' used throughout the thesis is employed in the creation of an extra mapping tool, the Munch Room module. The study includes an evaluation of the prototype model through the testing of four paintings and the assessment also addresses the adaptability of the prototype model for similar types of collections.

The practical impact of Paper IV is targeted at the wider museum community and the study was presented at the Munch 2022 conference in Oslo (*Understanding Munch and the Art at the Turn of the Centuries Between the Museum and the Laboratory*, 21–23 March).[67]

3.5 Summary of the main findings

The following summary provides an outline of the main methodological and physical findings concerning the varnishes from the four interlinked papers, related to the thesis's two main aims (see sect. 1.6.2). A more in-depth and detailed overview of all the results generated from the research are incorporated in the main discussion (ch. 4).

3.5.1 Summary of findings concerning knowledge on varnishes: aim 1

In Paper I, the group examination of the NM Munch collection's conservation historical context and archival material identified three distinct and separate phases of conservation and varnishing between 1909 and 2019. Furthermore, the conservation narrative of the entire NM Munch collection was found to act as a historical marker for the general progression of Munch conservation at the museum and in Norway.

[67] https://www.hercules.uevora.pt/THE_SCREAM/conference/.

A key outcome from the OCT presented in Paper III was the uncovering and mapping of Munch's original transparent (varnish) layers in five varnished paintings and in two unvarnished paintings, all dated between 1884 and 1900. These discoveries were supplemented by the important IRR uncovering of underdrawings in *Madonna* (Woll M 366) and *The Dance of Life* (Woll M 464) (Appendix 7.2).

The overall findings from the visual examinations and imaging techniques helped to create a revised survey with a more historically objective interpretation of the varnishes and their methods of application.

1. Between 1891 and 1993, over three-quarters (44 out of 57) of the Munch paintings were found to have been varnished and/or revarnished by the museum with either a mastic, dammar (natural) or ketone (synthetic) resin (Figure 15).
2. Seven different varnish types and mixtures are documented including the use of a wax-varnish paste to locally matt down surfaces in four paintings.
3. A total of 26 paintings are also recorded as having had only one varnish type applied, six with two and only one painting with three.
4. The remaining 13 paintings were confirmed as unvarnished.

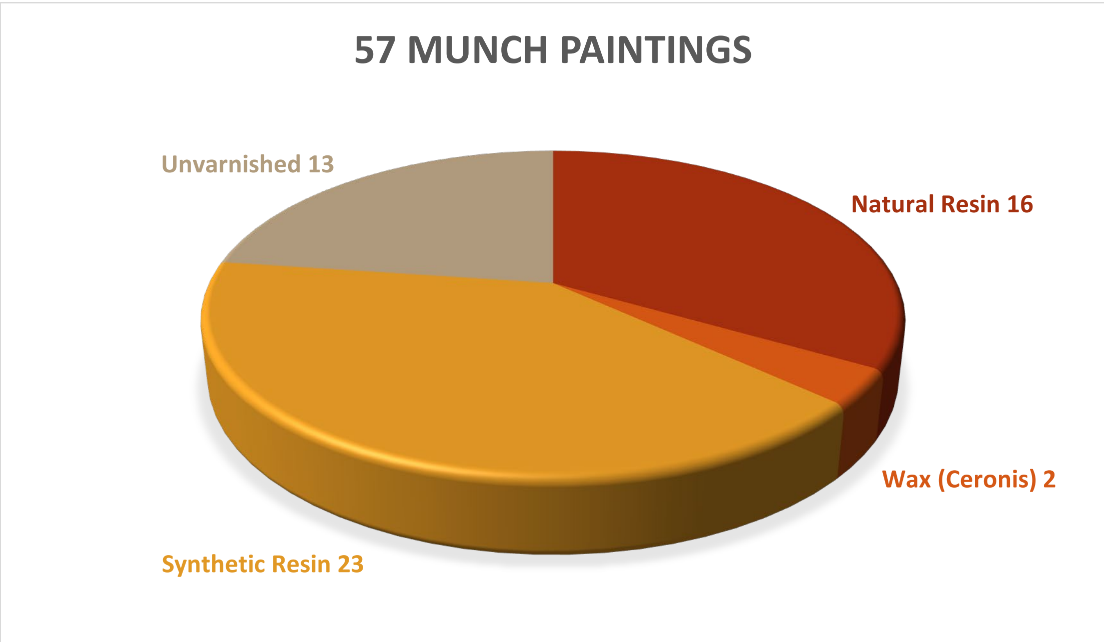

Figure 15. Pie chart showing the proportion of varnished paintings in the NM Munch collection

3.5.2 Summary of methodological findings: aim 2

The findings from Paper I demonstrate the advantages of a group case study approach. It provided a broader historical and interpretative perspective as to why, what type and when the various restoration varnishes were applied to the Munch paintings. Both Papers I and IV confirm the benefits of using the 'object itinerary' theoretical framework for the interpretation of artworks in flux. In the decision-making model, this methodological approach proved useful for the visual mapping of a painting's conservation narrative in context to the Munch Room's configurations over time.

The results generated from the two scientific studies (Papers II and III) confirmed the suitability and potential of using pFTIR combined with OCT as viable non-invasive methods for preliminary screening of varnishes in large paintings collections. FTIR spectral results acquired from three different paintings were able to confirm the positive identification of either a natural or synthetic resin in the upper surface layer. Furthermore, the technique helped to uncover a discrepancy between a varnish ketone resin documented in the condition dossier of *Night in Nice* (Woll M 224) and the lack of its physical presence on the painting. The importance of creating a reference library of standards was crucial for the interpretation of the FTIR spectra.

The practical benefits of OCT for the non-invasive screening of varnishes in paintings was reaffirmed with the identification and documentation of transparent and semi-transparent layers present in all the 13 paintings examined.

In Paper IV, the creation of the decision-making model proved useful as a platform for registration and fusion of historical and scientific data from the revised varnish survey. Moreover, the study showed that decision-making strategies for historical collections are not so dissimilar to those used for contemporary art. Both aspects can be tailored to create useful conceptual tools for the mapping and management of change in groups of paintings.

4. Discussion

The discussion of the findings from the four studies are presented chronologically and according to the sequence of the three research themes and the hypothesis: firstly, the group case study approach (sect. 4.1), secondly, the non-invasive methods (sect. 4.2) and thirdly, in terms of decision-making (sect. 4.3). The findings are evaluated in relation to previous and recent research, relevant methodological issues, and the practical and theoretical assessments of the tools and strategies used. Each section is also assessed in relation to the overarching theoretical framework of object itineraries. Finally, the limitations of the thesis are raised (sect. 4.4) and the impact of the research in terms of future perspectives is presented in the last section (sect. 4.5).

4.1 The impact of a group case study approach

In terms of the NM Munch collection's conservation history, previous studies on the paintings have presented useful vignettes concerning the individual biographies of early NM conservators (Rød 1993; Rød 1997; Skaug et al. 1999) or served as selective in-depth case studies of paintings (Aslaksby 2009; Aslaksby 2015; Plahter and Plahter 2015). However, this thesis has chosen to build on and depart from the past soloist tradition. Instead, the current research has shifted the focus to encompass a more collective and group case study approach to tackle the NM Munch collection's largely unwritten conservation history.

In Paper I, the mapping of the NM Munch collection's conservation history between 1909 and 2019 provided a broader historical context for the discussion and interpretation of the non-original restoration varnishes identified. This approach helped to trace the shifts in perception and attitudes of the conservation department regarding the paintings. It also recorded the institution's trends and display traditions which are manifest in the Munch Room concept. The benefits gained from establishing an overview of an institution's conservation narrative follows suit with parallel research concerning restoration varnishes present in similar high-profile artists, such as Van Gogh (Hendriks and Vellekoop 2019; Hendriks 2022) and Rembrandt (Duijn 2021a; Duijn and Noble 2021; Schmitt 2021). This contextual approach help conservators to acquire a more critical reflection of conservation choices made by their predecessors in light of the historic timeframes and present-day practices (Schmidt 2021: 105).

The NM Munch collection's 110-year historical varnish period is presented through the group's conservation narrative divided into three phases: Phase 1 Acquisition and display 1909–1944, Phase 2 Post-war restorations 1945–1965 and Phase 3 Conservation and research 1967–2019. This approach helped to identify a series of previously undocumented conservation-related patterns particular to each phase. Historical links between the application of restoration varnishes and shifts in NM's conservation philosophy were established.

4.1.1 Phase I Acquisition and display (1909–1944)

The historical context from the first phase reveals a museum varnish policy that was essentially the outcome of an aesthetic criterion in terms of display. The NM's early approach to varnishing is largely confirmed through director Thiis's mission to both represent and promote Munch as part of the national collection (Berman 2013; Messel 2022). In this light, the early varnishing can be understood as being on a par with Thiis's general upgrading of the Munch paintings. For example, the replacement of Munch's makeshift original wooden frames with the new ornate gilded ones for his new display (Ford 2022) (Appendix 7.3, Figures 21–30). Both these aesthetic policies can be interpreted as deliberate attempts to ensure Munch's position and the acceptance of his paintings in a museum environment, which was in keeping with the display standards of the existing collections. Hence, the '1909 controversial' varnishing of the NM Munch paintings (Stein and Rød 2015) were possibly due more to the consequences of the director's choice rather than solely that of the conservator. Placed in this historical context, the general varnish disagreements documented between conservator Brun and Thiis (Rød 1996) also mark the beginning of the paintings conservator's struggle for recognition and a seat at the museum's decision-making table. Moreover, it reflects the early emerging voice of conservation in Norway.

In comparison with neighbouring institutions, early 20th-century conservation decision-making at the NM was far from democratic. There is no archival evidence to suggest that aesthetical treatments such as cleaning and varnishing involved a special committee, customary at major European national museums (Blewett 2016; Étienne and Grevet 2017; Betelu and Jouves 2021;

Duijn 2021b). Instead, the historical sources portray an authoritative director upholding the institution's tradition for periodic cleaning and varnishing routines (Willoch 1937; Rød 1993).

Findings from the historical context also revealed that the two conservators employed between 1909 and 1944 (Harald Brun and Dørje Haug) were aware of Munch's experimental painting techniques. Brun, a conservator and established painter himself, contacted Munch on several occasions concerning the restoration of his paintings (Paper I). Whereas Dørje Haug's respect for Munch's matt surface finishes is documented during his early work experiences with the artist on the monumental Aula paintings (Rød 1997; Frøysaker 2008). Haug's approach is further reaffirmed through comments made during his later responsibilities for the bequeathed collection of paintings from Munch's Ekely estate in 1944 (Rød 1997; Strand Ferrer et al. 2019: 131).

4.1.2 Phase 2 Post-war restorations (1945–1965)

In the second historical phase post-WWII, the first condition reports were introduced at the NM and the earliest Munch report dates from 1949 (Figure 05). These help to provide a clearer insight as to why paintings were varnished and with what type of resin. The early documents essentially confirm the NM's continued use of traditional natural varnish resins from the first phase, namely mastic and dammar, both of which feature in Brun's early studio recipe book (Appendix 7.5). However, six of the reports also record the introduction of a new commercial matt picture varnish mixture, *Becker's tavel matt ferniss* (Becker 1955; Becker 1965) (Paper IV).[68] The natural resin varnish was used during a short period in 1950. Conservation reports confirm that it was applied to four of the later dated paintings (1915–1919) and two of Munch's thinly painted compositions with dominant areas of exposed ground (*Rue Lafayette*, Woll M 232, and *Julius Meier-Graefe*, Woll M 343, Appendix 7.5, Figure 40).

The varnish recipes dating from the second phase include several matt varnish options (Appendix 7.5, Figure 35) and many of the post-WWII conservation methods and treatments

[68] Wilhelm Becker's (Stockholm) matt *tavel* varnish (*ceramatt*/matt *tavelfernissa*) was used on 6 Munch paintings between March and May 1950. The Swedish picture varnish is a mixture of dammar and mastic with bleached beeswax in balsam turpentine (Becker 1955; Becker 1965).

noted in the NM's studio recipe book are taken from Morton Bradley's book on the treatment of pictures (Bradley 1950). In the dammar recipe applied in 1958 to the small study *From Vestre Aker* (Woll M 17), the addition of bleached beeswax is documented in the report as a measure to reduce the overall gloss (Paper IV). Furthermore, Bradley's publication mentions several wax mixtures and wax application methods as a matt alternative to the traditional varnish resin coating (Bradley 1950: 101–102, 105). The use of wax as a protective layer is known to have also been used by artists, such as Gauguin, at the turn of the century (Carol 1993: 92). According to Ravensberg, Munch was aware of Gauguin's use of wax in 1910, but his scepticism of the approaches of Thiis and Bruns to complete varnishing led him to recommend the partial use of a retouching varnish instead.[69]

In 1954, a locally applied Ceronis[70] matt wax-resin varnish paste was applied to the surfaces of *The Sick Child* (Woll M 130) and *Inger in Black* (Woll M 113) (Paper IV). Both paintings are documented as having traces of Munch's own use of a locally applied varnish (Aslaksby 2009) (Paper III). This selective adjustment of surface gloss suggests a careful attempt to uphold the intended interplay between matt and saturated passages in two of the most complex compositions, rather than a blatant misinterpretation of the paint surfaces through controversial varnishing.

In general, the post-WWII documentary evidence of the early use of matt varnish types, suggests a more nuanced approach to varnishing by the NM conservators. It can be interpreted as a conscious attempt to respect Munch's varied surface saturation effects and a move away from using thick glossy mastic coatings applied to the whole paint surface, such as the varnishes used in *Spring* (Woll M 173). Moreover, many of the paintings were in a fragile condition after their return in 1946 from the Kongsberg mines evacuation site (Paper I and Ford 2022). Despite claims made by Dørje Haug of stable climatic storage conditions in the silver mines (Rød 1997), the 43 Munch paintings were unframed and packed into 32 wooden crates, without insulation

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[69] Munch Museum, LR 541, 02.09.1910.

[70] LeFranc & Bourgeois Ceronis is a matt wax-varnish paste for paintings sold in 60 ml tubes. The exact content has not been chemically confirmed but, from undated sales catalogues, the varnish appears to be 28% wax (drying extract) dissolved in petroleum (unknown quantity). See Lefranc's Technical Guide for Oil Painting: Retouching Varnishes, Picture Varnishes, https://fliphtml5.com/mjoa/gfiy/basic (accessed 14.01.2022) (see also Appendix 7.5 Figure 37).

and mixed with other paintings according to their size (Appendix 7.4). The prioritised evacuation lists also reveal which paintings in the collection were deemed as the most valuable post-WWII. The status of certain motifs is also reflected in the earlier Munch wall configurations, where *Self-portrait with Cigarette* (Woll M 382) is central to the display until the formation of the 1924 Munch Room (Appendix 7.3, Figures 21, 22 and 24).

There are also theories that varnishing was used as a method to consolidate areas of matt powdery paint (Aslaksby 1988; Strand Ferrer et al. 2019). Furthermore, varnishing provided the ideal basis for achieving control over the final surface finish of a newly restored painting. The practical benefits of varnishing a painted surface after restoration perhaps accounts for the varnishing of 12 paintings during this period, all of which were linked to major structural treatments (Appendix 7.1). Many of the paintings (varnished and unvarnished) were also retouched using Lefranc's couleurs de muzii tempera paints to achieve the differences in surface gloss (Appendix 7.5, Figure 38).

The NM's activities between 1945 and 1965 show that varnishing Munch paintings had progressed from being part of an essentially longstanding routine tradition for display purposes to becoming more of an integral part of complex conservation treatments.

4.1.3 Phase 3 Conservation and research (1967–2019)

In retrospect to the publication of Paper I, the third historical phase should ideally be more precisely confined to the period 1965–1999, spanning Leif Plahter's term as head of conservation (Skaug 1999). However, findings from the third period, as delineated in the publication, reveal that the NM Munch collection continued to function as a barometer for the evolution of the institution's varnish practice. In the revised varnish survey (Paper IV) there is evidence of Plahter's early experimentation with a synthetic ketone varnish resin (MS2A). It was applied in 1960 to the painting *Study of a Head* (Woll M 98). This demonstrates Plahter's awareness of the new class of products available, some of which were developed specifically for conservation purposes (Phenix 1995; Fisher 1998). These were marketed as more stable alternatives to the traditional natural resins in terms of discoloration and solubility (sect. 1.3). In practical terms, the versatility of the new resin type may also have proved to be more easily adjustable to match differences in paint saturation. Experimentation with the gloss effect was undertaken by Plahter's early range of varnish mixtures. These were made up according to a coded matt/gloss factor from 1 to 9, which was determined by the wax content dissolved in each solution (Appendix 7.5, Figure 36). This range of ketone varnishes was employed as a standard at the NM until the mid-1990s.

In addition to the introduction of synthetic varnish resins, the third conservation phase reflects a new shift in the NM's varnishing philosophy. When assessed collectively, the varnishes applied to Munch paintings between 1967 and 1993 appear to have been intended as a preventive measure rather than an aesthetic one. There is also sufficient evidence from the condition reports and visual investigations to confirm a varnish policy which was possibly more in tune with Munch's matt surface finishes. Many of the reports describe the use of matt and thin sprayed coats of ketone varnish types which are visually more sympathetic towards this aim. For example, in the portrait of *Thorvald Løchen* (Woll M 1256), the thin ketone varnish from 1978 not only appears extremely matt, but it is also difficult to visually detect in normal light without confirmation from UVA-induced photography. Despite the varnish having aged with decreased transparency, the thin spray application appears to have always lent a subtlety in surface appearance.

The poor indoor air quality at the NG[71] and general pollution levels recorded in Oslo during the 20th century (Grøntoft et al. 2019) probably also influenced the use of varnish as a means of extra protection for the paint surfaces. Towards the latter part of the century, the introduction of non-shatter, low-reflective laminated glass gradually replaced this preventive function and provided an additional shield against physical damage, especially during transportation.[72] Between 1992 and 2001, 38 Munch paintings were glazed, most in conjunction with preparation for loans (Appendix 7.1).

Stein and Rød's interpretation of Plahter's varnishing describes it as purely based on aesthetic reasons (Stein and Rød 2015: 226). However, when assessed in a historical context, the

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[71] The damaging effects of indoor pollution caused by the NG's coal central heating furnace were noted in 1920 (NM archives; 27.3.1920. NMFK/NG-0011/A).

[72] Most of the Munch paintings were glazed with low-reflective Mirogard laminated glass (DESAG, Germany) with a UV filter. Low-reflective Amiran glass (Schott, Germany) was used for larger paintings. The NM now uses anti-reflective Optium Museum Acrylic® (Tru Vue, USA).

application of new and more stable synthetic varnishes appears to have also been part of a conscious approach to increase surface protection and reversibility prior to the introduction of specialised glazing. Furthermore, the revised varnish survey in Paper IV shows that the types of varnishes applied and their way of application was in keeping with Munch's varied surface effects and finishes. All the Munch paintings after 1971 were documented as revarnished, inferring the presence of an earlier varnish. The exception was the final painting to be varnished in 1993, *Self-portrait with Spanish Flu* (Woll M 1296). Thus, the NM's final campaign of varnishing (1979–1993) can be interpreted as more of a sympathetic adjustment of previously varnished surfaces rather than an ad hoc and controversial policy.

The reconstruction of the NM Munch collection's conservation history outlined in Paper I, provides additional information about the institution's conservation department and the general progression of Munch conservation in Norway. The second half of the 20th century witnessed a gradual increase in the NM conservator's autonomy and recognition of conservation as a discipline within the museum. This is reflected by the early technical and scientific examinations undertaken at the NM, the majority of which focused on Munch paintings (Plahter and Plahter 2015). Shifts in conservation policies and trends towards a more restrained approach are also noticeable in the Munch conservation dossiers. For example, no major structural inventions, such as lining treatments, were carried out after 1971. This probably coincides with rising international criticisms of lining methods and Plahter's attendance at the 1974 Greenwich conference that foreshadowed the moratorium on wax-resin lining (Villers et al. 2003).

The collective group study of the Munch paintings helped to evaluate the second public 'varnish controversy' which consisted of a series of accusations made by the Munch Museum (MM) to the NM in 1980 (Stein and Rød 2015) (sect. 1.4). Towards the latter part of the 20th century, there already existed an unspoken rivalry between both institutions which may have been fuelled by the post-war international spotlight on Munch and rise of iconic motifs such as *The Scream* (Paper IV and Ford 2022). In response, the two museums tried to assert themselves as centres of expertise in the wake of Munch research. Both the MM's version of *The Scream* (Woll M 896) and *Madonna* (Woll M 365) were assumed to be Munch's first versions of the motifs and have been previously catalogued by the MM as such (Eggum and Christophersen 1984; Woll 2008). However, questions concerning the chronology of the two versions of *The Scream* owned by the respective museums prompted Unn Plahter's seminal study on the identification of different cadmium yellow pigments found in the two paintings (Plahter and Topalova-Casadiego 2011; Plahter and Plahter 2015). The early scientific investigations initiated in 1974, not only led to the later confirmation of the NM's *Scream* as the first version, but it also places the NM as the first institution to undertake in-depth scientific research on a Munch painting. Despite these early results, the chronology of the *Scream* versions was contested until 2001 (Lange 2005) and that of the *Madonna* was only resolved with the IRR investigations carried out during this research (Paper III). Thus, when placed in a broader historical context, the 1980 varnish accusations made by the MM were perhaps no more than a brief exchange of personal criticisms between two former colleagues (Thurmann-Moe and Leif Plahter) rather than a full-blown public outcry. It can also be understood as a timely promotion of the former MM's head of conservation's 'kill or cure' theory (Thurmann-Moe et al. 1995). With the retirement and shifts in both curatorial and conservation staff, these institutional rivalries quickly disappeared after 2001. Moreover, the past and present engagement for the preservation and recreation of the anachronistic Munch Room display concept appears to have invited a comparatively more heated public debate than that of the two 'varnish controversies' (Paper IV).

In reference to the first research theme, employing a group case study approach provided a broader view of the NM Munch collection and its conservation history. It also invites a more objective perspective as to why paintings were varnished, when, and with what material. This overview would not have been feasible through a purely soloist, case-by-case approach. Furthermore, the concept of 'object itineraries' helps the conservator to build a mental map of a painting's individual conservation trajectory in relation to the overarching narrative of the whole collection. The theoretical approach also provides a contextualised perception of the restoration varnish layers in terms of their biographical significance. This notion draws parallels with the recently explored research concept of understanding the 'artwork as (an) archive', whereby the importance of the changing physical object is measured alongside archival data (Wielocha 2021). Finally, the critical interpretation of the Munch paintings in their collective and historical context resonates with Bomford's recommendation that past conservation should be viewed through the eyes of the period as well as the present (Bomford 2003; Bomford 2017).

4.2 A non-invasive approach

The second of the thesis's three research themes concerns questions related to the identification of the restoration varnishes. The two non-invasive diagnostic studies explored in Papers II and III demonstrated the potential of combining pFTIR with OCT as a means for scientific identification. Despite the focus on two smaller subgroups from the collection, the methods proved valuable as preliminary 'screening' techniques. The pFTIR and OCT instruments and methodologies were chosen for their practical advantages in terms of their non-invasive stance, namely gaining unrestricted access to the entire paint surface and the ability of taking multiple readings with good reproducibility (Miliani et al. 2010; Legrand et al. 2014; Brunetti et al. 2016). However, prior knowledge of past restorations combined with the pre-surface examination (UVA and microscopy) was shown to be essential for the interpretation of the findings from both techniques. For example, the use of standards for the UVA-induced photographic surface fluorescence helped to provide a viable comparative visual overview of varnished and unvarnished surfaces. Consequently, the CHARISMA guidelines (Dyer et al. 2013) have now been implemented as the norm for UVA-induced photography of paintings at the NM. The practical impact of the UVA-induced photography also functioned as a useful preliminary varnish guide for the selection of relevant areas for the non-invasive surface examinations.

4.2.1 Screening of varnishes: pFTIR

pFTIR was the first of the two diagnostic techniques tested as an experimental pilot study for the identification of the upper restoration varnishes in a selection of three representative paintings (Paper II). Given the unfamiliarity of the Agilent equipment and its employment on paintings in a diffuse reflectance mode, the study demonstrated the reliance on a varnish reference library as recommended by similar research (Arrizabalaga et al. 2014). This facilitated the deciphering of complex spectral data generated by the typical interference associated with overlapping absorption bands assigned to either pigments or the oil binding medium in each reading (Miliani et al. 2012). A prominent peak at 2088 cm^{-1} was observed in the spectra from all three paintings which can be attributed to the pigment Prussian blue. Other pigment-related overlapping bands, which masked the overall clarity of the varnish spectra, include the strong signals from lead white. These were particularly noticeable in the smoother and glossier surface readings from the painting of *Hans Jæger* (Woll M 174). Nevertheless, comparisons with the recreation of historical varnish solutions proved valuable for the interpretation process in this study. However, the creation of a useful library of varnish resin standards might not always be feasible and remains dependent on the historical varnish knowledge of the institution. Furthermore, due to the timeframe of the study, the historical varnish solutions tested remain limited to the three paintings examined and the samples applied to glass slides were not artificially aged.

The benefits of the Agilent instrument used in a DRIFTS mode were confirmed by the positive alignment of pFTIR spectral results with the varnish reference standards in two out of the three paintings tested. Both the natural resin varnish identified in *Hans Jæger* (Woll M 174) and the synthetic one in *Flower Meadow Field Veierland* (Woll M 148) corroborate with the mastic and ketone (Laropal K80) varnishes documented in the paintings' respective condition reports. Despite the non-invasive stance of the study, some comparative microinvasive analysis from a small selection of samples was regarded as necessary for the additional validation of the pFTIR method. Using a set of established analytical benchtop research methods for varnish identification – FTIR (ATR), THM-GC/MS and microscopy – it was possible to further substantiate the pFTIR spectral results. This multi-analytical approach was particularly useful with the third painting, *Night in Nice* (Woll M 224) for the clarification of a discrepancy between the Larapol K 80 (ketone) varnish resin noted in the condition report and the actual varnish present on the surface. Both the microinvasive analytical techniques and the pFTIR spectra confirmed the presence of a natural resin varnish (Paper II). This result demonstrates the capacity of pFTIR as a viable diagnostic technique for the differentiation between natural and synthetic upper varnish layers in paintings.

From a conservator's perspective, the experimental study showed the practical benefits of the Agilent pFTIR spectrometer. These include the ergonomic and lightweight design of the instrument facilitating its use in situ. Spectral data were also easily acquired and rapidly possessed through the software which renders the spectrometer on a par with similar off-the-shelf handheld instruments. When used with a tripod-supported device it provided a stable and conservator user-friendly instrument for the safe surface examination of easel paintings.

The outcome of the study in Paper II does not recommend the Agilent pFTIR spectrometer to be used as a standalone method for the conclusive identification of varnish resin types.

Moreover, the clarity of the spectral results appears to be influenced by pigment content, surface topography and thickness of varnish layers (Paper II: 9). However, the overall findings from the research have provided sufficient evidence for the instrument's suitability as a viable tool for the preliminary non-invasive 'screening' of varnishes in easel paintings. Furthermore, when used in combination with supplementary analytical techniques, pFTIR can be employed as a non-invasive method to assist with a more precise and targeted microinvasive sampling (Burnstock 2017: 47–48).

4.2.2 The revealing of hidden layers: OCT

The application of OCT as a non-invasive diagnostic technique proved extremely useful in terms of substantive results. Unlike the pFTIR study, OCT was not used in an experimental capacity. The suitability of OCT as an established diagnostic technique for the virtual cross-sectional imaging of varnish stratigraphy, thickness and spatial distribution across a paint surface for varnish identification is supported by a large body of research (Targowski et al. 2020).[73] However, the contribution of the study presented in Paper III builds on this research. It represents the first comparative OCT examination of varnished and unvarnished paint surfaces across a group of Munch paintings dated between 1884 and 1900.

In two of the unvarnished paintings, the OCT tomograms were able to detect subtleties in Munch's original surface finishes. These results helped to confirm the unevenly distributed transparent (varnish) layer in *The Scream* (Woll M 333) (Aslaksby 2015) and Munch's thicker use of oil medium in certain passages of *Self-portrait with Cigarette* (Woll M 382). The OCT scans were equally instrumental in uncovering evidence of original transparent layers lying beneath restoration varnish layers in five of the varnished paintings. Despite being masked by a later restoration varnish, the confirmation provided by the tomograms strongly suggests the presence of a locally applied artist's varnish. These discoveries are also an indication that Munch's use of varnish in his painting technique is present in more works than previously documented (Aslaksby 2009; Topalova-Casadiego 2012; Wardius 2015). Furthermore, their uneven distribution questions the common interpretation of Munch's authentic paint surface

[73] See also sect. 2.3.5 and http://www.oct4art.eu/.

effects as purely matt (sect. 1.4). The impact of these findings calls for a revised interpretation of Munch's earlier painting technique in paintings dated between 1880 and 1900.

According to surviving historical sources, Munch appears to have preferred his paintings to remain unvarnished and was critical of the glossy mastic restoration varnishes applied by both the NM and other institutions abroad (Stein and Rød 2015). However, the recent evidence from the OCT suggests that these comments probably refer to the application of restoration varnishes which typically cover the entire painted surface. Arguably, they should not be confused with Munch's own varnish effects in terms of an experimentational surface interplay between matt and more saturated, glossy passages of paint. The OCT findings echo Ravensberg's conversation with Munch concerning the original effect of a localised egg-white varnish in *The Frenchman, Marcel Archinaud* (Woll M 578), which he later described as having been destroyed by the NM's restoration varnish (sect. 1.4).[74] Likewise, these might also help to account for Munch's preference for using a retouching varnish (sect. 4.1.2) together with the surviving varnish bottles found at the artist's summer studio in Åsgårdstrand (Gansum and Knudsen 2013) (Appendix 7.6.1). Munch's artistic versatility is recognised through his experimentation with different paint, graphic and photographic media (Bjerke 2008; Topalova-Casadiego 2008; Ustvedt et al. 2009; Ustvedt 2020), and his use of retouching varnishes to enhance the saturation of certain passages may be seen in this light and was not uncommon practice for the period (sect. 1.4).

The OCT findings suggest a period of experimentation in terms of paint technique and surface finish in some of Munch's earlier works. There appears to be a marked difference with the matt surface effect which is more typical and common with Munch's later production during the 20th century. According to Ustvedt (2020), Munch was keen to stay at the forefront of the contemporary artistic progression both in terms of technique and style. Moreover, at the turn of the century (1900–1905), he is known to have ventured into a new direction in terms of painting style (Ustvedt 2020). Munch's craving for avant-garde recognition is reflected through his critical comments towards Jens Thiis's acquisition and display of his earlier paintings at the NM in 1909. In a letter to his friend Jappe Nilssen, Munch described the NM's collection of his mainly post 1900 paintings as 'more of an impression of what I have achieved than what I have

[74] Munch Museum, LR 536, 27.12.1919.

dared and desired – the future world will not be given an impression of what I have wished and experimented within force and purity of colour'[75] (Flaatten 2019: 75).

The OCT results play a valuable role in clarifying Munch's early use of and attitude towards varnishes. They are an indication that varnish was used in his painting technique to locally saturate colours, contours and passages in the composition. Although these original varnish layers still need to be chemically confirmed, their presence echoes the problems that Munch's contemporaries experienced with saturation and the sinking of colours over time when leaving their paint surfaces unvarnished (Katz 1990; Swicklik 1993: 168). The findings from Paper III therefore have critical implications for future conservation and decision-making concerning the removal of the upper layers of non-original restoration varnishes. This is particularly relevant for the paintings of *Puberty* (Woll M 347) and *Madonna* (Woll M 366). Until now, there has been no previous record of original underlying varnish layers in both paintings. Without the OCT examinations, traditional microinvasive cross-sectional samples taken from the edges of the paintings would have given a false indication of the total number of varnish layers present across the entire paint surface. Moreover, in the case of *Madonna*, the combined use of OCT with the newly discovered underdrawings using IRR has also contributed to a greater understanding of Munch's compositional process aligned with his painting technique. In sum, the outcome of the OCT examinations has provided a significant new insight into the current and generalised perception of Munch's paintings as predominantly matt and 'fresco like'. The impact of the study's findings advocates a more nuanced and period-specific interpretation and description of Munch's paint surfaces.

The immediate interpretation of the tomograms was one of the main practical advantages of the OCT technique and it proved to be comparatively easier than that of pFTIR spectra. In addition, the OCT's live-view image facilitated the diagnostic investigation process in terms of acquiring a context to the area analysed. The digital cross-sections (B-scans/tomograms) provide easily comparative information of the surface (varnish) layers present in a painting. The technique also enables the conservator to obtain a digital spatial overview of an entire paint surface, which is more representative than that achieved through a limited number of traditional cross-sections. For example, the OCT tomograms from *Madonna* and *Puberty* helped to provide a more

[75] The National Library, Oslo. Letter collection 604 (PN 724), 24.03.1909, letter to Jappe Nilssen.

realistic and precise overview of multiple and original varnish surface layers in the central passages of a painting's composition which otherwise might prove difficult for physical sampling. A further practical attraction to OCT is the reusability of the technique for different operative stages in the conservation of a painting such as cleaning. The technique's continuum has already been explored with similar types of paintings (Berg et al. 2019) and it will be extremely beneficial for monitoring the removal of the more complex varnished surfaces present in the NM Munch collection.

4.3 Decision-making and data fusion

The final stage of the research serves as the 'point of integration'. This research term is borrowed from the mixed methods approach used in social sciences to illustrate the final stage of data fusion from a diverse set of methodologies towards a common objective (Johnson et al. 2007; Schoonenboom and Johnson 2017). In this research context, it represents the integration of the historical findings from the group case study approach (Paper I) with the results from non-invasive investigations (Papers II and III) (sect. 1.6.2 and Figure 04). The collation of the various types of data are integrated into a revised varnish survey of the entire NM Munch collection (Paper IV).

From a conservator's perspective, one of the main methodological challenges encountered with the use of different investigative methods is the establishment of a suitable platform for the fusion of different data types produced from the various disciplines (Streeton 2017). This raises questions on how to logically select, connect and process the combined results generated from the current research for practical decision-making purposes. In terms of decision-making strategies, Paper IV shows the benefits of incorporating design elements adopted from existing models used for contemporary art. The outcome is a decision-making model which is specifically tailored to the requirements of the NM Munch collection but can be adapted for similar historical collections.

In the Munch decision-making model, the emphasis has been placed on evaluating the paintings both individually (Appelbaum 2010) and collectively using a design tailored to the collection (Ashley-Smith 2017; Wharton 2018). This approach also helped to incorporate the study's biographical perspective (Vall et al. 2011) based on the theoretical concept of ‘object itineraries’ (Joyce and Gillespie 2015).

One of the main practical advantages with the theory of ‘object itineraries’ is the ability to visually present the historical interactions of the paintings, thereby helping the conservator to plot the map of a painting’s individual conservation narrative in relation to the narrative of the group and the Munch Room display concept. Prior to this research, the Munch Room’s display concept had not been systematically documented in terms of display shifts. This inspired the addition of the Munch Room module in the decision-making model which functions as an additional visual aid in the decision-making process. It creates a platform for the interpretation of the individual and collective historical context of the Munch paintings. Using a basic timeline design, derived from the ‘map of interactions’ concept (Lawson and Marçal 2021), it was possible to simultaneously plot the historical shifts in conservation with those of the Munch Room between 1909 and 2019. This extra visual design aspect, referred to as the Munch Room module, proved extremely useful in documenting the relationships between the changing physical form in artworks and social historical context during the various stages of interpretation. Thus, the impact of this conceptual tool is both relevant for the conservator and the curator. Although, the prototype model is ‘collection specific’ and remains to be fully implemented across the whole Munch collection, its viability as a suitable decision-making process was confirmed through the four test paintings.

Another design feature of the Munch decision-making model that was inspired by models for contemporary art is the inclusion of a wider group of decision-makers consisting of custodians (museum staff) and stakeholders (public). Although the more critical conservation-related choices should ideally remain with the custodians (Spaarschuh and Kempton 2020), the participation from the public introduces a more transparent and interactive approach towards decision-making. This perspective addresses the principles of ‘intersubjectivity’ and ‘semantic sustainability’ insofar as decisions can be considered by a broader audience in terms of the current and future meanings of the paintings (Muñoz Viñas 2005; Muñoz Viñas 2020: 112). Hence, a more balanced approach will assist future discussions concerning which restoration varnish layers to remove and which to keep in terms of their relevance as historical markers versus their aesthetical impact.

In sum, the strengths of the decision-making model as a conceptual tool are fourfold. Firstly, it provides a visual mapping and structure for the interpretation of the paintings' trajectories, which is in line with changes in the museum's collective and historical display context over time. Secondly, it incorporates the perceptions from a wider audience (stakeholders and custodians). Thirdly, it produces a flexible decision-making template which can easily be adapted for similar collections both within and outside of the NM. Finally, the model provides a platform for the integration and fusion of different types of data generated from the interdisciplinary research approach.

4.4 Limitations

Physical access to the paintings on display in the Munch Room at the NG was limited during the first year of the study until the closure of the NG in January 2019.[76] Thereafter, seven paintings from the room were sent to a separate Munch exhibition in Bergen (6 September 2019–19 January 2020) (Sandvik and Daatland 2019). The physical examination of the paintings was further restricted by the COVID-19 lockdown disruptions which occurred between 16 March and 15 May 2020. Additional limitations, in terms of access to relevant archival data, were also experienced. These included the permanent closures of both the NM and MM libraries and archives between 2019 and 2021 due to their successive relocations to new premises and COVID-19 restrictions.[77] All these unforeseen limitations had a challenging impact on the chronology of data acquisition. As a practitioner, it was important to establish and implement a logical sequence for the integration of historical documentation combined with the renewed visual observations and processing of the scientific data. However, in practice, the real-time sequence of the research and the progression of writing of papers was affected by these logistical limitations. In some instances, this affected the early interpretation of the total number of varnished paintings in the collection and accounts for these initial discrepancies in Papers I and II with Paper IV.

[76]All the paintings in *The Munch Room* are protected by a sheet of protective glass integrated into their historic frame which limited the feasibility of in-situ examinations in the exhibition room itself.

[77] The NM library and archives closed in December 2019 and were not made accessible again to the museum staff in the new building until April 2021. The MM's library and archives were closed to the public from 1 July 2019 to 26 October 2021.

The main challenge with pFTIR as a technique was the interpretation of the spectral data related to the heterogeneous structure of paintings. This produced complex overlapping absorption bands generated from strong pigment and medium interference from the upper paint layers or due to possible pigment migration into the varnish layers (Sutherland 2003; Poli et al. 2017). Unfortunately, the scope of the research could only allow for the reference library and the depth of penetration tests to be performed on single varnish layers, instead of a more scientifically representative, multilayered pigment, binder and aged varnish 'mockup' (Stoveland et al. 2021). A further disadvantage encountered with pFTIR when employed in diffuse reflectance (DRIFTS) was the inability to obtain spectral readings from black pigmented passages. This imposed limitations for the investigation of varnishes in a dark painting such as the background in *Inger Munch in Black* (Woll M 113). Despite these drawbacks, the advantages of the equipment and technique have been envisaged for the further screening of varnishes in the entire NM Munch collection.

Although, there are some commercially available OCT instruments for cultural heritage use,[78] OCT is still less of an 'off-the-shelf, plug and play' instrument compared to pFTIR and pXRF. In addition, it requires specialised trained expertise in terms of equipment use and the post processing of the tomograms. In retrospect, OCT should ideally have been used prior to the pFTIR investigations in terms of the sequence of diagnostic techniques. Thus, the pre-stratigraphical knowledge from OCT tomograms would have guided a more precise selection of pFTIR examination spots as demonstrated in the FTIR/OCT coordinated campaign for Van Gogh's *Sunflowers* (Berg et al. 2019).

One of the shortcomings with the conservation decision-making model lies with the design of the Munch Room module. The interactive timeline presented in Paper IV is based on a simple prototype developed in Adobe Photoshop. For a more effective comparative visualisation of the entire collection of 57 paintings, the design format would benefit from a computerised data simulation of all the timelines. The implementation of the module was therefore restricted to four paintings and is yet to be tested on the entire collection and in context to the NM's new exhibition spaces.

[78] https://www.thorlabs.com/.

4.5 Future perspectives

The beneficial outcomes of the research and its implications for the NM Munch collection and to the field of conservation in general, have already been outlined in the main discussion. However, several of the main overarching methodological issues deserve to be highlighted in terms of their potential for future research.

Firstly, the success of the pFTIR experimental study on three paintings has initiated subsequent non-invasive screening of varnishes from a larger section of the NM Munch collection. These additional pFTIR results are to be assessed alongside the OCT tomograms in a forthcoming publication, which is intended as a continuation of the PhD study. In addition, the establishment of a practical methodological approach and newly created reference library of varnish standards for the equipment now makes this method more attractive for the varnish identification in other paintings and collections belonging to the NM.

Secondly, the discovery of Munch's localised use of transparent and semi-transparent layers has raised important questions concerning his known use of locally applied artists' or retouching varnishes. The research has unveiled a definite ambiguity in Munch's intended surface finishes in paintings from the 1880s and 1890s. It also provides added scope for comparative studies with a range of artists from the same period in Norway and abroad. Both Harriet Backer (Lange 2003) and Van Gogh (Jooren 2013) are just two examples of such artists contemporary to Munch. Consequently, these new findings have already generated further and ongoing research into this phenomenon. Based on the OCT results from the seven Munch paintings discussed in Paper III, a more conclusive sampling of Munch's use of varnishes is scheduled. Moreover, the unevenly distributed transparent (varnish) layer found on *The Scream* (Woll M 333) has recently been identified as one of the major causes of the painting's light-induced colour change (Thomas 2020).

Since the planning of this study, the NM Munch collection has been relocated in the new purpose-built museum and the curatorial display has changed slightly compared to that of 2019. In addition to the revised selection of 18 paintings displayed in the newly recreated Munch Room, 13 Munch paintings are also to be displayed across seven rooms alongside paintings contemporary to Munch. The continuation of the investigations and the implementation of the Munch decision-making model will therefore focus on the new Munch Room configuration.

Furthermore, the NM has established a second single-artist room which has been dedicated to the female painter Harriet Backer. This recent development presents an interesting parallel in terms of collective display issues given that the majority of her original paint surfaces are also covered by restoration varnishes.

Finally, one of the main challenges of the research was the reconstruction of the collective historical narrative through surviving documentary evidence and interpretation of the decisions for varnishing. This notion generates a further question in terms of future perspectives regarding conservation-related documentation: what type of information will be the most relevant and should be prioritised for future conservator generations in an age of ever increasing and multiple data production?

5. Conclusion

The thesis's broad endeavour to increase the knowledge of a historically complex, 'controversially varnished' and iconic NM Munch collection affected the choice of interdisciplinary methods and techniques used for the research. A group case study combined with a non-invasive stance was explored using a four-step methodological approach. The conservator's perspective was central to the choice and evaluation of the two main examination techniques.

Significant contributions have been made to the art historical and conservation-related research of the NM Munch collection. The four papers have provided the first complete conservation overview of the Munch paintings as a collection. In addition, exploring the wider historical context outlines the value of the collection's conservation narrative which helps to provide a more balanced perspective of the NM's past varnishing practices. This was facilitated through the theory of 'object itineraries' which presented a successful framework for the visual mapping of the paintings' historical paths and their conservation treatments over time (1909–2019). Three restoration varnish time periods were identified as relevant historical markers for the NM and Munch conservation in Norway. Consequently, the historical survey of the conservation varnishes now plays a more explanatory role in the evaluation of the collection and for the newly recreated Munch Room display concept.

The experimentation with pFTIR and OCT used for the diagnostic screening of paintings generated valuable research results for the interpretation of the varnishes. Findings from the OCT helped to shed new light on Munch's painting technique and surface effects from his earlier period (1884–1900). Considering the recent acceleration in the development and diversity of novel, non-invasive and imaging techniques used in cultural heritage research, the thesis provides an important hands-on evaluation of two more readily accessible techniques. It demonstrates the consequences of choosing conservator user-friendly methods, both in practical terms and regarding the challenges of data interpretation. The research also provides a decision-making model which functions as a useful platform to fuse and process the technological data in line with the historical findings. This conceptual tool has a flexible template which can easily be adapted to fit similar collections.

In summary, the findings of this thesis contribute equally to methodological approaches in conservation as to the varnish history and future of the NM Munch collection. The research demonstrates the feasibility of acquiring the relevant knowledge using non-invasive methods combined with archival research by adopting a collective approach in terms of a group case study. It underlines the value of renewed visual examinations applied through the critical revisitation of the paint surfaces and interpreted in a historical context. Finally, in practical terms, the findings provide the knowledge base necessary for the conservation of the Munch paintings with decision-making protocols for the future of the non-original varnishes.

Figure 16. The recreated Munch Room in the new National Museum
(2022, Guicciardini and Magni Architetti)

6. Research Papers

6.1 Paper I

ICOM-CC
19th Triennial Conference
2021 Beijing

THEORY, HISTORY, AND
ETHICS OF CONSERVATION

An integrated conservation approach to a historic collection: The controversial varnishing of Munch's paintings

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Keywords
conservation histories, display legacies, group case study, integrated conservation approach, Edvard Munch, varnish controversy

Abstract
Since 1909, the collection of 57 Munch paintings at the National Museum of Art, Norway, has been subject to a legacy of specific acquisition and display policies. These run parallel to a largely unwritten, complex and controversial conservation history regarding the application of non-original varnishes. This study adopts an integrated conservation approach involving the re-examination of the paint surfaces in light of the history of conservation and display of the paintings over the past 110 years (1909–2019). The findings of this group case study approach influenced the choice of diagnostic tools and non-invasive methods employed to re-visit the paintings and perform systematic technological and scientific examinations. The study also lays a good foundation for future considerations and allows for a more integral approach to decision-making that takes on board the condition, appearance and history of the collection as a whole.

INTRODUCTION

This paper investigates the impact and benefits of applying an integrated conservation approach to the examination of a collection of paintings by Edvard Munch (1863–1944), belonging to the Norwegian National Museum of Art (NM), as a group case study.[1] The aim of the study was to examine the concept of the group's historical and biographical itineraries over the past 110 years (1909–2019), with renewed visual and scientific observation of the paint surfaces (Joyce and Gillespie 2015). The investigation of the contested practice of non-original varnish layers, applied and re-applied in the past by the Museum's conservators until 1993, was central to the study.

A well-known disadvantage of varnishing easel paintings, especially those meant to be left unvarnished, is how this alters our visual perception of the paintings (Feller et al. 1985, Callen 1994). Furthermore, the ephemeral nature of varnish coatings, which are naturally prone to degradation and discolouration, greatly affects the decision-making regarding their removal (Phenix and Townsend 2012).

The present study aimed to establish the conservation history of the Munch paintings with regard to past varnish application and removal practices. The physical condition of each artwork was assessed in relation to the whole group rather than considered as an isolated case study. This group approach influenced the choice of technical and scientific methods for investigation and contributed to an effective examination process suitable for large collections. Care was taken to acknowledge the additional historical 'complex layers of value and meaning' acquired over time through past conservation treatments (Muir 2009, 2). The aim was to avoid a purely 'clinical' examination approach focussed exclusively on the technical characterisation of the non-original varnish layers.

BACKGROUND

The NM houses one of the most important painting collections by the expressionist artist Munch. It is arguably the best-known section of the NM's collections, and the 57 paintings, dating from the artist's earlier period, have a distinct display history. In June 1909, under the directorship of Jens Thiis (1908–41), a selection of Munch paintings were hung together as a group, on a single wall in the East galleries. This formed part of the re-opening of the newly refurbished south wing of the former National Gallery of Art (Figure 1). Ever since, the Munch collection has continued to be presented

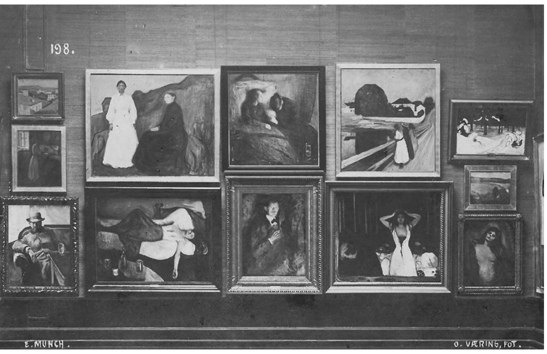

Figure 1. 'The Munch Wall', National Gallery, Oslo, postcard published in 1909 (O. Væring, Nils Messel)

Figure 2. The Munch Room, National Gallery, Oslo, 1943

and displayed in the same configuration, culminating with the creation of a permanent Munch Room in 1937 (Willoch 1937, Messel 2012; see Figure 2).[2] Parallel to this, the ensemble became the most controversial group of works in the museum in terms of their restoration history. Public concerns were first raised in 1909 and in reference to the varnishing of unvarnished Munch paintings by the Museum's conservators. This invited the question of how Munch had intended his painted surfaces to look (Rød 1993). Past research focussing on Munch's varied and experimental painting techniques has pointed towards the artist's preference for matt surfaces rather than the overall glossy effect a varnish coating can bring. However, Munch's use of varnish remained a topic for proper investigation (Ormsby et al. 2015, Stein and Rød 2015).

METHODS

Since its foundation in 1837, the NM has had a long history of employing conservators, and the first official conservator position was established in 1870 (Willoch 1937). Despite this tradition, only a limited amount of early conservation documentation survives. Treatments undertaken on the Munch paintings were not recorded before the introduction of conservation reports in 1949. This study included a first in-depth group archival survey of the NM's Munch conservation records and incorporated surviving documentation of past varnishing recipes.[3] Given that no analytical identification of the various varnish types had been previously undertaken across the whole Munch collection, this documentary information provided a basis for establishing an initial overview of the NM's historical varnishing practices and the types of varnish resins used. Information for the period prior to 1949 could only be acquired from archival research that addressed the broader historic context. The sources consulted concerned the Museum's acquisition policies, display legacies, exhibitions, activities, historic events, press references, and the attitudes and activities of the conservation community and neighbouring institutions. Archival findings were evaluated in relation to a series of screening tests carried out on a selection of paintings. The tests employed visual assessment and different photographic imaging techniques, such as ultraviolet-induced fluorescence photography (UVA), combined with non-invasive analytical techniques. Portable Fourier transform infrared (pFTIR) spectroscopy was used for the characterisation of the different types of varnish resins present and optical coherence tomography (OCT), for the visualisation of the different layers (Ford et al. 2019).[4]

FINDINGS

Through this integrated approach, it was possible to chart the NM's changing practices and attitudes towards conservation over the past 110 years (1909–2019) and to divide the conservation history of the Munch collection into three periods.

ACQUISITION AND DISPLAY (1909–44)

The first period was essentially governed by the acquisition and display policies of the first director, Thiis. Given the lack of pre-1949 conservation records, it remains unclear how many of the Munch paintings were treated under his directorship. However, documents consulted on his policies suggest that the restoration interventions undertaken were essentially aimed towards presentation. Thiis, who was also a close friend of Munch, made no secret of promoting him as an artist (Messel 2012). He also advocated that Munch's paintings deserved to be displayed as an ensemble and, ideally, in one room dedicated to the artist (Willoch 1937). A total of 33 paintings were acquired under his directorship within a 30-year period (1908–38), either bought directly from the artist or through generous donations. Between 1909 and 1937, Thiis moved Munch's paintings to different locations throughout the building but always displayed them as a group. Prior to the creation of the Munch Room, Munch also surpassed his contemporaries in terms of the total number of his paintings displayed in the gallery (Messel 2012). Archival photographs not only helped to document the earlier displays by Thiis but proved useful in showing the director's early replacement of the original frames (Figure 1). Munch's simple, thin wooden frames were exchanged for new, gilded and ornate 19th-century profiles with metal labels, to give the paintings a grander museum status.[5]

Conservator Harald Brun

Public reactions to the Museum's controversial varnishing of 1909 have also provided a valuable source of information for the early conservation history of the Munch collection. In his press review for the opening and the new Munch hanging, the art critic Jappe Nilssen accused the Museum's conservator Harald Brun (employed 1905–21) of 'vandalism' (Nilssen 1909, Stein and Rød 2015). Serious damage, through varnishing, had been inflicted to the paintings *Puberty* (Woll M 347), *The Day After* (Woll M 348) and *Ashes* (Woll M 378). Nevertheless, a noteworthy letter from Brun to Munch confirmed that he sought both the artist's permission and advice for the critical restoration of *The Day After* prior to the opening (Brun 1909, Stein and Rød 2015). Information gained from the recent survey combined with a re-examination of the painting's surface confirmed that it had been varnished and lined twice since 1909. Despite the public outcry of 1909, Munch remained silent on the matter. Furthermore, the Museum's archives revealed that there existed a long tradition for the periodic cleaning and varnishing of the painting collections at the NM, which can be dated back to the 1860s (Willoch 1937). Like the changing of frames, the cleaning and varnishing of paint surfaces was essentially carried out for display and presentation purposes. This was probably necessitated by poor indoor air quality and general pollution present in Oslo at that time (Grøntoft et al. 2019). Surface examination of *Night in Nice* (Woll M 224) and *Winter in the Woods, Nordstrand* (Woll M 445) confirmed the presence of a first varnish (natural resin) applied to the paintings in their frames. Interestingly, both artworks also feature in the earliest surviving photograph of the Munch hanging of 1909 and it is plausible that they share a similar varnishing history (Figure 1). When revisiting the surface of *Night in Nice* in 2019, only one thick natural resin varnish was detected. No visual or chemical evidence was found for a second and synthetic varnish layer stipulated in the treatment report

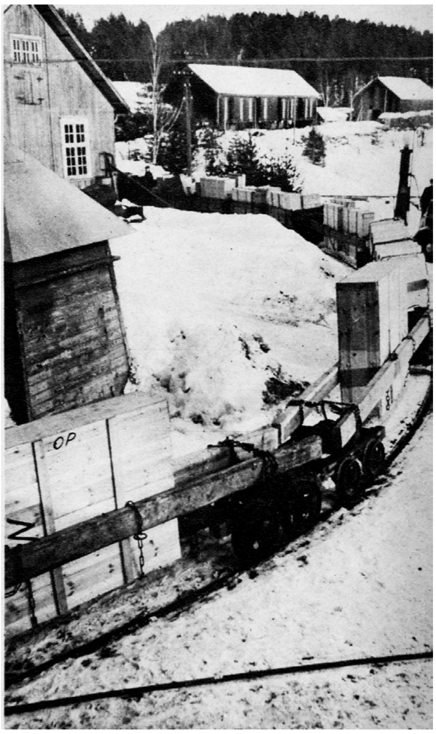

Figure 3. The return rail transport of evacuated paintings (In *Bilder* 1946, p. 21)

of 1983 (Ford et al. 2019). This contradictory information reaffirmed the importance of aligning documentary research with the outcomes of visual and scientific investigations to reveal the full conservation history.

During his time at the NM, Brun did not varnish the two tempera works, *Death in the Sickroom* (Woll M 329) and *The Scream* (Woll M 333). He also left the small oil study *Moonlight by the Mediterranean* (Woll M 274) and Munch's large *Self-Portrait with Cigarette* (Woll M 382) unvarnished. *Self-Portrait with Cigarette* had been acquired by the Museum from Munch in the same year that it was painted, 1895. The painting is neither varnished nor has it undergone any restoration and remains a unique example of an untouched oil paint surface, as Munch had intended. In this light, and contrary to the 1909 criticism, Brun appears to have had an understanding and respect for the matt appearance of Munch's tempera technique, which made it especially unsuited to varnish. Notwithstanding the Museum's tradition for the periodic varnishing of the collections, Brun made exceptions to this practice. His restrained attitude is also evident in later disagreements with Thiis. Brun was reluctant to carry out what he described as the unnecessary periodic cleaning of the collection, which was strongly advocated by the director, a standpoint that finally cost Brun his position in 1921 (Rød 1993).

Conservator Ole Dørje Haug

Thiis quickly replaced Brun with the restorer Ole Dørje Haug (employed 1921–52). Haug had a closer relationship to Munch than Brun and was possibly more in tune with the artist's experimental and challenging techniques. Assisted by his brother, Martin, he had already installed the monumental Munch paintings in the Aula of Oslo University in 1916 (Frøysaker 2008). As for Brun, the lack of conservation reports pre-1949 makes it difficult to discern which Munch paintings Haug restored. However, in 1938 the NM owned 42 Munch paintings, and with the outbreak of World War II Haug is documented as having been responsible for the safe evacuation of the paintings by road and rail (Kongssund 2006). Once more, the NM's archives and articles in the press provided useful written and visual source material relating to the conservation history. The Munch paintings were unframed and packed into 30 makeshift wooden crates, some mixed with other paintings according to their size. The first wave of the evacuation took place in March 1940 with a specific prioritisation of paintings.[6] Haug claimed to have monitored and reduced the high humidity levels in the silver mines at Kongsberg with weekly checks between 1943 and 1945, although no records exist to substantiate this (Rød 1997). Moreover, the wooden crates were not insulated, and the paintings were exposed to the Scandinavian winter climate during the various transports (Figure 3).

The entangled relationship between the paintings' acquisition, display and controversial conservation histories reflects the importance of understanding the implications of the historical trajectory of the collection.

POST-WAR RESTORATIONS (1945–65)

The second period, two decades after Munch's death in 1944, witnessed the restoration of Munch's paintings on an unprecedented scale throughout

Figure 4. Wax-lining treatment of *Mother and Daughter* (Woll M 404), National Gallery, Oslo, ca. 1960s

Norway. At the NM, conservation dossiers document several extensive and structural treatments undertaken, such as the consolidation of unstable paint layers through lining. A total of five wax-linings, six glue-paste linings and one marouflage were carried out during this period, and 23 of the Munch paintings were cleaned and re-varnished (Figure 4). These activities were probably prompted by a combination of damages incurred from the evacuation transport and storage conditions combined with the post-war re-hanging of the galleries and loan requests. However, it is also significant that these treatments coincided with neighbouring restoration activities from the three other main Munch public collections. The Munch paintings from the NM, Aula of Oslo University, Munch's studio at Ekely and Rasmus Meyer collection in Bergen (KODE) were all linked together by a small group of conservators. Having either been trained or worked under the guidance of Haug, this group exchanged conservation methods and experiences concerning Munch's paintings. Haug remounted and re-installed the monumental Munch paintings in the Aula of Oslo University in 1946 (Frøysaker 2008). He was also in charge of the restoration of the artworks remaining in Munch's studio after the artist's death. This collection formed the core of the Munch Museum in 1963, where conservation responsibility was given to Haug's NM apprentice, Jan Thurmann-Moe (Thurmann-Moe 2016). Concurrently, the Bergen conservator Bjørn Kaland and his apprentice Leif Plahter are also known to have been both trained and supervised by Haug (Rød 1997). The gain derived from studying the archival conservation records, combined with the physical conservation traces present in the paintings, reveals how artefacts can also assist in documenting the biographies of people and histories related to specific institutions (Rudolph 2011, Ebert 2019).

CONSERVATION AND RESEARCH (1967–2019)

The third period of the conservation history of the Munch collection reflects an attitude of minimal intervention with an emphasis on preventive measures related to loans and display. By 1965, under the leadership of Leif Plahter (employed 1956–99), the NM's paintings conservation department had both photographed and documented the condition of most of the Munch collection. During the 1970s and 1980s, some structural work was undertaken on the Mustad family donation of ten paintings. The recent archival survey confirmed this diversity, revealing that 80 percent of the Munch paintings had been varnished and 40 percent re-varnished by the museum, involving five different types of resin applied using six different recipes between 1909 and 1993. The last painting documented as varnished by the NM was *Self-Portrait with Spanish Flu* (Woll M1296), in 1993. Throughout the 1980s–90s, a steady increase in loans and the theft of *The Scream* in 1994 prompted increased security measures. The emphasis shifted towards preventive conservation treatments related to loans and display, with the introduction of protective glazing and conservation framing. However, in contrast to the curatorial group presentation approach (Munch Room), conservation research has remained historically focussed on individual case studies. Between 1970 and 2015, the NM's conservation department was central in establishing conservation research on Munch in Norway (Plahter and Plahter 2015).

Figure 5. The Munch Room, NM, 2020 (Guicciardini & Magni Architetti)

However, only 6 of the 57 paintings were scientifically investigated and none of them in relation to the rest of the group, or specific to the varnish controversy (Plahter 1999, Aslaksby 2009, Singer et al. 2010, Plahter and Topalova-Casadiego 2011, Aslaksby 2015).[7]

Current activities concerning the planned relocation and recreation of the Munch Room in the new museum building (opening 2022) have influenced new conservation attitudes related to aesthetics and display (Figure 5). With the rediscovery of an original frame for *Study of a Head* (Woll M 98), ongoing research into Munch's original frames further helped to address the collection as a group in terms of a combined conservation and curatorial approach.[8] This combined group approach also influenced the type of recent scientific examinations employed to identify the historical varnish layers present. Non-invasive diagnostic techniques (UVA, pFTIR and OCT) were chosen to provide effective screening methods for identification of the varnish layers present over the whole surface of the works and enabled comparisons across and within the group of Munch paintings (Ford et al. 2019). A non-invasive approach was favoured for the technical investigations due to the scale of the collection and the examination of large surface areas. The advantage of employing non-invasive techniques overcomes the disadvantages associated with micro-sampling and reproducibility issues encountered with the analysis at a specific spot. This is an important criterion given the intertwining of the group approach with the complex conservation and varnish history, enabling comparison of varnishes that differ among paintings and even between different areas of one painting.

CONCLUSION

The conservation histories of museum institutions are often undervalued as a source when revisiting the surface of complex artefacts. By tracing the controversial conservation history of NM's Munch paintings as a collection, this group case study exemplifies how the integration of a broader historic context allows for a better understanding of an institution's past conservation and working practices. Despite the lack of early conservation records, archival, press, and acquisition and display histories can also act as valuable sources for specific groups or collections. The relevance of historical links and conservation trends concerning Munch's paintings in general was noted across collections and parallel institutions. Acknowledging the collection as an ensemble of 57 paintings and adopting a group approach was significant. It was shown that the often clinical and technical approach to complex conservation issues can be misleading if it is solely evaluated in isolation from both an object's conservation history and its history as part of a group. An example of inconsistency between documental and technical evidence was given by *Night in Nice*. Piecing together the conservation history of a leading institution also demonstrated its relevance as a marker for the development of a conservation research in Norway. The methodology of integrating the display and conservation histories influenced the choice of a non-invasive approach using specific diagnostic tools to re-examine the paint surfaces. Although the study did not yet give any specific answers as to the type of future conservation treatments, it underlined an important shift in attitudes towards future preservation. The value of adopting a group case study approach exemplified the historical complexity of a specific ensemble of artworks, collected over time, sharing a specific group display legacy, and intertwined with a controversial conservation history. Future conservation strategies, such as the removal of the controversial varnishes, can now be more precisely formed in line with the collection's history and specifically tailored for the whole group, parallel to the curatorial approach and to the Munch Room.

Finally, by adopting a more holistic assessment of the conservation issues in question, the integrated approach underlined the additional biographical significance of specific groups or collections in museums. Like the multi-layered physical aspect of the varnishes present in the paintings, this study demonstrates that the unique conservation and display histories similarly add inseparable, heterogeneous and complex layers of value and meaning to the works over time.

NOTES

1 Since 2003, the former collection of the National Gallery of Art is now part of the NM. The historical background to the collection is part of the author's PhD study and was revised from an earlier introductory text (Ford et al. 2019).

2 To date, 18 to 20 Munch paintings have hung in the Munch Room, which will be re-created in the new museum building opening in 2022.

3 The NM's historical varnish recipes and Munch conservation dossiers (1949–2019) were examined together as a group by the author and form the basis of his PhD study.

4 The OCT results will be presented at the inArt2022 conference with a forthcoming publication in the *European Physical Journal – Plus* (Ford et al., 2021, 'Munch and optical coherence tomography. Unravelling historical and artist applied varnish layers in painting collections').

5 Thiis spent Kr. 425.00 on new frames, which included the five Munch paintings recently purchased from Blomqvist (NM, Korrespondansearkiv/sakarkiv, 1909).

6 In 1940–43, the Munch paintings were documented as having been evacuated in six different groups to Bagn Bygdesamling and Hadeland Folkmuseum. All but two (*Spring* and *Death in the Sickroom*) were stored together in the silver mines at Kongsberg until the end of the war (NM, Korrespondansearkiv/sakarkiv, D-0023,24 and 26, 1942–46).

7 The following paintings have been technically examined: *Death in the Sickroom*, *Spring*, *The Sick Child* (Woll M 130), *Betzy Nilsen* (Woll M 144), *Hans Jæger* (Woll M 174) and *The Scream*.

8 The original wooden frame had been replaced by a new gilded frame at the time of purchase. It was re-discovered in the museum stores by Thierry Ford in 2015.

ACKNOWLEDGEMENTS

The author is greatly indebted to Ella Hendriks, Tine Frøysaker and Nils Messel for their advice and to Marie von Möller for the examination of records and paintings at KODE. He is grateful to the NM for funding his PhD research.

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To cite this article:
Ford, T. 2021. An integrated conservation approach to a historic collection: The controversial varnishing of Munch's paintings. In *Transcending Boundaries: Integrated Approaches to Conservation. ICOM-CC 19th Triennial Conference Preprints, Beijing, 17–21 May 2021,* ed. J. Bridgland. Paris: International Council of Museums.

6.2 Paper II

Ford et al. Herit Sci (2019) 7:84
https://doi.org/10.1186/s40494-019-0327-1

Heritage Science

RESEARCH ARTICLE

Open Access

A non-invasive screening study of varnishes applied to three paintings by Edvard Munch using portable diffuse reflectance infrared Fourier transform spectroscopy (DRIFTS)

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Abstract

The availability and popularity of portable non-invasive instrumentation for the study of paintings has increased due to a shift away from using micro-invasive techniques. Fourier transform infrared spectroscopy (FTIR) is a successful and established technique for the characterisation of organic materials in varnish coatings and paint films. In addition, portable FTIR (pFTIR) spectrometers allow for non-invasive in situ analyses. This overcomes the disadvantages associated with micro-sampling and reproducibility issues encountered in analysis at a specific spot, as pFTIR enables examination of the whole painting. However, the practical applications and capabilities of pFTIR as a suitable screening method for the chemical characterization of varnish coatings in painting collections require systematic evaluation. This study involves a selection of three paintings from the collection of 57 works by Edvard Munch belonging to The National Museum of Art in Norway. Its focus is the identification of the non-original varnish types that were applied by the museum. Between 1909 and 1993, the Museum was embroiled in a varnish controversy due to their application of, first natural and then synthetic, varnish coatings to 48 of these Munch paintings. A series of public debates arose about the Museum's varnishing practice, which ran counter to the artist's usual custom of leaving paint surfaces unvarnished (or occasional locally varnished). The three paintings were screened using a pFTIR spectrometer. Different regions of the varnished and unvarnished painted surfaces were analysed with Portable Diffuse Reflectance Infrared Fourier Transform Spectroscopy (DRIFTS). These paintings date from 1887 to 1891 and are documented as having been treated at the Museum with one of the following types of natural or low-molecular-weight synthetic varnish coatings: dammar, mastic, polycyclohexanone (Laropal K 80 from BASF) and reduced or hydrogenated cyclohexanone-co-methyl-cyclohexanone (MS2A from Howards of Ilford). Surface microscopy and multispectral imaging of the varnished surfaces initially assisted the mapping and choice of areas relevant for the portable DRIFTS measurements. Portable X-Ray fluorescence and surface gloss readings were also made at the pFTIR spot locations to complement the results. Using known dry varnish samples, pFTIR reference spectra were obtained and a DRIFT spectral library was also created from known historic batches of varnishes used by the museum. These were then compared with the in situ pFTIR surface readings taken from the paintings together with additional spectra acquired from a selected number of micro-samples from the same spot locations. The preliminary measurements provided an insight into the capabilities, limitations and practical aspects of using portable DRIFTS for the identification of varnish coatings present in this specific selection of Munch paintings.

Keywords: Portable FTIR, Varnish coatings, Painting collections, Practical applications, 1887–1891

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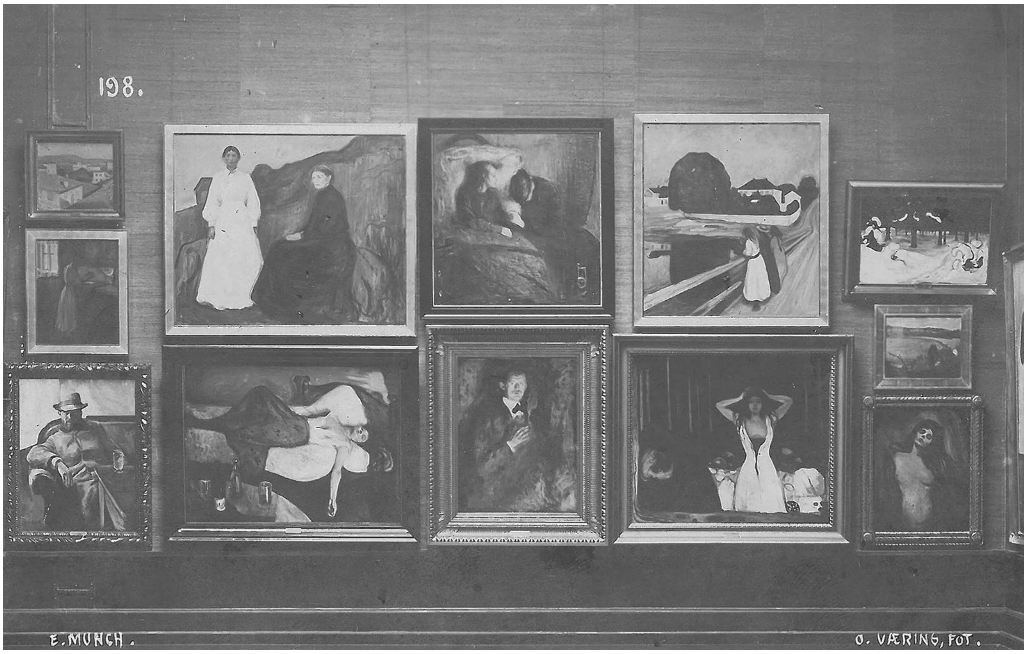

Fig. 1 The National Gallery, Oslo: 'The Munch Wall'. Postcard published 1909. (O. Væring, Nils Messel)

Introduction

The National Museum of Art (NM) in Oslo, Norway, houses one of the largest and the most important single collections by the expressionist artist Edvard Munch (1863–1944).[1] It comprises 57 paintings from Munch's earlier period and the bulk of the collection was acquired within a 30-year period (1908–1938) by the museum's first director, Jens Thiis (1908–1941) [1]. In June 1909, J. Thiis reopened the newly refurbished South wing of the former National Gallery of Art and set a precedent in terms of how the Munch paintings should be presented and displayed in the museum. A selection of the newly acquired Munch paintings was hung together on a single wall in the East galleries (Fig. 1) and J. Thiis made no secret of the fact that Munch's paintings deserved to be displayed as an ensemble and, ideally, in one room dedicated to the artist [1].

His desire was finally fulfilled in 1937 with the creation of 'The Munch Room' where an ensemble of 18–20 Munch paintings have hung to the present day [2]. This display legacy, viewing the Munch paintings as a group and in one room, will also be re-created in the new NM building, opening in 2020 [3]. In addition to this specific set of display policies, the paintings have been intertwined with a controversial conservation history in terms of varnish coatings. J. Thiis' 1909 re-hanging sparked a critical press review, directed primarily at recent varnish treatments of some of the Munch paintings, described as 'vandalism' [4]. Despite the critique, the museum continued with the contested practice of applying and re-applying natural and synthetic varnish coatings to the Munch collection for a period of 80 years, attracting further criticism [5].

Recent research documents Munch's painting technique but it also points out the need to clarify remaining aspects relating to varnish on the artist's paintings [6, 7]. According to Stein et al. [5] Munch's own attitude to varnishing is unclear due to the ambiguity from the artist's correspondence, contemporary critical sources and the lack of surviving original varnish layers. In general, Munch appears to have favoured matt surfaces with an almost 'fresco-like' finish [8, 9]. Irrespective of this, *Self-portrait with Cigarette* (Woll 382) was acquired by the NM in the same year that it was painted, 1895 (Fig. 2). According to the conservation records and recent visual examinations, the painting has an unrestored surface with an original locally applied glossy film, used by Munch to saturate certain passages of colours in the composition [10].

The varnishing of easel paintings plays a critical role in the final and intended visual perception of an artwork. Traditional picture varnishes are often complex mixtures and have been classified throughout the history of easel paintings as being either a drying oil without the addition

[1] Since 2003, the former collection of The National Gallery of Art is now part of the National Museum of Art.

Fig. 2 pFTIR set up at NM conservation studios, *Self-portrait with Cigarette* (Woll 382)

of resin, an egg white mixture, an oil-resin varnish (a heated natural resin and drying oil mixture) or a solvent/spirit type (a dissolved resin in a volatile solvent) [11, 12]. The varnishes induce physical changes to the surface topography, refractive index (gloss) and saturation of oil paint layers underneath [13]. In addition, the intrinsic chemical degradation and discolouration of these varnishes pose ethical dilemmas concerning conservation decisions associated with varnish removal (cleaning) and re-varnishing [14].

Acquiring a thorough understanding of the chemical nature of non-original varnish coatings applied to paint surfaces is imperative for devising tailored cleaning strategies. This is particularly relevant for the treatment of larger groups of paintings by a single artist when displayed together, where the visual interrelationships regarding surface gloss and the subtlety of reflected hues play an important role. Traditionally, a variety of laboratory-based analytical methods, including Fourier transform infrared spectroscopy (FTIR), are successfully used for the molecular characterisation of organic compounds, such as those present in varnish coatings [15–18]. However, most of these approaches remain micro-invasive, thus requiring physical sampling from an artwork (albeit involving the removal of non-original material). Recent studies have shown the benefits of portable FTIR spectrometers (pFTIR), which allow for a non-invasive in situ analysis of painted surfaces [19, 20]. This method of analysis further overcomes the restrictive disadvantages associated with micro-sampling that—when allowed—is often limited to a specific spot [21]. In fact, the pFTIR instrument enables systematic and repeated examination from multiple spots on paintings.

This study is concerned specifically with the evaluation of pFTIR as a viable analytical method for the characterisation of the disputed varnishes types applied to an ensemble of Munch paintings at the NM. Given the complex morphology and topography of varnished paint surfaces, the study evaluates how effectively pFTIR can be used to identify some of the known varnish types and/or to distinguish between a natural and synthetic resin. In addition, the work addresses the practical context of the technique for conservators in terms of the possibilities and limitations of the equipment as a viable, non-invasive screening method for varnish identification in this collection.

A selection of three varnished Munch paintings were chosen for the study, *Flower Meadow Field* (Woll 148), *Portrait of Hans Jæger* (Woll 174) and *Night in Nice* (Woll 224). The paintings were carefully selected to provide a degree of consistency according to the following criteria: (i) early creation date; (ii) early acquisition; (iii) solid information about the provenance (some having been purchased from the artist himself); (iv) a minimal record of restoration treatments; (v) a visually noticeable varnish coating. Conservation dossiers note that the portrait of Munch's bohemian friend and author, *Hans Jæger* (Woll 174), was last treated in 1954 with mastic varnish, whilst a synthetic coat of varnish polycyclohexanone (Laropal K 80 from BASF) had been applied in 1983 to the other two works [22–24].

Materials and methods

Research methods included a survey of the NM's conservation records, backdating from the 1950s, and incorporated surviving documentation of past varnishing recipes. Given that no analytical identification of the various varnish types had been previously undertaken across the whole Munch collection, this documentary information provided a basis for establishing an initial overview of the NM's historical varnishing practice and the types of resins used.

Imaging techniques

Close observation of the paint surfaces and their condition was first carried out using a Leica Wild M8 stereomicroscope (5× to 50× magnification range) (Ortomedic AS, Lysaker, Norway). Raking light photography was employed to study surface topography. Examination with UVA-induced fluorescence photography of the paint surfaces was undertaken to map the distribution of the varnish layers and to assist with the relevant selection and recording of the pFTIR spots. Care was taken to employ photographic standards for the UVA imaging, as advocated by the CHARISMA user manual [25]. A Hasselblad H6D-400C MS digital camera (Interfoto AS, Oslo, Norway) with a Baader UV/IR Cut/L-Filter (Baader Planetarium, Mammendorf, Germany) was used in conjunction with a Target-UV calibration patch (Image

Science Associates, LLC, Williamson, NY, United States) to control colour and intensity of UVA-induced visible fluorescence. Two UVA luminaires were placed at equal distance, on either side of the painting, with three 40-W UVA fluorescent tubes per luminaire, radiating in the 355–360 nm region. Infrared reflectography (IRR) with false colour was also carried out to help characterise the distribution of possible infrared transparent pigments (ARTIST camera by the former Dutch company ART Innovation, IR spectral range 700–1100 nm). Where possible, the characteristic colouration of certain pigments excited by the UVA-radiation (which induces visible light fluorescence), assisted the portable X-Ray Fluorescence (pXRF) spectral results for pigment identification.

pFTIR

In situ spectra were acquired in diffuse reflectance (DR) with the 4300 handheld FTIR spectrometer by Agilent (Matriks AS, Oslo, Norway), equipped with a deuterated triglycine sulfate detector and spot size of 6 mm in diameter. In order to evaluate the reproducibility of the approach, multiple readings were taken in the same spots at different times. DR spectra were plotted in pseudo-absorbance (y-axis = log(1/R)) and were acquired between 650 and 4000 cm^{-1} by accumulating 256 scans (with 8 background scans) at a resolution of 4 cm^{-1}. With this configuration, a high signal to noise ratio was obtained. The spectra were processed with OMNIC Spectra software (version 7.2 by Thermo Fisher Scientific, Oslo, Norway) without the use of correction algorithms. Due to the fragile nature of the paint surfaces and weight of the pFTIR instrument (2.2 kg), the latter was fitted to a movable counterweight stand. This facilitated control and mobility across the painted surfaces, stability for long acquisition times, whilst also significantly reducing the risk of damage to the artwork. Paintings were secured onto a movable and height-adjustable easel, which allowed for a direct but controlled perpendicular surface contact, required for the spectral reading (Fig. 2).

Reference materials

A reference library was first created using DRIFT spectra together with the NM's still extant historic solvent varnish mixtures and replicated recipes. The following types of natural and low-molecular weight synthetic varnish coatings were characterized: dammar, mastic, polycyclohexanone (Laropal K 80 from BASF) and reduced or hydrogenated cyclohexanone-co-methyl-cyclohexanone (MS2A from Howards of Ilford). New batches of varnishes were made up according to the original NM's recipes and materials sourced from the museum's dry resin stock. Reference spectra were collected from brush-applied and air-dried solutions of the historic varnishes on MirrIR low-e microscope slides for reflective infrared studies (Kevley Technologies, Chesterland, OH, United States). These slides have no interfering absorption between 400 and 4000 cm^{-1}, thus providing clean varnish reference spectra without any signals from the slide substrate (Table 1).

Varnish thickness in paintings varies according to many factors, such as: surface topography, mode of application, and the drying properties of multiple layers. Recent research, on examples of eighteenth and nineteenth century easel paintings, employing optical coherence tomography to visualize and measure the thickness of varnish coatings, observed a variable thickness between around 10 and 100 µm, dependent on the texture of the paint at a specific location [26]. According to the manufacturer (Agilent) of the pFTIR unit, the radiation penetrates at 250–500 µm when in reflectance and depending on the response in the infrared region of the sample. Given the irregular surface topography and non-uniformity of the three varnished Munch painted surfaces in question, tests were first undertaken to establish an approximate depth of penetration for the pFTIR in DR. A synthetic varnish recipe (Laropal K 80 grade 9 with wax and stand oil) typically used at NM was applied to both rough and smooth glass slides with an adjustable micrometric film applicator (TQC Sheen, Tønsberg, Norway). The practical limits of the micrometric film applicator together with Agilent's claimed depth of penetration range for the pFTIR unit, governed the application of the varnish tests with the following thicknesses: 250 µm, 500 µm, 750 µm and 900 µm. The Si–O–Si stretching from the glass was employed as an approximate marker for the spectral depth-of-penetration test.

Surface gloss measurements

Surface gloss readings were undertaken at the same pFTIR spot locations in order to investigate the possible influence from different surface topographies on the pFTIR readings. Four measurements were acquired at each spot location using a Horiba IG-331 gloss checker (Labolytic AS, Trondheim, Norway) and the average is reported here. The spot size for the measurements was $6 \times 3\ mm^2$ with an optical angle of 60°.

Micro-sampling

For the further validation of some of the pFTIR results, spectra were also compared with those obtained from additional microscopic varnish samples. (Table 2). Where possible, care was taken to select micro-samples from the same areas analysed with pFTIR or immediately adjacent to them. When present in the scrapings, microscopic flakes were mounted as cross-sections to clarify stratigraphy. Layers in cross-section were analysed by attenuated

Table 1 Library of standards for pFTIR. Historic varnish recipes and additives applied to MirrIR low-e microscope slides

MirrIR slide	Varnish reference	Additives	NM historic recipe/supplier/comments
MirrIR.01	Test slide—no varnish		Control
MirrIR.02	Laropal K 80—*standard varnish solution*	Stand oil	750 g resin (BASF) 1200 mL white spirit 300 mL vegetable turpentine (Talens) 150 mL *n*-butylacetate 75 mL stand oil (Talens)
MirrIR.03	Laropal K 80—*matt varnish solution*	Stand oil + microcrystalline wax	400 mL *standard varnish solution* 1300 mL white spirit 90 g microcrystalline wax (Cosmolloid H80) 700 mL vegetable turpentine (Talens)
MirrIR.04	Laropal K 80—grade 5 varnish	Stand oil + microcrystalline wax	2 parts per vol. *Standard varnish solution* 1 part per vol. *Matt varnish solution* (shiny varnish)
MirrIR.05	Laropal K 80—grade 9 varnish	Stand oil + microcrystalline wax	1 part per vol. *Standard varnish solution* 1 part per vol. *Matt varnish solution* (semi-shiny varnish)
MirrIR.06	Dammar—standard varnish solution		1 part per vol. resin (Winsor and Newton) 3 parts per vol. white spirit
MirrIR.08	Laropal K 80—*standard varnish solution*		750 g resin (BASF) 1200 mL white spirit 300 mL vegetable turpentine (Talens) 150 mL *n*-butylacetate (*no stand oil*)
MirrIR.10	Stand oil		Stand oil (Talens)
MirrIR.11	Tinuvin 292		Tinuvin 292 (Ciba-Geigy)
MirrIR.12	Microcrystalline wax		Cosmolloid H80—melted on slide
MirrIR.13	Mastic standard varnish solution		1 part per vol. resin (Lascaux) 3 parts per vol. vegetable turpentine (Talens)

Table 2 Micro-samples from paintings for comparative benchtop analyses

Painting	Colour code reference	Documented varnish type	pFTIR spot sample area	pFTIR spot and micro sample coordinates (cm)	Sample type	Analytical method
Woll 148	Gr.02 (green paint)	Laropal K 80 grade 9 (1983)	Bottom right-hand corner—varnish layer over green paint	L 39.5–B 4.5	Micro scraping and cross-section	ATR-FTIR, THM-GC/MS and microscopy
Woll 148	Bl.01 (blue paint)	Laropal K 80 grade 9 (1983)	Left edge—varnish in sky	L 1.5–B 50.5	Micro scraping and cross-section	ATR-FTIR, THM-GC/MS and microscopy
Woll 148	Bl.02 (blue paint)	Laropal K 80 grade 9 (1983)	Mid sky—varnish	L 12.5–B 54	Micro scraping	FTIR and THM-GC/MS
Woll 224	V.06 (blue/red paint)	Laropal K 80 grade 9 (1983)	Blue/red paint right side with varnish	L 32–B 3.5	Micro scraping and cross section	ATR-FTIR, Raman, THM-GC/MS and microscopy

L indicates the distance from the left edge. B indicates the distance from the bottom edge

total reflection (ATR)-FTIR. When samples featured residues of underlying paint, Raman micro-spectroscopy (785 nm laser excitation) was used for pigment identification, in support of pFTIR and pXRF results.

ATR-FTIR and FTIR

For ATR-FTIR, layers in cross-section were analysed through the 20× ATR germanium-crystal objective of a Hyperion 3000 microscope, featuring a liquid-nitrogen-cooled mercury cadmium telluride detector, and interfaced to a Tensor 27 spectrometer (both instruments by Bruker Optics, Billerica, MA, United States). The spectra were acquired as an average of 64 scans in the range from 600 to 4000 cm^{-1} at a resolution of 4 cm^{-1}. For scrapings, the samples were crushed in a diamond micro compression cell (Spectra-Tech, Inc., Oak Ridge, TN, United States) and analyzed using a 15× FTIR objective using the instrumental set-up and acquisition conditions reported above.

THM-GC/MS

Further tests using thermally assisted hydrolysis and methylation-gas chromatography coupled with mass spectrometry (THM-GC/MS) were employed for the analysis of selected micro samples. Micro samples with a mass between 15 and 30 µg were accurately weighed on an Ultramicrobalance UMX2 (Mettler Toledo, Columbus, OH, United States) in the pyrolysis cup (Eco-cup, Frontier lab, Fukushima, Japan). 3 µL of TMAH solution ((tetramethyl)ammonium hydroxide 25% (w/w) in methanol) were added to the sample prior to pyrolysis at 550 °C in the vertical micro-furnace of the double-shot 2020iD pyrolyzer (also from Frontier lab). The micro-furnace is interfaced to the gas chromatograph Agilent 6890 coupled with the Agilent 5973 Network Mass Selective Detector (Agilent Technologies, Inc., Santa Clara, CA, United States). The analysis was carried out in split mode at a split ratio 15:1. An Agilent J&W DB-5ms capillary column (30 m × 0.25 mm × 0.25 µm) was used. The inlet and the MS transfer line were kept at 320 °C. Helium was used as the carrier gas at a constant flow of 1 mL/min. The GC oven temperature program was: 40 °C for 2 min, up to 320 °C with a rate increase of 6 °C/min, followed by 10 min of isothermal conditions. Analysis was conducted in full scan mode (35–600 m/z). Temperatures at MS source was 230 °C and at quadrupole 150 °C. A solvent delay of 2 min was used.

pXRF

pXRF was employed for the surface elemental characterization of some of the pigments present in Munch's paintings. This provided a supplementary non-invasive form of analyses which assisted the interpretation of the pFTIR and the discernment of pigment interference attributable the underlying paints. In addition, it provided information on Munch use of pigments. Measurements were taken with a Thermo Niton XL3t 900 energy dispersive pXRF spectrometer (Thermo Scientific, Holger Hartmann, Oslo, Norway) with a Si-drift detector (GOLDD—Geometrically Optimized Large Drift Detector) attached to a tripod. Multiple readings were taken from the same areas analysed by pFTIR or adjacent passages with dominant primary, secondary, black and white colours. The proprietary "Mining Cu/Zn Testing Mode" was used. This mode allowed to detect the largest range of elements. Total measurement time was ca. 60 s for each sampled area and the instrument switched automatically from main (Al/Fe filter, potential: 50 kV, maximum current: 40 µA) to low (Cu filter, potential: 20 kV, maximum current: 100 µA), high (Mo filter, potential: 50 kV, maximum current: 40 µA) and light range filters.

Results and discussion

Initial findings from the survey of the NM's conservation dossiers revealed that 48 paintings from the total of 57 Munch paintings had a varnish coating and that 30 of these 48 varnished paintings were documented as having been varnished by the NM [27]. The reports also revealed a gradual shift from using traditional natural resin varnishes (post-1950) towards the dominant use of two synthetic types (Laropal K 80 and MS2A) by the mid-1980s. Information from the NM's historic varnish recipes confirmed the use of common additives in small percentages to various mixtures [27]. Microcrystalline wax was included in some recipes to reduce gloss and in some cases a light stabilizer, bis(1,2,2,6,6-pentamethyl-4-piperidyl) sebacate and methyl-1,2,2,6,6-pentamethyl-4-piperidyl sebacate (Tinuvin 292, Ciba-Geigy Marienberg GmbH, Germany), had been incorporated as a preventive method against light ageing [28]. In some cases, the anomalous addition of a heat-bodied linseed oil (stand oil) had also been introduced, possibly to control the application process, saturation and gloss. Notwithstanding the significance of the documentary information, inconsistencies and variations in recording conservation data between 1949 and 1993 were noted in the dossiers, emphasising the need for a chemically specific form of identification of the varnish coatings.

Depth of penetration tests undertaken in DR on varnish applied to glass slides recorded interference signals from the Si–O–Si stretching from the glass between thicknesses of 250 µm and 500 µm. This helped to establish an approximate depth of penetration range for the detection of Laropal K 80 grade 9 varnish, applied to the paintings.

Flower Meadow Field (Woll 148)

Munch's small *plein air* painting, *Flower Meadow Field* was painted whilst he resided with his family on the island of Veierland, South of Oslo in the summer of 1887 [8]. The composition (66.5 cm × 44 cm) donated to the museum in 1921 has been executed rapidly with thick brush strokes and raised impasto on a relatively thin white ground layer. Evidence of early framing marks in the wet oil paint can be seen around all four edges of the composition and the thinly woven canvas support has been later marouflaged onto a cardboard support. Conservation dossiers only record the application of Laropal K 80 grade 9 varnish in 1983 [24]. The purple coloured fluorescence emitted under UV and the stereomicroscopic investigations confirmed the presence of a thick,

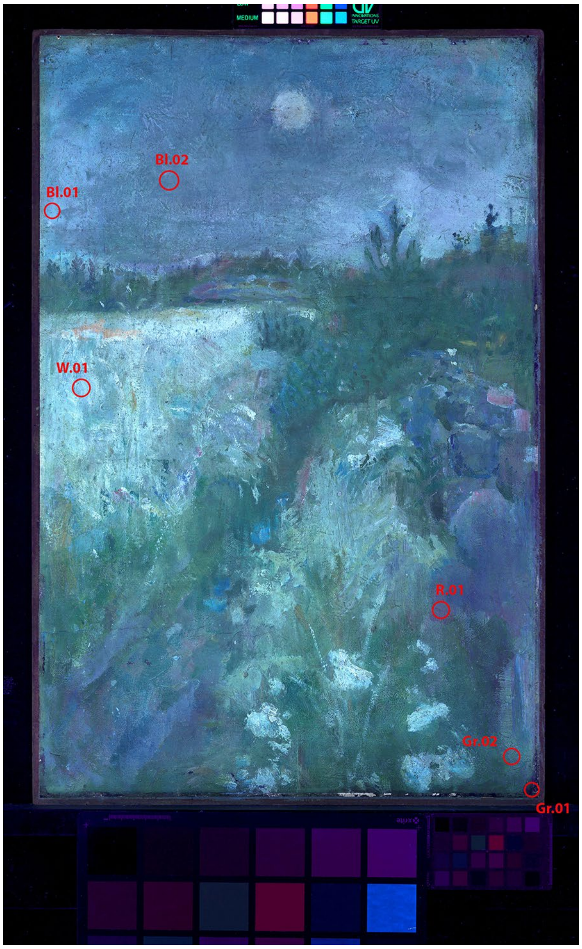

Fig. 3 Flower Meadow Field (Woll 148), UVA-induced fluorescence photography, showing fluorescence of the upper varnish coating and pFTIR spot locations

discoloured (yellowing) and evenly distributed top varnish layer (Fig. 3).

pFTIR spectral readings were taken from four different coloured areas with varnish (Green Gr.02, Blue Bl.01, Bl.02, White W.01 and Red R.01) and one green spot without (Gr.01, old cleaning test). Spectra obtained from all the varnished areas showed intense peaks related to the aliphatic C–H stretching band around 2857 cm^{-1} and 2945 cm^{-1}. These, together with the strong peaks noted at 1451 cm^{-1} and 1712 cm^{-1}, in the green (Gr.02) and red (R.01) pigmented areas, appear to be in line with spectral features of the synthetic resin Laropal K 80 [29] (Fig. 4). For quantifying the reproducibility of the measurements, the coefficient of variation (CV) of the wavenumbers of three independent readings carried out at different times was calculated on different bands (stretching bands of OH, CH_2–CH_3, C≡N and C=O). This ranged from 0.027% for the CH_2–CH_3 peaks centred at around 2930 cm^{-1} to 0.695% for the same bands. This shows a very good reproducibility of the measurements. When relating gloss measurements with the quality of the spectra obtained, a slightly lower value, 8–10 GU, was observed in the varnished green (Gr.02) and red (R.01) areas compared to those noted in the varnished white and blue areas (12–14 GU). In raking light, the surface topography of the paint in the blue sky and white meadow regions revealed a slightly smoother (glossier) surface compared to the more irregular topography from the impasto in the green and red passages of paint. Significantly lower surface gloss measurements (1–2 GU) were recorded in the unvarnished and matt area (Gr.01) and its pFTIR spectrum, plotted with the adjacent varnished area (Gr.02), recorded a definite reduction of the bands around 2854 cm^{-1} and 2940 cm^{-1} (Fig. 5). This confirms that the synthetic Laropal K 80 varnish layer had been removed or reduced to undetectable in the Gr.01 area, after cleaning. Supplementary micro-invasive analysis by THM-GC/MS confirmed the presence of Laropal K 80 in the Gr.02 area. Synthetic resin, and additionally detected components of dammar resin, probably from a previous unrecorded varnish application, as well as a substantial amount of siccative oil, which could have migrated from the paint to the varnish layer [30] (Fig. 6).

The prominent peak at 2088 cm^{-1} noted in many of the spectra could be attributed to the C≡N stretching associated with the pigment Prussian blue from the paint layer [31]. The presence of a stretching band at 3545 cm^{-1} (OH) and a stronger one around 1450 cm^{-1} (carbonate stretching) in the red area (R.01) indicate also the presence of lead white ($2PbCO_3 \cdot Pb(OH)_2$) in that coloured paint.

The identification of the various pigments was difficult to ascertain by their colouration under UVA examination alone, given the overriding and dominant fluorescence of the varnish coatings present. The diffuse presence of lead in all the pXRF readings helped to confirm the use of lead white throughout. Mercury was identified in passages with red paint and implied a palette containing vermillion whilst the iron peaks noted in the XRF spectra of the blue sky helped to further confirm the pFTIR finding for Prussian blue. The presence of chromium recorded in the green areas combined with the dark character (UVA-absorbing) of the unvarnished green area (Gr.01) in UVA light, suggested the use of a chromium green oxide based pigment [32]. Peaks for cadmium and iron were detected in the XRF spectra from various passages of yellow paint and indicated the use of both cadmium yellow and yellow earth, respectively.

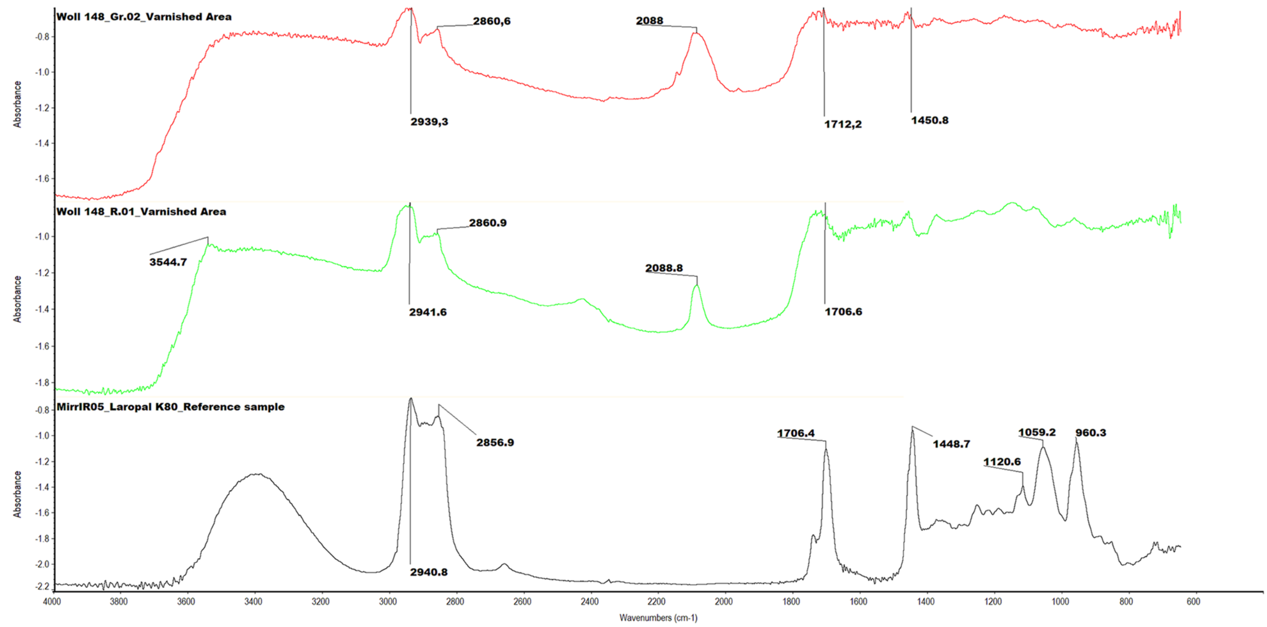

Fig. 4 Portable DRIFT spectra for readings from green and red varnished paint passages (Gr.02 and R.01) and Laropal K 80 grade 9 varnish reference (MirrIR.05), Flower Meadow Field (Woll 148)

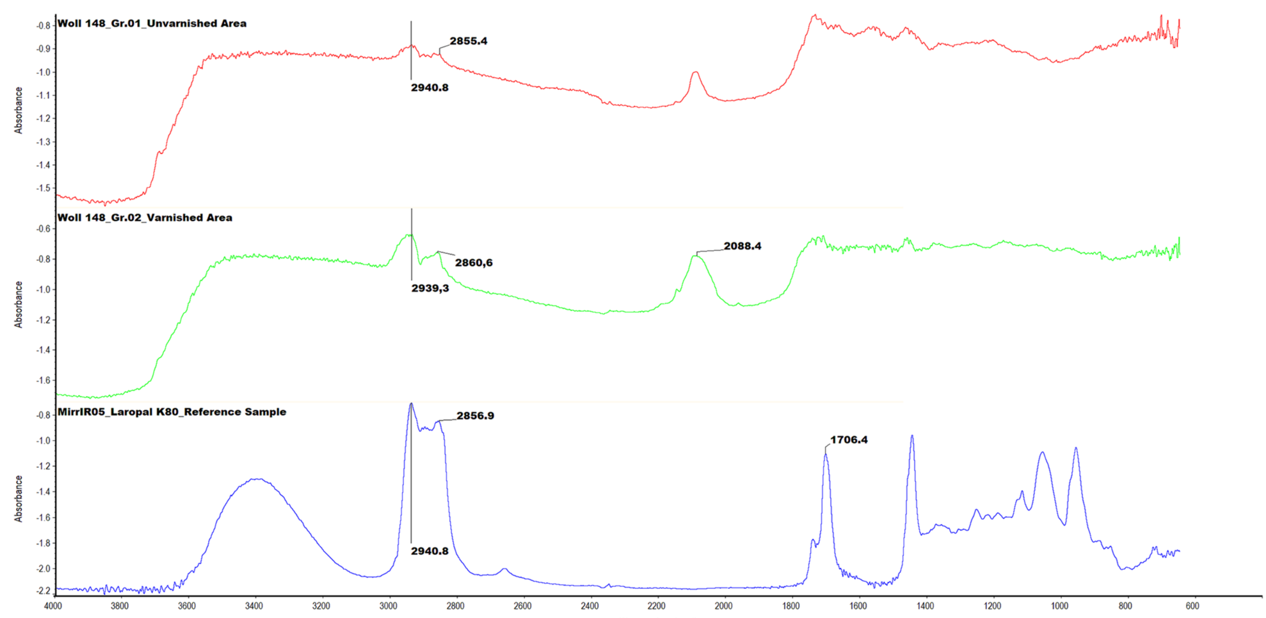

Fig. 5 Portable DRIFT spectra for readings from unvarnished green area (Gr.01), varnished green area (Gr.02) and Laropal K 80 grade 9 varnish reference (MirrIR.05), Flower Meadow Field (Woll 148)

Portrait of Hans Jæger (Woll 174)

Munch painted the portrait of his friend, the bohemian author Hans Jæger (1854–1910), in March/April of 1889 and the painting (109 cm × 84 cm) was owned by Munch until it was purchased by the NM eight years later. Conservation dossiers only mention one major restoration carried out in 1954 when it was cleaned, glue-paste lined and varnished with mastic [22]. Like *Flower Meadow Field*, the paint application is thick with little exposed ground.

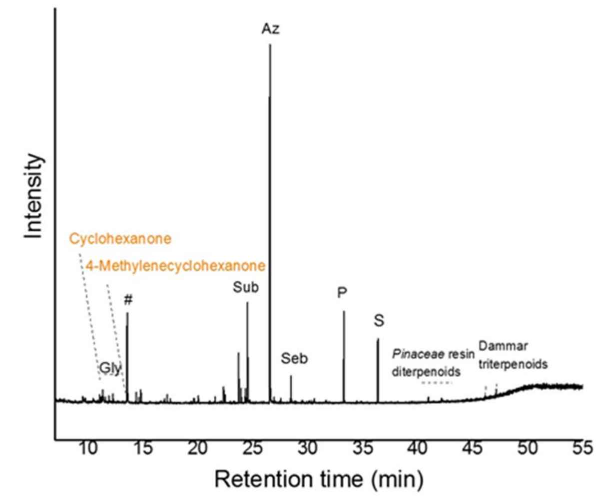

Fig. 6 Total ion chromatogram obtained from THM-GC/MS of varnish scrapings (Gr.02) from Flower Meadow Field (Woll 148). Laropal K80 markers: cyclohexanone and 4-methylcyclohexanone. The drying oil was detected based on the distribution of the methyl esters of fatty acids. *Sub* suberic, *Az* azelaic, *Seb* sebacic, *P* palmitic, *S* stearic, *gly* methyl esters and glycerol. #: reagent peak

Fig. 7 Portrait of Hans Jæger (Woll 174), UVA-induced fluorescence photography, showing fluorescence of the upper varnish coating, pigment differences and pFTIR spot locations

UV photography confirmed the presence of a varnish coating with a dull yellowish, green fluorescence evenly applied throughout (Fig. 7). pFTIR spot readings were taken from different areas, the blue coat (Bl.01 and Bl.02), white background (W.01 and W.02), red/pink flesh tints (R.10), the dark red/brown wood colour from sofa (R.01–R.09) and the yellow paint along the top edge (Y.01). Marked spectral differences were observed between the different coloured areas. The spectra for the reddish/brown spots (R.01) showed intense peaks at 2849 cm^{-1} and 2918 cm^{-1} (Fig. 8). The shapes of the aliphatic CH stretching bands suggested the presence of an oil-natural resin rather than a synthetic one. Moreover, the spectra contained similarities to the mastic reference sample with the association of the carbonyl band at 1740 cm^{-1} with an oil-resin. In contrast, spectral readings taken from the white painted areas (W.01 and W.02) had strong signals typically associated with presence of lead white in the paint layers with an OH band at 3540 cm^{-1} and the broad carbonate band at about 1450 cm^{-1} [33]. This made it difficult to assign spectral characteristics associated with a specific resin varnish. As with *Flower Meadow Field*, for quantifying the reproducibility of the measurements, the CV of three independent readings carried out at different times was calculated on different bands (stretching bands of OH, CH_2–CH_3, C≡N, and CO_3^{2-}). This ranged from 0.010% for the CO_3^{2-} peaks centred at around 1450 cm^{-1} to 0.653% for the CH_2-CH_3 stretching bands centred at around 2950 cm^{-1}. Again, this showed a very good reproducibility of the pFTIR measurements. Surface gloss measurements revealed higher values recorded in the smoother surface topography of the white regions (17–22 GU) compared to those from the irregular surface topography of the textured brush strokes in the reddish/brown areas (4–8 GU). As noted in the painting, *Flower Meadow Field*, the clarity of the spectra for varnish resin identification appeared to be influenced by its thickness, surface texture, and pigment composition. A similar low 1–2 GU range was also recorded in unvarnished regions, along the painted tacking edges.

X-radiographs taken in 1993 revealed that Munch had extensively re-worked the bottom right-hand corner of the composition, the table, and had also undertaken some minor alterations to the sitter's seated position by lowering the right-shoulder, arm and hand [34]. In contrast to *Flower Meadow Field*, the distinctive colouration of certain pigments, when illuminated by UVA radiation, could be detected. Two different types of white pigment, lead white and zinc white, appear to have been used by Munch, possibly in relation to the compositional process and later alterations. In the passages of white paint

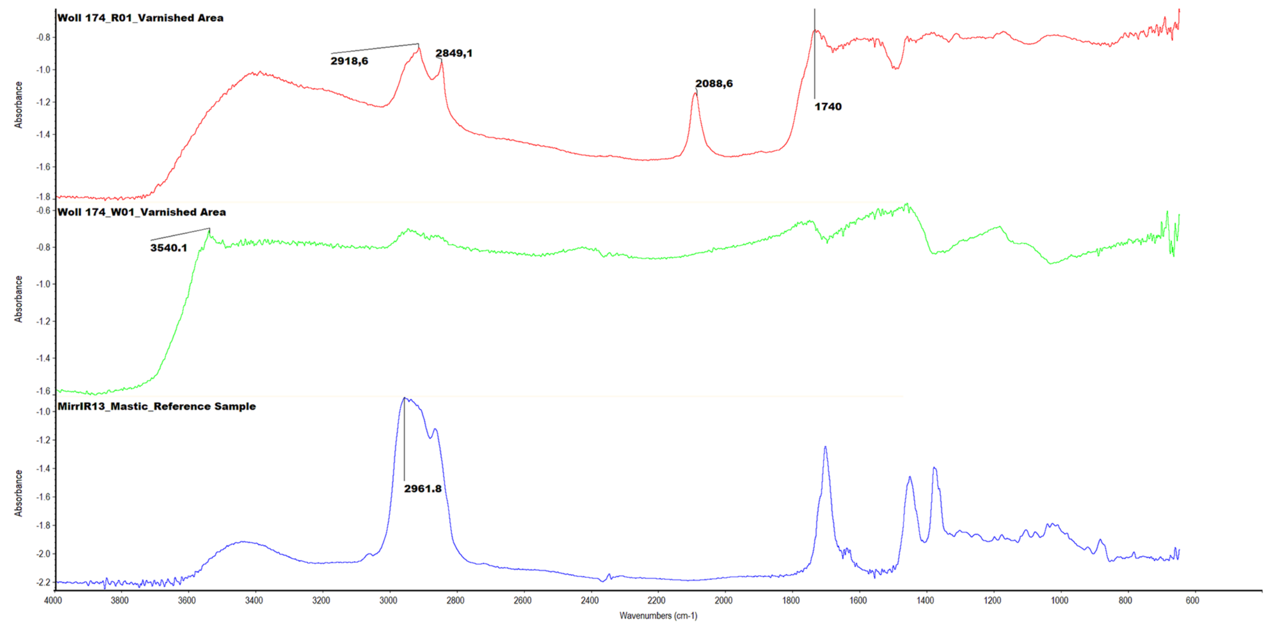

Fig. 8 Portable DRIFT spectra for readings from red (R.01) and white paint areas (W.01) and mastic varnish reference (MirrIR.13), Portrait of Hans Jæger (Woll 174)

and pigment mixtures, a difference between the characteristic reddish-purple UVA-fluorescence colouration of lead white and the opaquer greenish-yellow colouration associated with zinc white was noted [32]. The presence of lead and zinc was further supported by pXRF. A typical dark blue UVA-induced fluorescence witnessed in the blue region (Bl.02), combined with traces of iron detected by pXRF, helped to confirm the presence of Prussian blue. Vermillion was also probably identified using pXRF through the presence of mercury.

Night in Nice (Woll 224)

The NM's first Munch acquisition is the small painting, *Night in Nice* (40 cm × 54 cm), which was purchased from the autumn state art exhibition (Høstutstillingen—Statens Kunstutstilling) in the same year as it was painted, 1891 [1, 2, 8]. As an early work, Munch's painting technique is relatively traditional in terms of paint application. The build-up is simple compared to the two other works examined, thinly executed and with no distinct raised impasto or surface textural effects. Part of the motif is present on the lower tacking edge and a canvas stamp with no. 15 on the reverse indicates a French commercial standard format of 65 cm × 54 cm. The canvas has been later reduced (cut) in height from 65 to 48 cm by the artist and stretched onto a smaller stretcher. According to the conservation records, a coat of Laropal K 80 grade 9 varnish was sprayed over the paint surface in 1983 after a light surface cleaning [23]. The presence of varnish was confirmed by the strong yellow/green coloured fluorescence under UVA examination (Fig. 9).

Closer microscopic examination further confirmed a varnish coating that does not extend to all four edges of the canvas. Moreover, drip marks in the varnish along the lower canvas edge appear to correspond precisely

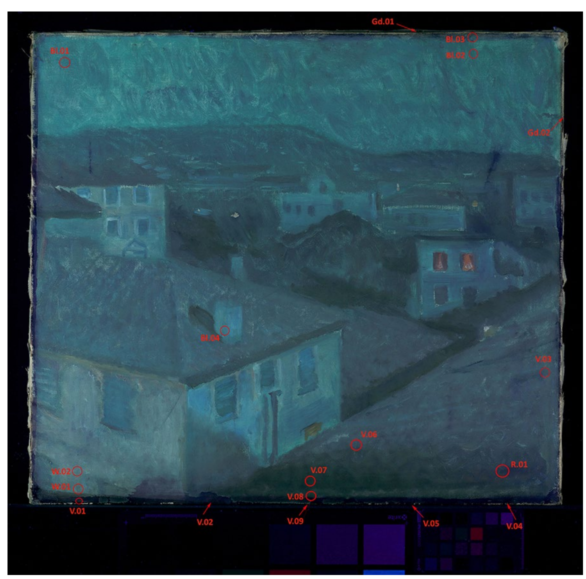

Fig. 9 Night in Nice (Woll 224), UVA-induced fluorescence photography, showing fluorescence of varnish and pFTIR spot locations

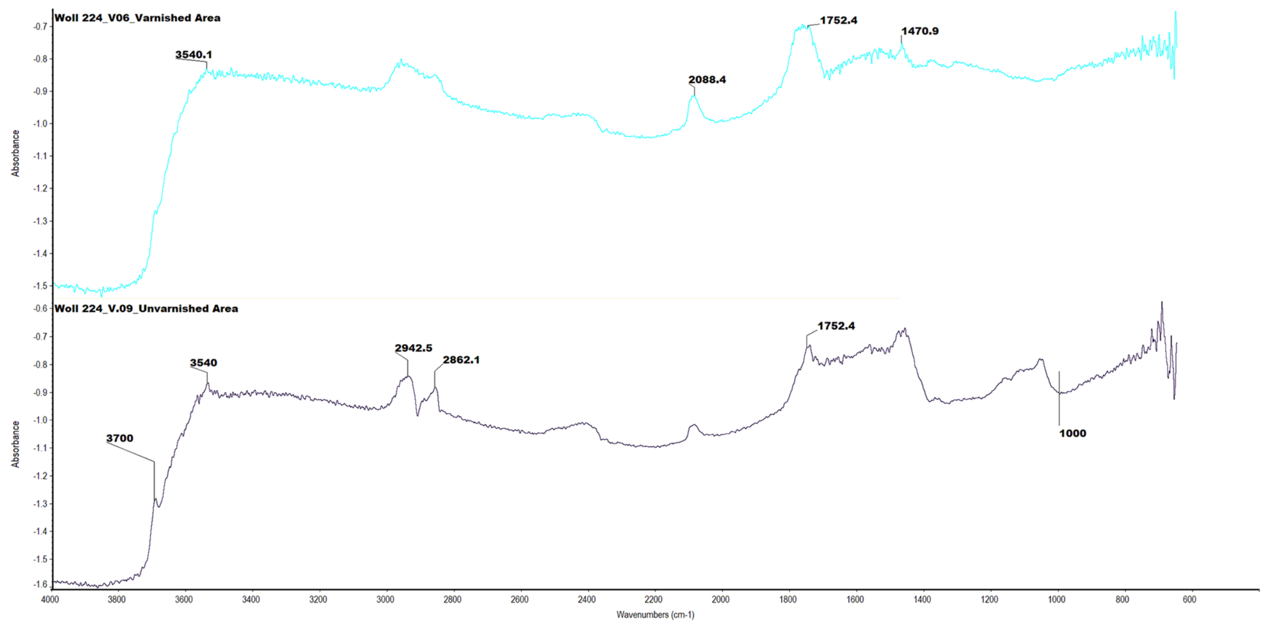

Fig. 10 Portable DRIFT spectra for readings from blue/red paint spots (V.06 and V.09), Night in Nice (Woll 224)

with a fluorescence pattern detected under UVA light along the lower inner sight-edge of the original frame. These findings confirmed the presence of an earlier and previously undocumented varnish layer underneath the aforementioned thinly applied synthetic varnish (Laropal K 80 grade 9) recorded from 1983. It is possible that this varnish was directly applied whilst the canvas was still in its frame. In situ pFTIR measurements were recorded over different coloured areas of blue (Bl), violet (V), white (W) and red (R), and along the lower unvarnished tacking margin including areas with exposed ground (Gd) (Fig. 9). Preliminary results captured characteristic spectral features for lead white with typical absorptions for OH bond at 3540 cm^{-1} and for carbonate around 1470 cm^{-1}, predictably more prominent in the unvarnished areas [33] (Fig. 10).

As in *Flower Meadow Field*, the reoccurring prominent peak at 2088 cm^{-1} present in many of the spectra could be associated with the presence of Prussian blue in the underlying paint. However, no bands typical of a synthetic Laropal K 80 resin, allegedly applied to the surface in 1983, were detected in any of the spectra. As noted by Miliani et al. [20] caution is required when extrapolating data from the FTIR spectra due to the often-complex stratigraphic character and heterogeneous nature of paint layers and surface coatings, which need to be understood. Comparisons between readings taken from two similarly pigmented areas, one varnished (V.06) and one unvarnished (V.09), revealed some minor spectral differences. In the unvarnished area, sharp derivative inverted bands at 2862 cm^{-1} and 2942 cm^{-1}, typical of the CH_2 and CH_3 stretch for an oil, were detected, as was the carbonyl stretch at around 1752 cm^{-1}. In the varnished area, the absorptions for the CH_2 and CH_3 stretch are relatively weak. Supplementary micro-invasive analysis was thus undertaken for clearer identification of the varnish coatings. The presence of Prussian blue was confirmed with ATR-FTIR and Raman analyses (V.06) and further tests using THM-GC/MS confirmed the presence of a drying oil and components of dammar. No Laropal K 80 resin was detected suggesting that either it had been removed post-1983 or that the painting was never actually varnished with it, contrary to the conservation report. Gloss measurements taken from all the varnished pFTIR spot locations recorded values of 12–14 GU and low values (1–2 GU) in the unvarnished regions. The similar high gloss surface readings recorded on the various varnished parts of the paint surface correspond to the painting's relatively flatter surface topography and minimal surface texture. Like with *Flower Meadow Field*, the identification of the various pigments proved difficult to be ascertained by their colouration under UVA radiation. pXRF helped to confirm the use of lead white, vermillion and cadmium yellow. Traces of iron, associated with Prussian blue, were also detected.

Conclusion

This study aimed to test the versatility of pFTIR for the surface analysis of non-original varnish coatings on three Munch paintings from the NM's collection.

pFTIR proved useful for the investigation and further understanding of the historic varnish controversy regarding this specific collection. In two cases, it was possible to align the pFTIR results with information derived from archival sources, but the discrepancy observed with *Night in Nice* highlighted the need for a reliable and comprehensive methodology for the identification of the varnish coatings. Spectra collected in DR from different passages of paint in all three paintings showed a certain degree of pigment interference. In fact, bands associated with known pigments, such as Prussian blue and lead white, were observed in some of the recorded spectra. A strong pigment interference was especially noted with the more optically flat and glossy surfaces. Yet, marked differences in gloss readings between a matt or irregular surface topography with a glossier, smoother varnished area, also appeared to influence the clarity of the DRIFT spectra. The possible impact of surface topography, varnish thickness and pigment type require further investigation. The integration of historical conservation documentation with visual examinations and pigment identification, remained paramount for pFTIR spectral interpretation as did the creation of a good reference library in DR, comprised of relevant and known varnish recipes. Nevertheless, the typical heterogeneous structure of paint and varnish films often contributed to the acquisition of complex pFTIR spectra. Overlapping bands attributable to compounds from pigments and varnishes restricted the possibility of unambiguously matching DRIFT spectra from paintings with the reference samples. Results from micro-invasive techniques (namely, ATR-FTIR, Raman and THM-GC/MS) were thus necessary for a more decisive validation of the results. Notwithstanding these limitations, it was possible to detect and confirm the presence of Laropal K 80 resin on one of the paintings. The preliminary results further served to evaluate the use of pFTIR as a suitable screening method for the chemical characterization of varnish coatings for the remaining varnished Munch paintings in the NM's collection. As a method for non-invasive and in situ analyses of painted surfaces, it was found to offer several practical and user-friendly advantages for the conservator. These included the benefit of taking unlimited readings from multiple areas, with good reproducibility. A controlled and safe contact was also achieved between the measuring interface and the paint surface for spectral readings. In addition, although the pFTIR equipment is relatively user-friendly to operate, the complexity of interpreting results underlined the importance of collaboration between conservator and scientist. Despite its drawbacks, the use of a portable DRIFTS device notably contributed to the preliminary screening of upper and non-original varnish coatings applied to the three Munch paintings, when used in a multi-analytical context.

Abbreviations

ATR-FTIR: attenuated total reflection infrared Fourier transform spectroscopy; CV: coefficient of variation; DR: diffuse reflectance; DRIFTS: diffuse reflectance infrared Fourier transform spectroscopy; pFTIR: portable infrared fourier transform spectroscopy; GC/MS: gas chromatography–mass spectrometry; GU: gloss units; IRR: infrared reflectography; NM: The National Museum of Art, Norway; THM-GC/MS: thermally assisted hydrolysis and methylation-gas chromatography–mass spectrometry; UVA: ultra violet light between 315 nm and 400 nm, after ISO 21348 definitions of solar irradiance spectral categories; pXRF: portable X-ray fluorescence spectrometry.

Acknowledgements

The authors are grateful to the National Museum of Art, Norway, for full access to the paintings. The authors would also like to thank Børre Høstland and Duncan Slarke for their assistance with the UV and IRR photography and to the art historian, Nils Messel, for advice on the Munch collection.

Authors' contributions

TF designed the research and performed the pFTIR experiments. ATR-FTIR, benchtop FTIR, Raman and THM-GC/MS experiments were carried out by AR. TF, AR and FC contributed in analysing and interpreting the data. TF wrote the first draft of the paper. All the authors contributed by interpretation and writing the paper. All authors read and approved the final manuscript.

Funding

The project is part of Thierry Ford's Ph.D. study, which is fully funded by the National Museum of Art, Norway.

Availability of data and materials

Raw data is available from the authors on request.

Competing interests

The authors declare that they have no competing interests.

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Received: 19 June 2019 Accepted: 2 October 2019
Published online: 22 October 2019

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Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

6.3 Paper III

Eur. Phys. J. Plus (2021) 136:899
https://doi.org/10.1140/epjp/s13360-021-01758-5

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Munch and optical coherence tomography: unravelling historical and artist applied varnish layers in painting collections

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Received: 1 November 2020 / Accepted: 14 July 2021

Abstract Effective care of large-scale museum collections requires planning that includes the conservation treatment of specific groups of art works, such as appropriate cleaning strategies. Optical coherence tomography (OCT) has been successfully applied as a non-invasive method for the stratigraphic visualisation of the uppermost transparent and semi-transparent layers in paintings, such as varnishes. Several OCT case study examples have further demonstrated the capabilities of the non-contact interferometric technique to measure the thickness of the various varnish layers, to help monitor cleaning and associated optical changes, and to detect past restorations. OCT was applied for the detection of varnishes to 13 paintings by Edvard Munch (1863–1944) owned by the Norwegian National Museum of Art. The paintings have a controversial and complex varnish history and are displayed as a group according to their acquisition legacy. A prototype high-resolution portable SdOCT instrument was used in combination with complementary imaging techniques. Questions concerning thickness, stratigraphy and the identification/location of the artist's original varnish layers and/or pigmented glazes were addressed. Findings confirmed the complexity of the historical layers present and provided new evidence for Munch's use of transparent and semi-transparent layers as part of an occasional, localised varnishing and/or glazing technique.

1 Introduction

The 57 paintings by Edvard Munch (1863–1944) housed at the Norwegian National Museum of Art (NaM) represent the first historic public collection by the artist. Acquired over a period of 79 years (1891–1970), the paintings are a hand-picked *ensemble* of Munch's earlier

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and mid-career masterpieces (1881–1920). Their international *renommé* and significance, in terms of national cultural identity, are coupled with their distinct display history as a specific group, exhibited in a dedicated space known as the *'Munch Room'* [1, 2]. Munch's attitude to varnish as a surface coating and its employment in his painting technique has been described as 'unclear', and a prior survey of conservation documents recommends that *'best source for investigating Munch's varnishing practice is the paintings themselves'* [3].[1] Munch's paint surfaces are typically associated with a matt and unvarnished finish, yet there are several recent references from works dated between 1880–1900, inferring his employment of varnish resins as part of an occasional, localised saturation/gloss effect [4–9]. Today, many of Munch's original surface effects have been visually reduced by past restorations and natural ageing. Evidence of the museum's repeated often controversial application of non-original varnishes has been both documented and recently investigated [3, 10]. A large proportion of the paintings (48 out of 57) were initially varnished and then re-varnished by the NaM between 1891–1993, with either a natural varnish resin, a synthetic one or a mixture of both. The overall goal of this study was to gain a better insight into the non-original varnish coatings and Munch's own intended surface finishes from the specific period, 1880–1900.

To understand the current visual relationship of these works displayed as a group requires a proper discernment of the stratigraphy, composition and condition of their surfaces, especially given that there is recent evidence to suggest that Munch practised local varnishing or the application of pigmented glazes to adjust matt–gloss relationships.[2] These subtle orchestrated effects are now lost due to the application of later varnishes so that they can no longer easily be discerned using visual or ultraviolet-induced fluorescence (UVA) inspection and require other means of clarification. Given this reason, and in line with the collection's long and complex conservation history, this study explores the diagnostic capabilities of optical coherence tomography (OCT) as a promising non-invasive detection method to investigate this phenomenon [12]. The benefit of employing OCT is its ability to non-invasively provide a cross-sectional imaging of the uppermost transparent and semi-transparent layers in paintings, such as varnishes and glazes, without physical sampling [13–19].

Thirteen paintings were investigated with a specific selection criterion. All works represent early acquisitions by the NaM and date from the period 1884–1900. The study also includes one of the few paintings where there is both documentary and analytical evidence of Munch's use of varnish in his painting technique, *The Sick Child* (Woll M 130) [8]. Two paintings have unvarnished and unrestored paint surfaces, serving as a comparison (*The Scream* Woll M 333 and *Self-portrait with Cigarette* Woll M 382). Questions concerning the layering and morphology of the later non-original varnish coatings (either lying on top of the paint surface or absorbed into the ground layer) were also addressed.

The study represents the first OCT non-invasive investigations of original and secondary stratigraphic varnish layers present across a specific group of late nineteenth-century Munch paintings (1880–1900). Complementary investigations were adopted to support the OCT analyses; optical and digital microscopy, visible photography, UVA-induced fluorescence photography, infrared reflectography (IRR) and portable X-ray fluorescence spectroscopy (pXRF).

The findings aim to contribute to long-term preservation and conservation decisions, namely how to design suitable methods and protocols for the removal of later non-original

[1] The term varnish refers to the resinous coating (natural or synthetic) which has been applied as final and unified transparent top layer to a paint surface. It can also be used as an intermediate layer, selectively employed by the artist to control the saturation of the paint.

[2] The term glaze refers to the application of transparent pigments in clear vehicle. It can be used locally to either modify the colour of the paint underneath or as an 'over-all toning layer' [11].

varnish coatings. In addition, this paper builds on an earlier study whilst also laying the foundation for further research, for the characterisation of the varnish layers in the Munch collection [10].

2 Material and methods[3]

2.1 Imaging techniques

The paint surfaces, varnish coatings and their condition were first documented through the combination of optical and digital microscopy with photographic techniques. A Leica Wild M8 stereomicroscope, (5 × − 50 × magnification range, Ortomedic AS, Lysaker, Norway) and Hirox RH-2000-3D digital microscope (Full HD 20 × − 160 × zoom lens, Hirox Europe, Limonest, France.) were employed to study and capture the surface topography relevant for finding appropriate locations for OCT readings. All thirteen paintings were also examined with UVA-induced fluorescence photography following the CHARISMA standards [20]. A Hasselblad H6D-400C MS digital camera (Interfoto AS, Oslo, Norway) with a Baader UV/infrared (IR) Cut/L-Filter (Baader Planetarium, Mammendorf, Germany) was employed in conjunction with a Target-UV calibration patch (Image Science Associates, LLC, Williamson, NY, the USA) to control colour and intensity of UVA-induced visible fluorescence. Two UVA luminaires were placed at equal distance, on either side of the painting, with three 40-W UVA fluorescent tubes per luminaire, radiating in the 355–360 nm region. IRR was taken using the Apollo digital scanning InGaAs IRR camera (operation wavelength 0.9–1.7 μm, Opus Instruments, Norwich, the UK).

2.2 pXRF

pXRF measurements were taken with a Thermo Niton XL3t 900 energy dispersive pXRF spectrometer (Thermo Scientific, Holger Hartmann, Oslo, Norway) with a Si-drift detector (GOLDD—Geometrically Optimized Large Drift Detector) attached to a tripod. Multiple readings were taken from the same areas analysed by OCT or adjacent passages with dominant primary, secondary, black and white colours. The proprietary "Mining Cu/Zn Testing Mode" was used. Total measurement time was ca. 60 s for each reading and the instrument switched automatically from main (Al/Fe filter, maximum current: 40 μA, operating at 50 kV) to low (Cu filter, 20 kV, operating at 50 kV maximum current: 100 μA), high (Mo filter, maximum current: 40 μA, operating at 50 kV) and light range filters.

2.3 OCT

OCT is a non-contact interferometric scanning technique employing broadband infrared radiation which is either scattered or reflected by the surface. The depth of penetration is determined by the absorption properties of the medium examined and allows the precise measurement of the various varnish layers (and/or glazes) present, as well as detecting past restorations [14, 16]. A virtual cross section (OCT tomogram) can be rapidly created from the consecutive and adjacent set of penetration scans (B-scans) along a specific line [15].

OCT examinations were carried out using a prototype high-resolution portable SdOCT instrument designed and built under the EU FP7 CHARISMA and H2020 IPERION CH Pro-

[3] The description of the following techniques and analyses, except for OCT, are revised from an earlier methodology text [10].

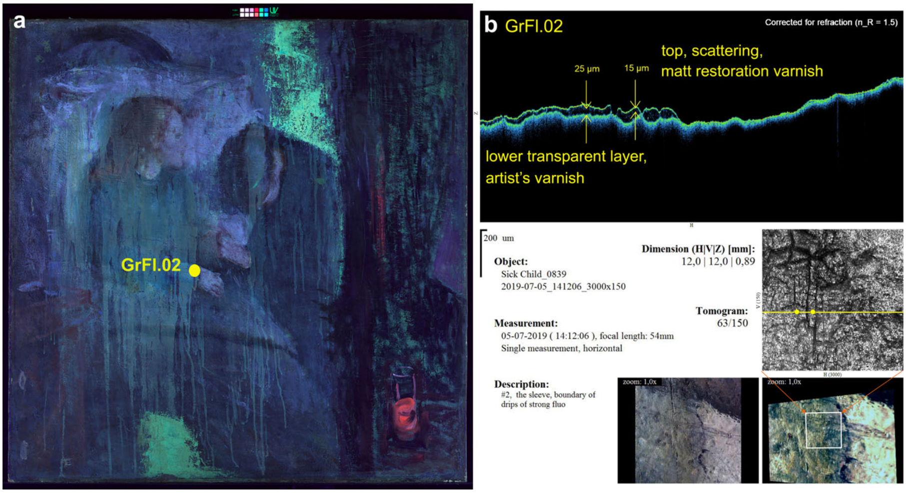


Fig. 1 *The Sick Child* (Woll M 130), **a** UVA-induced fluorescence photography with location of OCT examination spot, **b** OCT tomogram and IR reflectogram from same examination spot GrFl.02 (green sleeve/girl's hand)

grammes (at Nicolaus Copernicus University, Toruń, Poland) [21]. Scanning was performed at a 43 mm distance to the surfaces, with the paintings placed horizontally on a table. The OCT instrument was operated with a broadband superluminescent light source with a spectral range of 750–950 nm (M-T-850-HP broadlighter, Superlum, Ireland) and a maximum of 800 µW of probing light at the object's surface. A complete set of resultant vertical and/or horizontal 2D tomograms (B-scans) were obtained from selected areas of interest, previous analysis and/or from pXRF spots. These images were obtained with a 2.2 µm axial resolution in the varnish and with a lateral resolution of 15 µm. The OCT tomograms were corrected for refraction of light, using a common value of refracting index $n_R = 1.5$ and are presented in a false colour scale (blue to green for low and moderate scattering, yellow to red for high scattering and black for complete transparency or beyond the range of penetration). Horizontal and vertical scale bars correspond to 200 µm with the vertical axis stretched tenfold for readability. The data were collected in the form of 150 parallel 2D slices acquired from a 12×12 mm^2 area with the most representative slice presented in the figures. The OCT data presented as composite panels (see Figs. 1 and 2 and A.1in Electronic Supplementary Materials) show the whole cross section $12 \times 0{,}89$ mm^2, complemented by an IR reflectogram generated directly from the OCT data and two macrographs of the scanned area. The positions of the measurement readings and annotations in the OCT cross section are also marked on the corresponding yellow scan line in the IR reflectogram.

3 Groups and categories

Thirteen paintings were selected from the period 1884–1900 and divided into three categories according to date, painting technique and surface finish (Table 1). The OCT findings were closely correlated with previous treatment histories recorded in either post 1949 conservation dossiers or from other archival sources [12]. Dammar, Mastic, Laropal K-80 and MS2A var-

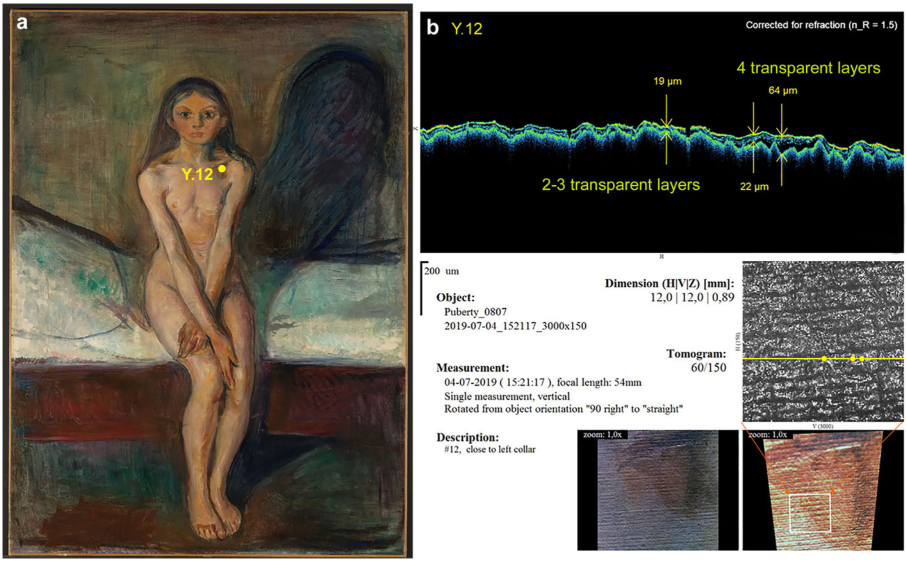


Fig. 2 *Puberty* (Woll M 347), **a** normal light photography with location of OCT examination spot Y.12, **b** OCT tomogram and IR reflectogram from same examination spot Y12 (3 locally applied transparent layers underneath restoration varnish)

nish resins are documented as having been used by the NaM since the first Munch acquisition [10].

3.1 Group 1: 1884–1889

In 1885, Munch was awarded a travel grant to study in Paris and was both accompanied and surrounded by an important group of Norwegian painters [22–24]. The five paintings selected for group 1 (Table 1) share visible common traits in the form of thicker paint application, combined with prominent brush work and uneven surface topographies. This characteristic in Munch's painting technique during the 1880s has been described as *'in keeping with the naturalistic trend and Parisian influence*' [25].

3.2 Group 2: 1890–1900

Group 2 features the NaM's versions of the paintings, *Puberty, The Day After* and *Madonna* (Woll M 347, 348 and 366) which have interesting similarities in terms of their acquisition, conservation history as well as paint technique and production date (Table 1). Moreover, all three works are central to Munch's conceptualisation of the woman, and in the scholarly literature, they are often discussed as a group [26]. All three were acquired by the NaM in 1909 and have undergone cleaning, lining and varnishing treatments.[4] The paintings are early versions of Munch's iconic motifs and *Puberty* and *The Day After* were named as being *'vandalised'* by the museum through varnishing in 1909 [27]. The group also includes two early works, *Night in Nice* (Woll M 224) and *Winter in the Woods, Nordstrand* (Woll M 445). The former represents the NaM's first Munch acquisition in 1891, and both works bear

[4] NaM conservation dossiers; NG.M.00807, NG.M.00808 and NG.M.00841.

Table 1 Summary of OCT analyses; group 1 (1884–1889), group 2 (1890–1900) and group 3 (unvarnished paintings)

Painting details	Group	Fig.	Total no. OCT examination spots	OCT Main observations and layer thickness (μm)
Woll M 113 *Inger Munch in Black*  1884, oil on canvas (97 × 67 cm)	1	Figure 3; A.1 ESM Figs. 1, 2, 3	22	Up to four transparent/semi-transparent layers (24–100 μm) in flesh areas (face, neck and hands) (spot Fl.03) Two transparent varnish layers present over dark dress and background (average total thickness, ca. 45 μm) Two thin restoration varnish layers over red signature (spot RBk.15) Artist's alterations under two restoration varnish layers (spot BkFl.09). Some of the black/dark paint layers are semi-transparent to IR

Table 1 continued

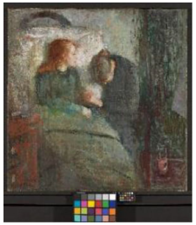
Painting details	Group	Fig.	Total no. OCT examination spots	OCT Main observations and layer thickness (µm)
Woll M 130 *The Sick Child*  1885/6, oil on canvas (120 × 118.5 cm)	1	Figure 1	5	Locally applied transparent and semi-transparent layers Evidence of the later restoration matt varnish layer (15–20 µm) over Munch's transparent varnish drips (ca 25 µm) (spots: Gr.01 and GrFl.02)

Table 1 continued

Painting details	Group	Fig.	Total no. OCT examination spots	OCT Main observations and layer thickness (µm)
Woll M 133 *Self-portrait*  1886, oil on canvas (33 × 24.5 cm)	1	A.1 ESM Figs. 9, 10	8	In all scanned areas, there are two transparent varnish layers The upper layer is generally thicker (ca 15–30 µm) and the lower, generally thinner (ca 5–10 µm) The red signature is located between the two layers (spot RGr.08)

Table 1 continued

Painting details	Group	Fig.	Total no. OCT examination spots	OCT Main observations and layer thickness (μm)
Woll M 148 *Flowery meadow at Veierland*  1887, oil on canvas on board (66.5 × 44 cm)	1	A.1 ESM Figs. 11, 12	10	Four layers of varnish (combined thickness 30–49 μm) in the foreground (spot Gr.04) One to two thin layers (5–7 μm) present in the blue sky

Table 1 continued

Painting details	Group	Fig.	Total no. OCT examination spots	OCT Main observations and layer thickness (µm)
Woll M 174 *Hans Jæger*  1889, oil canvas (109 × 84 cm)	1	A.1 ESM Figs. 15, 16	7	One transparent varnish layer present over the whole painted surface. Unevenly applied (spot Br.06)

Table 1 continued

Painting details	Group	Fig.	Total no. OCT examination spots	OCT Main observations and layer thickness (μm)
Woll M 224 *Night in Nice*  1891, oil on canvas (48 × 54 cm)	2	–	4	Only one varnish layer present (4-17 μm)

Table 1 continued

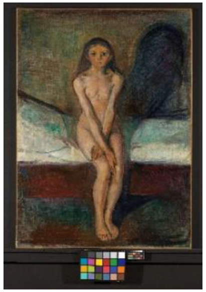
Painting details	Group	Fig.	Total no. OCT examination spots	OCT Main observations and layer thickness (µm)
Woll M 347 *Puberty*  1894/5, oil on canvas (151.5 × 110 cm)	2	Figures 2, 4; A.1 ESM Figs. 4, 5, 6	23	In most of the examined spots, there is one varnish layer (thickness usually not exceeding 20 µm) Second transparent layer identified in red drips, foreground (fig. spot R.02) Up to four locally applied transparent layers in the figure (spots: Y12-15) Some of the artist's alterations are visible in OCT (spots: Fl.04 and Y15)

Table 1 continued

Painting details	Group	Fig.	Total no. OCT examination spots	OCT Main observations and layer thickness (μm)
Woll M 348 *The Day After*  1894, oil on canvas (115 × 152 cm)	2	A.1 ESM Figs. 13, 14	20	Two varnish layers were found in most of the measured spots Semi-transparent paint was imaged in some spots as a finishing on an opaque paint layer (spots: Fl.01, Br.03, R.16 and 17, Gr.18 & 19) Previous restorations also visible

Table 1 continued

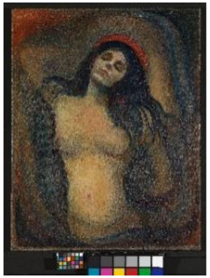
Painting details	Group	Fig.	Total no. OCT examination spots	OCT Main observations and layer thickness (μm)
Woll M 366 *Madonna*  1894, oil on canvas (90.5 × 70.5 cm)	2	Figure 5; A.1 ESM Fig. 7	10	In most of the examined spots, there are two transparent layers Three transparent layers were found in boundaries between face and hair, on top of crayon lines (spots: Bk.08, RBk.09 and 10)

Table 1 continued

Painting details	Group	Fig.	Total no. OCT examination spots	OCT Main observations and layer thickness (µm)
Woll 445 *Winter in the Woods*  1899, Oil on board (60.5 × 90 cm)	2	–	8	Two varnish layers were found in most of measured spots Artist's fingerprint (spot BrGr.05) is covered by 2 varnish layers (11–19 µm)

Table 1 continued

Painting details	Group	Fig.	Total no. OCT examination spots	OCT Main observations and layer thickness (µm)
Woll 464 *The Dance of Life*  1899-1900, oil on canvas (125 × 191)	2	Figure 6; A.1 ESM Fig. 8	28	Evidence of locally applied artist's varnish and saturation effects Drips and patches of added oil binder found (result of Munch's alterations). In some case, these have been retouched (spot R.22) The binder creates thick layers which in many cases are covered by a scattering layer, which may be ascribed to secondary restorers' attempts to even out the gloss of the surface by means of a matted varnish Blue crayon (Munch's addition) lies over a transparent layer (spot Bl.11) The dark red signature is located on top of the transparent layer (spot RBl.17)

Table 1 continued

Painting details	Group	Fig.	Total no. OCT examination spots	OCT Main observations and layer thickness (µm)
Woll M 333 *The Scream*  1893, Tempera, casein/egg, oil on unprimed cardboard (91 × 73.5 cm)	3	Figure 8; A.1 ESM Figs. 19, 20	9	Despite lack of varnish, a transparent layer is visible locally (spot Bl.05)

Table 1 continued

Painting details	Group	Fig.	Total no. OCT examination spots	OCT Main observations and layer thickness (µm)
Woll 382 *Self-portrait with Cigarette*  1895, oil on canvas (110.5 × 85.5 cm)	3	Figure 7, A.1 ESM Figs. 17, 18	9	The overall uneven surface gloss appears to be the result from locally applied semi-transparent paint layers (spot Bl.04) Artist's alterations (added oil) visible (spot Bl.07)

evidence of varnishes applied by the museum whilst framed.[5] *The Dance of Life* (Woll M 464) was the last motif that Munch painted for his frieze of life, summing up elements of love and the way of life [28]. Conservation dossiers record the presence of an uneven surface gloss throughout, with the possibility of a locally applied artist's varnish.[6]

3.3 Group 3: unvarnished paintings

The last category is comprised of the two iconic works, *Self-portrait with cigarette* and the first version of *The Scream,* dated 1893 (Table 1). Both paintings were chosen for comparative reasons in so far as they are unvarnished and unadulterated by previous restoration treatments.[7]

4 Results and discussion

4.1 Artist's varnish and adjustments

Munch's portrait of his 16-year-old sister, Inger, in her black confirmation dress (Woll M 113, group 1) is the earliest painting investigated in terms of production date. The realist style of the portrait has been compared to the work of the Norwegian artist Hans Heyerdahl (1857–1913) and the painting made Munch's *'international debut'* at The Antwerp International Exhibition [25]. A year later, Munch painted *The Sick Child* (group 1), which marked a turning point in the artist's career and has been described as a masterpiece [25]. Unlike his portrait of Inger, this painting created a stir at the 1886 Annual Autumn Exhibition in Kristiania (Oslo), attracting both strong criticism and praise, due to Munch's new and radical paint application [8]. The motif has been heavily reworked by Munch with deliberate scratches and scoring which break-up the texture of the thick oil paint layers. Much of the public outcry concerning the painting in 1886 was related to Munch's rough rendering of the paint surface with visible streaks of varnish running down the figures (Fig. 1a).

Conservation dossiers from 1954 record that both paintings were in poor condition after their return from the World War II evacuation sites which resulted in extensive restorations involving surface cleaning, varnish removal, lining and re-varnishing.[8] Moreover, traces of an artist's varnish had also been noted by the responsible conservator in both reports. UVA photography of *Inger Munch in Black* reveals an uneven greenish fluorescence (Fig. 3a). In addition, the visually thick, discoloured semi-transparent layers in her face further suggest the possibility of earlier resinous layers lying underneath a more recently applied restoration varnish.

In the case of *The Sick Child,* the 1886 varnish streaks which are no longer visible to the naked eye are clearly distinguishable in the UVA photograph (Fig. 1a). Furthermore, *The Sick Child* is one of the few paintings at the NaM to have undergone previous technological examinations and represents also one of the rare instances where Munch's use of a pine resin varnish has already been chemically confirmed [8].

5 The varnish coatings stop short of the four canvas edges by approximately 5 mm and both paintings were framed by the NaM after their acquisition. NaM conservation dossiers; NG.M.00394 & NG.M.00570.

6 NaM conservation dossier; NG.M.00941.

7 NaM conservation dossiers; NG.M.00470 and NG.M.00939.

8 NaM conservation dossiers; NG.M.00839 and NG.M.01862.

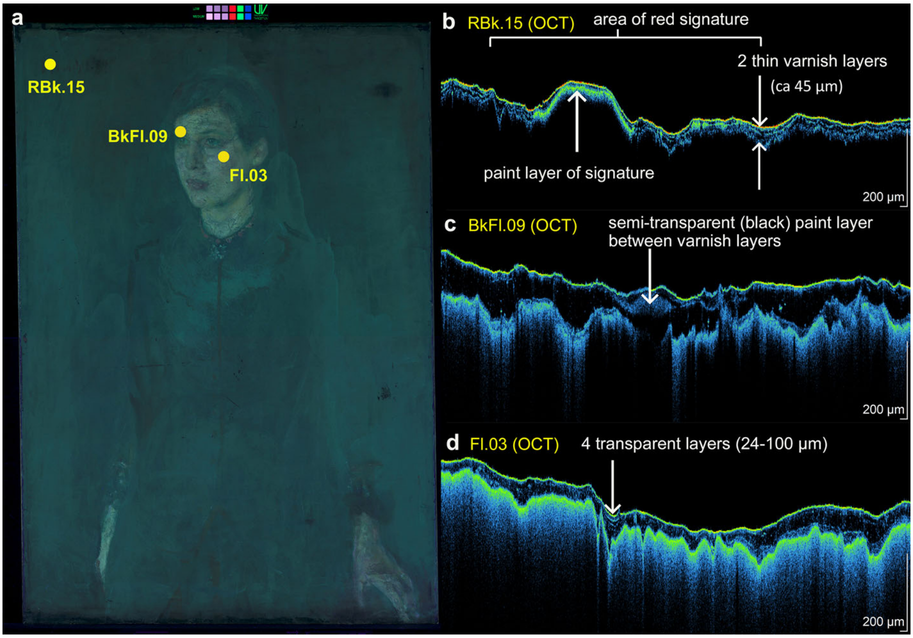


Fig. 3 *Inger Munch in Black* (Woll M 113), **a** UVA-induced fluorescence photography, **b** OCT tomogram examination spot RBk.15 (red signature under 2 varnish layers), **c** OCT tomogram examination spot BkFl.09 (right eyebrow, semi-transparent black paint, artist's alteration), **d** OCT tomogram examination spot Fl.03 (left cheek with 4 varnish layers)

The focus of the OCT examinations was thus on distinguishing between the artist's varnish layers with those applied later by the NaM. A total of twenty-two OCT scans from *Inger Munch in Black* revealed two restoration varnish layers (average total thickness, ca 45 µm) present throughout the background and lying on top of the red signature (Table 1, Fig. 1b and A.1 of ESM Fig. 1 spot RBk.15).

Compared to the background, a more complex stratigraphy of up to four layers was recorded in the face, consisting of either translucent glazes or varnish layers (Fig. 3d and A.1 of ESM, Fig. 3 spot Fl.03). Marked differences in varnish thickness were also captured with OCT corresponding to strong fluorescent boundaries around the figure of *Inger* seen in UVA (Fig. 3a). The OCT tomogram (Fig. 3c and A.1 of ESM, Fig. 2 spot BkFl.09) for *Inger's* right eyebrow captured semi-transparent black paint localised on top of a thin transparent layer but lying underneath the two restoration varnish layers. This minor retouching is most probably synonymous with Munch's own finishing touches rather than part of a later restoration.

Scans from *The Sick Child* visually confirmed the presence of the artist's transparent varnish (25 µm) lying directly under a later restoration varnish (15 µm), consistent with the previous study employing chemical analyses (Fig. 1b spot GrFl.02) [8]. The OCT tomograms also record Munch's unevenly distributed varnish over the paint surface. This suggests that he locally saturated out certain passages of paint during the process of painting. In 1928, Munch reflected on his struggles with the compositional process of the painting, *'I reworked the picture countless times in the course of a year—scratched it out'*, and *'- allowed it* [the local varnish] *to infuse the paint medium'* [25].

In summary, the OCT examinations from both *Inger Munch in Black* and *The Sick Child* were successful in locating hidden transparent layers related to the use of a locally applied artist's varnish. This new evidence supporting Munch's experimentation with surface finishes, in terms of interplay between matt and glossy passages of paint, relates closely to contemporary practices noted amongst French artists. At the end of the nineteenth century, many artists are known to have questioned the academic tradition of applying an overall varnish coating [29]. Inspired by the impressionists, a variety of techniques are documented, involving the use of either, homemade and commercial retouching varnishes, transparent glazes or mixing varnish or extra oil to paint layers for increased saturation [11, 30–32]. Likewise, there was an increase in the use of absorbent grounds and thinning of paint with diluents to create matt counter effects to glossy areas [33].

4.2 Munch's surface finishes

OCT scans taken from 23 different regions on *Puberty* (group 2), identified an even upper varnish layer present over the entire pictorial surface (20 µm), corresponding to the most recent synthetic varnish applied in 1979 (A.1 of ESM, Fig. 4). Tomograms from drips in the red foreground (A.1 of ESM, Fig. 5, spot R.02), visible in UVA fluorescence, identified a second transparent layer lying between the paint layer and the upper varnish. Reminiscent of the varnish drips in *The Sick Child*, a similar effect is also present in the Munch Museum's (MM) earlier and sketchier version of *Puberty* painted in same year (Woll M 346). Previous comparative research between the MM and NaM versions of *Puberty* concluded that there were marked differences in terms of surface finish and technique [7]. In particular, the rendering of the flesh tones in the NaM's version appears more integrated, with fewer marked boundaries between matt and glossy areas. In the MM's *Puberty*, the visible application of a localised artist's varnish denotes the relationship between different saturated passages of paint, whilst in the NaM's version, traces of any original surface saturation effect are completely masked by the later restoration varnish. However, OCT scans taken from different areas of flesh tones (Fig. 2) were able to reveal up to three additional transparent (varnish) layers beneath the upper varnish coating. These appear to be locally applied and have a total thickness range between 29 and 42 µm. Although invisible to the naked eye, these findings suggest the presence of a more layered and saturated approach present in the contours of the girl's body flesh tones than previously observed. Given that Munch painted both versions in 1894, it is plausible that they were in fact not so dissimilar in terms of the original interplay between matt and glossy surface finishes.

pXRF readings from the bright orange-red highlight in the figure of *Puberty*, identified mercury (Hg) confirming the presence of a vermilion pigment (HgS) (A.1 of ESM, Fig. 4, spots: R.28–30). However, Munch appears to have also used a synthetic red lake pigment for certain passages. The tomograms from red bed base captured a thinly applied semi-transparent paint layer (9–19 µm) lying beneath the varnish (Figs. 4a, b spot R.06). pXRF spectra from the same examination spots showed no peaks for Hg but instead, very small peaks for aluminium (Al) indicative of a red lake pigment bound to an alum substrate (Fig. 4c, and A.1 of ESM, Fig. 6) [34].[9]

Like *Puberty* and *The Day After*, the NaM's version of *Madonna* (group 2) also appears to have been exhibited in numerous international exhibitions by Munch prior to its donation to the museum in 1909 [35]. All three works were painted in 1894 with a similar palette, on

[9] Five different pXRF readings were taken from spots in the red bed base colour (R.06, R.07, R.Bl.08, R.24 & R.25). Peaks for Al were present in all readings. The paint layer is thinly applied in this passage and the dominant peaks for Pb are from the commercially prepared lead white lead ground (A.1 of ESM Fig.6).

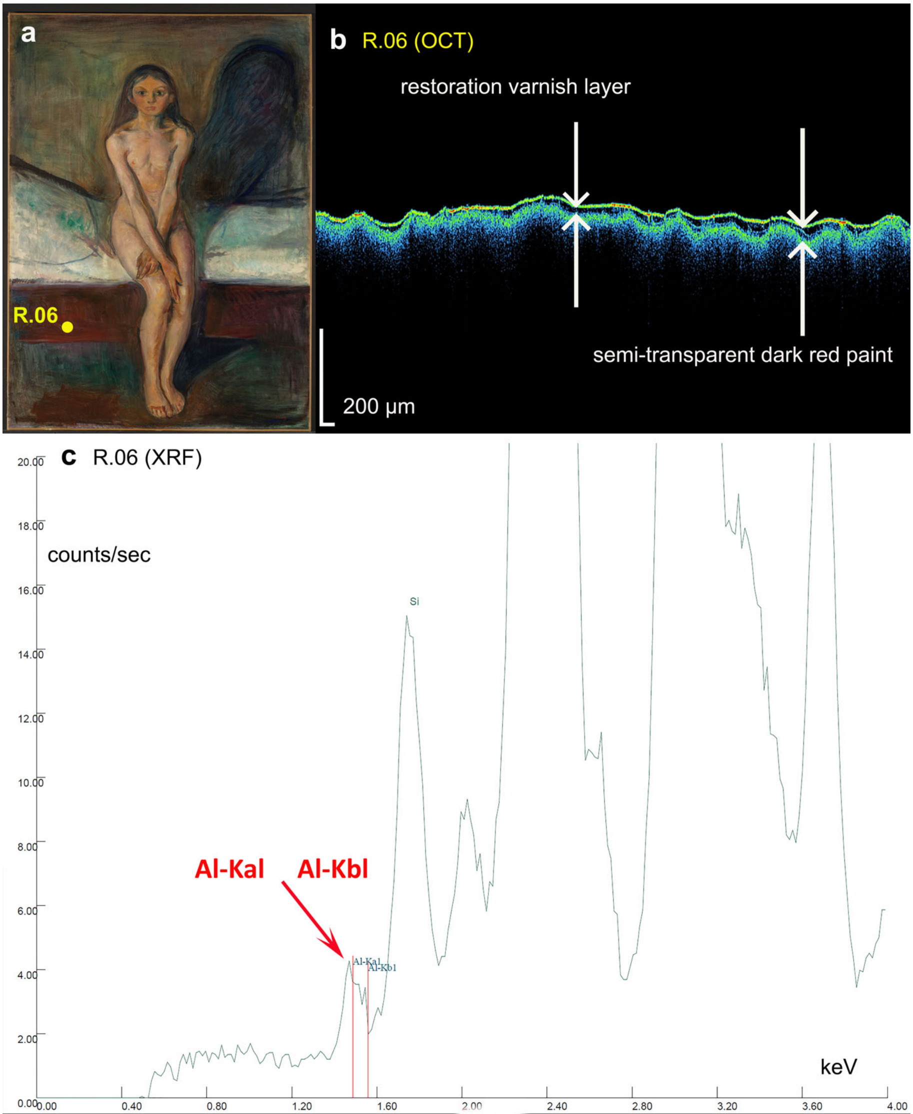


Fig. 4 *Puberty* (Woll M 347), **a** normal light photography with location of OCT & pXRF examination spot R.06, **b** OCT tomogram, examination spot R.06, **c** pXRF interval spectra (0.40–4 keV), spot R.06, showing small peaks for Al

a commercially prepared canvas with a lead white ground. Munch used the same model for *Madonna* as in *The Day After* (group 2) and there exist five similar-sized painted versions (Woll M 365, 366, 367, 368 and 369) [35]. The chronology in which Munch painted the five is uncertain, yet evidence of pentimenti (alterations to her right arm), revealed by the dark underdrawings from recent IRR examination (September 2020), supports earlier theories that the NaM's version is the first in the series (Fig. 5b) [35, 36]. As with *Puberty*, the female

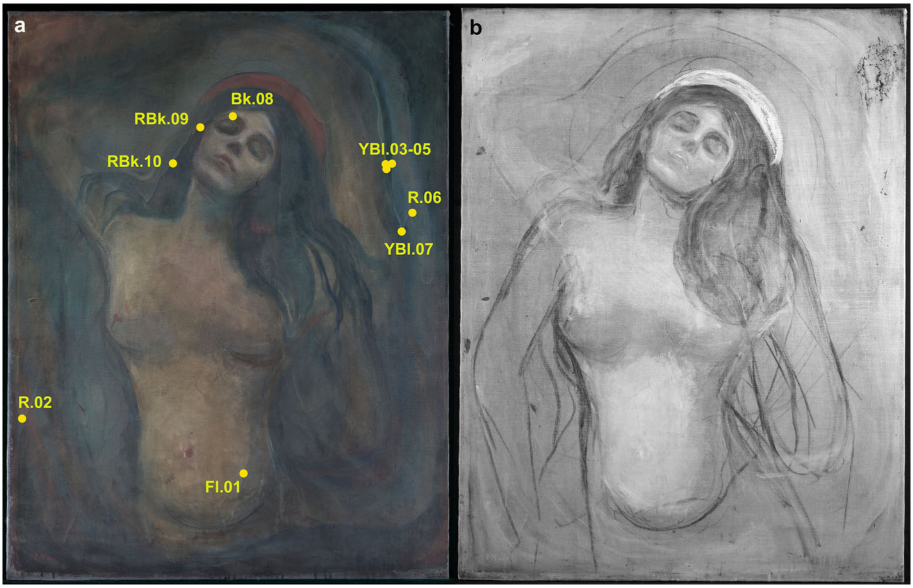


Fig. 5 *Madonna* (Woll M 366), **a** UVA-induced fluorescence photography with location of OCT spot examinations, **b** IRR image showing artist's underdrawings/contours (NaM©)

figure is painted in a relatively subdued palette employing thicker brush strokes which follow the contours and under-drawing of the figure.

Madonna's conservation history at the NaM can be traced back to 1955, and in 1968, it was wax-lined and varnished with a synthetic coating of MS2A.[10] OCT examinations revealed two restoration varnish layers present over the whole pictorial surface (Table 1). Conservation reports from 1964 also document previous restorations (localised retouches) executed with tempera colours (Couleures de Muzii LeFranc) which are clearly visible in the top right-hand corner of the IRR photograph (Fig. 5b). OCT tomograms taken from regions above the underdrawings revealed a third and lower transparent layer located beneath the two restoration varnishes and on top of the dark paint layer (Fig. 5a spots: Bk.08, RBk.09 and RBk.10 and A.1 of ESM, Fig. 7 spot RBk.10). Like *Puberty*, variations in thickness and morphology were recorded between the tomograms acquired from the three examination spots. These findings suggest the presence of locally saturated finishes along contours, as the result of either touches of a medium-rich glaze or varnish, rather than a residual oil skin.

A similar interplay between matt and glossy passages of paint can be seen in *The Dance of Life* (group 2), created by differences in paint media. Munch used a matt, dark blue crayon over the thin oil wash for the rendering of the sea in contrast to the medium-rich paint for the figures. There is an uneven distribution of UVA-induced greenish fluorescence present over the paint layers in some of the figures and the foreground (A.1 of ESM, Fig. 8). Like Madonna, there is IRR evidence of Munch's preparatory dark under-drawing. Furthermore, a solvent etched paint effect (paint thinned with turpentine) remains in the upper region of the red dress and yellow drips are clearly visible running halfway down the back of the white dress in the right figure. OCT examinations confirmed a complex surface topography. Thick transparent layers (34–84 µm), corresponding to the visible yellow drips in the white dress seen in the

10 NaM conservation dossier; NG.M.00841.

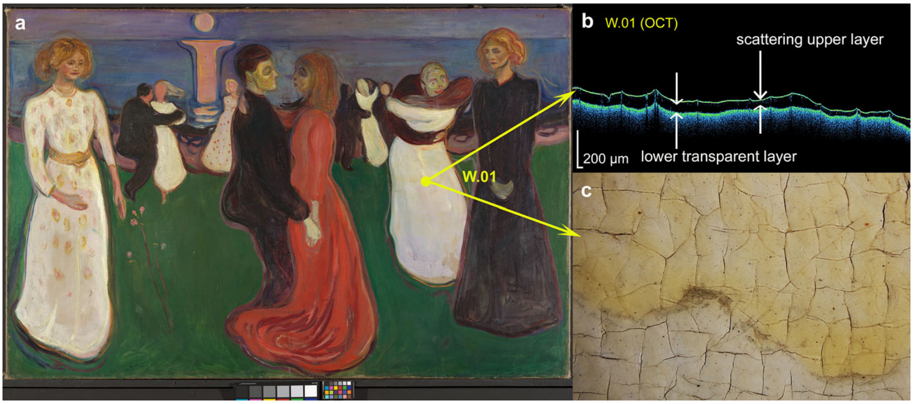


Fig. 6 *The Dance of Life* (Woll M 464), **a** normal light photography with location of OCT examination spot, **b** OCT tomogram examination spot W.01, **c** microscope detail of yellow drip, spot W.01 (Hirox, normal light, 20 ×, FOV 15,155.01 µm, resolution 7.89 µm)

Hirox microscope image, are also clearly visible in the OCT tomograms (Fig. 6b-c). Given their yellow colouring in UVA, these could be associated with an excess of oil medium rather than an artist's varnish. In some cases, these thicker layers lie beneath a thinner scattering layer (10–17 µm), indicative of the later and locally applied matt restoration varnish with a wax content.[11] In contrast, both the dark red signature and the blue crayon, top right, appear to lie over a greenish fluorescing transparent layer (artist's varnish). Furthermore, many of the red, blue and green pigmented paint layers were found to be semi-transparent to the OCT infrared radiation. This suggests that Munch also manipulated the translucency of his paints in certain passages to create variations in saturation.

OCT was successful in visually capturing the disparity in the varnish stratigraphy present in each painting in terms of the mismatch between restoration interventions (matting down of glossy drips and complete varnishing of the paint surfaces) and the surface effects envisaged by Munch. The evidence of the artist's interplay between saturation and gloss brings a new and invaluable understanding about Munch's paintings that will help make informed conservation choices in the future.

4.3 Restoration varnishes and former cleaning treatments

OCT was also employed to understand and locate past restorations and restoration varnishes that remain undocumented in the NaM's archives. For example, there exist no past conservation records for Munch's small *Self-portrait* (Woll M 133, group 1) acquired by the NaM in 1938, yet the canvas has been wax-lined at some point in time. Furthermore, the uniform greenish fluorescence present over the whole surface under UVA examination is indicative of a varnish coating (A.1 of ESM, Fig. 9). The portrait dates from the same period as *The Sick Child* and has a similar paint technique, thickly applied, raised impasto, scratches, scoring and the additional traces of the use of a palette knife (see Sect. 3.1, group 1 and Table 1). OCT was successful in quickly establishing the presence of two distinct transparent layers over the whole surface. A relatively evenly distributed upper layer (average thickness, 16–24 µm) corresponds to the evenly distributed top restoration varnish seen in UVA. However, there are

[11] Partial varnishing and matting of glossy drips were carried out during the 1958 restoration. NaM conservation dossier; NG.M.00941.

marked differences in thickness between the flesh paint (average thickness, 12–18 μm) and the background (average thickness, 7–9 μm) in the lower transparent layer. These variations could be assigned to a selective cleaning of the background in conjunction with the previously mentioned lining. Furthermore, OCT tomograms from the signature (A.1 of ESM, Fig. 10, spot RGr.08) revealed it to be lying on top of the lower transparent layer. This suggests that the first varnish was most probably applied by the artist. Given the comparative evidence from the OCT tomograms combined with similarities in painting technique, it is probable that Munch's *Self-portrait* could have originally had a similar surface finish to *The Sick Child*, in terms of glossy effects from an artist's varnish.

If left undocumented, the specifics of past cleaning and selective cleaning in terms of varnish removal can be difficult for a conservator to establish based solely on UVA photography of paint surfaces. Equally, there are practical and ethical limitations with micro-destructive samples for cross-sectional analysis of varnish stratigraphy. In the case of *Flowery meadow at Veierland* (Woll M 148, group 1), the benefits of OCT facilitated an understanding of the distribution of the various transparent layers. The small plein-air study was painted in the summer of 1887, whilst Munch was residing on the island of Veierland, south of Oslo. Like the four other paintings from group 1, Munch's paint during the 1880s is relatively thickly applied with many areas of impasto (Sect. 3.1 and Table 1). Recent chemical analysis confirmed the presence of an upper varnish coating of Laropal K 80 which is also noted in the treatment record from 1983 [10]. However, OCT examinations identified up to four layers of varnish (combined thickness 30–49 μm) in the foreground (A.1 of ESM, Figs. 11, 12 spot Gr.04) compared with only 1–2 thin layers (5–7 μm) present in the blue sky. The information retrieved from the OCT tomograms thus gives a more precise insight into the spatial locations of past and undocumented restorations and highlights the complexity of multiple varnished-layered regions.

The NaM's controversial varnishing of two paintings from group 2 (1890–1900) *Puberty* and *The Day After* is well documented in the Norwegian press of 1909 (Table 1, and group 2) [27]. Both paintings were purchased by the NaM in 1909 from Munch. Painted in Berlin, The *Day After* (A.1 of ESM, Fig. 13) remained in the artist's possession since its creation in 1894 and travelled to no less than nineteen exhibitions [35]. The international travel and handling of the painting appear to have taken a toll on the painting's condition. Prior to its acquisition, a letter addressed to Munch from the museum's conservator, Harald Brun (employed 1905–1921) commented on the need for restoration [37]. The canvas was described with several holes which had been badly filled and poorly retouched by Munch and without a proper colour match to the surrounding area. In addition, Brun recommended cleaning and varnishing. Since its acquisition, the painting has been restored several times at the NaM and has a history of unstable paint.[12] When selecting suitable spots for OCT, care was taken to identify areas of past and existing restorations with regions remaining relatively untouched apart from varnishing. In most of the OCT scans, two distinct varnish layers were detected, both lying over Munch's red signature. These findings suggest the presence of two restoration varnishes with the possibility of the lower layer being Brun's controversial 1909 varnish. OCT was also able to detect semi-transparent paint layers present beneath the two varnish layers in the cracked deep red and green bottles (A.1 of ESM, Fig. 14). This is indicative Munch's use of lake pigments as suggested in the findings from *Puberty* (Fig. 4).

OCT was also used to correlate varnish treatments noted in past conservation dossiers with the physical paint surfaces and to check for any inconsistencies. Only one treatment

[12] The painting underwent major structural treatments in 1909 & 1956 and remedial treatments between 1986–2012. NaM conservation dossier; NG.M.00808.

record from 1954 survives for Munch's portrait of the bohemian writer and critic, *Hans Jæger* (Woll M 174, group 1).[13] It describes a glue-paste lining, cleaning and varnishing with mastic. The OCT tomograms confirmed the presence of a single varnish layer with no evidence of residual transparent layers. Large variations in layer thickness, concentrated in the recesses surrounding areas of impasto (52–75 µm) and resulting in an uneven distribution of the varnish, are perhaps indicative of a brushed application of varnish over an undulated surface (A.1 of ESM, Figs. 15, 16).

The inconsistency between written conservation records (two varnish layers) and the actual physical state of the varnish (one layer) on the painting *Night in Nice* was discovered in a recent study that employed various analytical methods [10]. Only one thin transparent varnish layer (average thickness, 4–17 µm) instead of the documented two was also confirmed, over the whole painted surface with OCT (Table 1). This highlights the usefulness of OCT as a viable non-invasive diagnostic screening tool for entire painted surfaces.

4.4 Unvarnished paintings

Self-portrait with cigarette (group 3) represents a rare example of an oil paint surface that appears to have evaded restoration and conservation interventions since its acquisition from the artist in 1895.[14] Notwithstanding the ageing processes inherent in painting's materials, which have altered the original visual effect, Munch's paint surface remains physically intact. UVA and reflected light photography reveal an uneven and locally distributed glossy residue over the surface (Fig. 7a). The paint technique varies from thicker brushstrokes used for the face and hands, combined with a diluted wash employed in the dark blue background. Paint, possibly thinned with turpentine, has dripped vertically down the canvas and along the bottom tacking margin (Fig. 7d). The OCT imaging identified a technique involving the application of local glazes with semi-transparent paint layers, resulting in marked differences between glossy finishes and the matter diluted paint. Residues of excess oil were also detected suggesting that Munch manipulated the medium to achieve the variations in gloss and saturation rather than adding a local varnish (Figs. 7b-c and A.1 of ESM, Figs. 17, 18).

The fragile and absorbent nature of *The Scream's* (group 3) paint media and unprimed cardboard support probably explains why earlier restorers refrained from varnishing the painting. Having abandoned a first sketch to the reverse, Munch flipped the board over and repainted *The Scream* motif using, matt tempera-based paints containing casein, egg and some drying oil [38]. Since the donation of the painting to the NaM in 1910, by the wealthy patron Olav Schou, the paint surface has retained Munch's reparations, alterations and early candlewax deposits, previously thought to be bird excrement (Figs. 8a–c and A.1 of ESM, Figs. 19, 20) [39]. Despite the lack of an overall varnish, a locally applied transparent layer is visible in the blue passages (fjord) with OCT (Figs. 8b and A.1 of ESM, Fig. 19 spot Bl.05). This surface coating varies in thickness and has also been identified as a main source of colour change in a recent micro-lightfastness study (MFT) [40].

5 Conclusion

The application of OCT on 13 paintings belonging to the NaM has been proven as a valuable non-invasive methodology to clarify hidden complexities and diversities between original

[13] NaM conservation dossier; NG.M.00485.

[14] NaM conservation dossier; NG.M.00470.

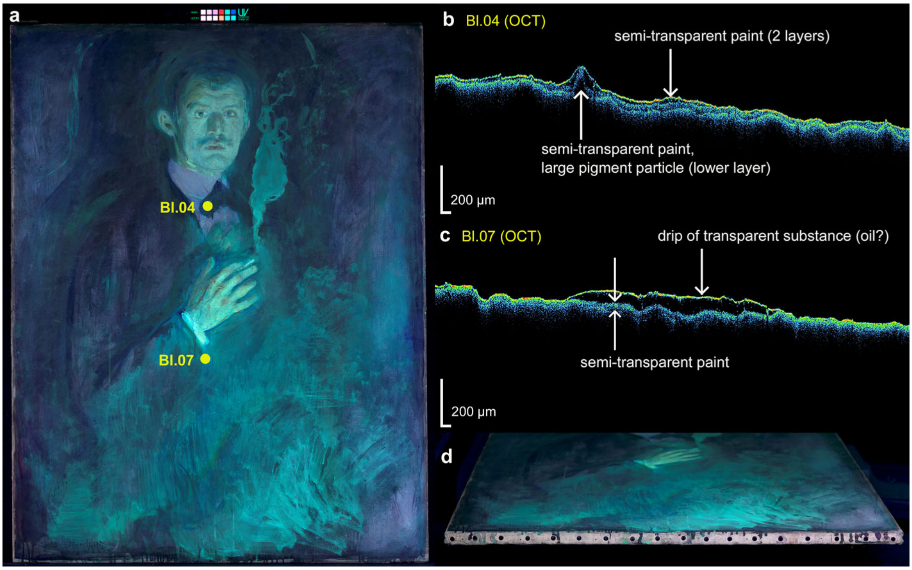


Fig. 7 *Self-portrait with cigarette* (Woll M 382) **a** UVA-induced fluorescence photography, **b** OCT tomogram examination spot Bl.04 (evidence of semi-transparent paint layers/glazes), **c** OCT tomogram examination spot Bl.07 (residues of excess oil), **d** lower tacking margin edge with drips from thinned paint (UVA)

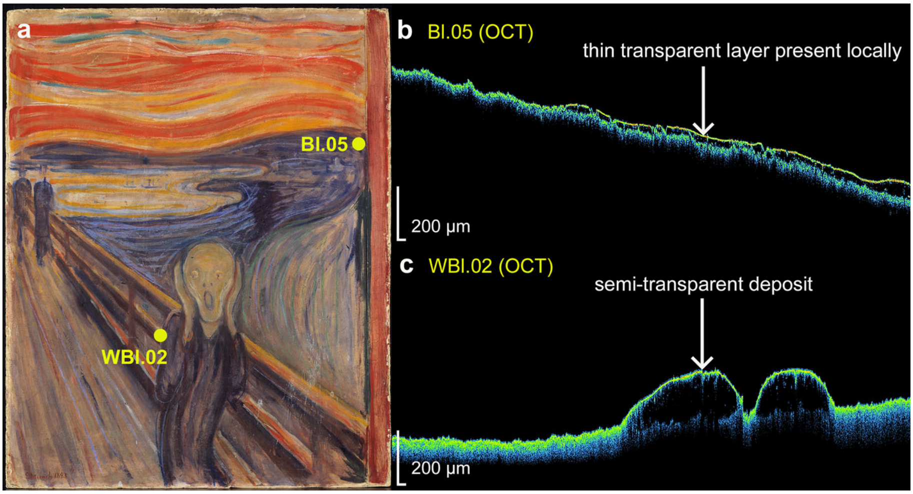


Fig. 8 *The Scream* (Woll M 333) **a** normal light photography, **b** OCT tomogram examination spot Bl.05 (evidence of locally applied transparent layer), **c** OCT tomogram examination spot WBl.02 (candlewax deposit)

and secondary varnish layers present across three groups of Munch paintings dating from 1884 to 1900. This information is of paramount importance when translated to the visual relationship of these works displayed as a group regarding future preservation and restoration strategies.

OCT tomograms revealed the presence, thickness and the precise location of locally applied artist's varnish layers and/or transparent glazes in seven artworks; *Inger Munch in Black, The Sick Child, Puberty, Madonna, The Dance of Life, Self-portrait with Cigarette and The Scream.* Despite the documentary uncertainty concerning Munch's own attitude towards varnishing, the present findings highlight the high suitability of OCT as a non-invasive diagnostic technique for mapping transparent paint layers at the painting surface. OCT analyses of *Puberty, Madonna* and *The Dance of Life* give an important insight into Munch's varied paint technique and the intricate surface qualities lying beneath the NaM's application of later restoration varnishes. This finding has important art historical implications when evaluating Munch's early painting technique, in terms of surface finish and interplay between saturated and glossy passages of paint contrasted against matt areas. Until now, this surface effect has been previously misunderstood with the past restoration varnishing and toning down of the glossy areas in paintings, such as *The Dance of Life*. In all but two cases, the Munch's original though aged surface effects are no longer visible, nor can be retrieved, but the results of this research allow for a more informed assessment of the intended appearance as a basis for deciding conservation and lighting strategies. Furthermore, the OCT results clearly unveiled variations and discrepancies in the conservation varnish history within the group.

Several of the OCT tomograms recorded an uneven distribution of varnish layers and spatial location of Munch's adjustments. This further underlies the non-invasive technique's success in supplying a more realistic overview of varnish layers across an entire paint surface. Nevertheless, there are several practical challenges with the portable SdOCT equipment in terms of the limited and small surface scanning area (12×12 mm) combined with the post-processing of large image data files. Moreover, OCT remains essentially a diagnostic method for the stratigraphic visualisation of the uppermost transparent and semi-transparent layers. This is due to the use of near-infrared radiation (750–950 nm), close to the visible, limiting the imaging to surface layers since most paint layers strongly absorb the probing light in this spectral range. This makes it difficult to detect the extent of possible varnish penetration into the ground or paint layers underneath.

Notwithstanding these impediments, the complementary information gained from OCT scans in this study, combined with historical records, UVA, IRR, and pXRF have revealed new insights concerning Munch's technique and surface effects on paintings created between 1884 and 1900.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1140/epjp/s13360-021-01758-5.

Acknowledgements The authors are grateful to the National Museum of Art, Norway, for full access to the paintings. The authors would also like to thank Børre Høstland for assistance with the UVA and IRR and photography.

Authors' contributions TF contributed to conceptualization, investigation, data curation, interpretation, resources, writing—original draft, writing—review and editing, visualisation. MI was involved in investigation, data interpretation—OCT, writing—review and editing. EP and EH contributed to supervision, writing—review and editing. PT was involved in investigation, data curation—OCT, resources, writing—review and editing.

Funding Open access funding provided by University of Oslo (incl Oslo University Hospital). The project is part of Thierry Ford's PhD study which is fully funded by the National Museum of Art, Norway.

Availability of data and materials Raw data are available from the authors on request.

Declarations

Competing interests The authors declare that they have no competing interests.

Data Availability Statement This manuscript has associated data in a data repository. [Authors' comment: The additional raw data that support the findings will be made available following a (6 month) embargo after the completion of the PhD program (2022/23).].

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A.1 Supplementary figures and OCT tomograms

Munch and optical coherence tomography. Unravelling historical and artist applied varnish layers in painting collections.

The European Physical Journal Plus

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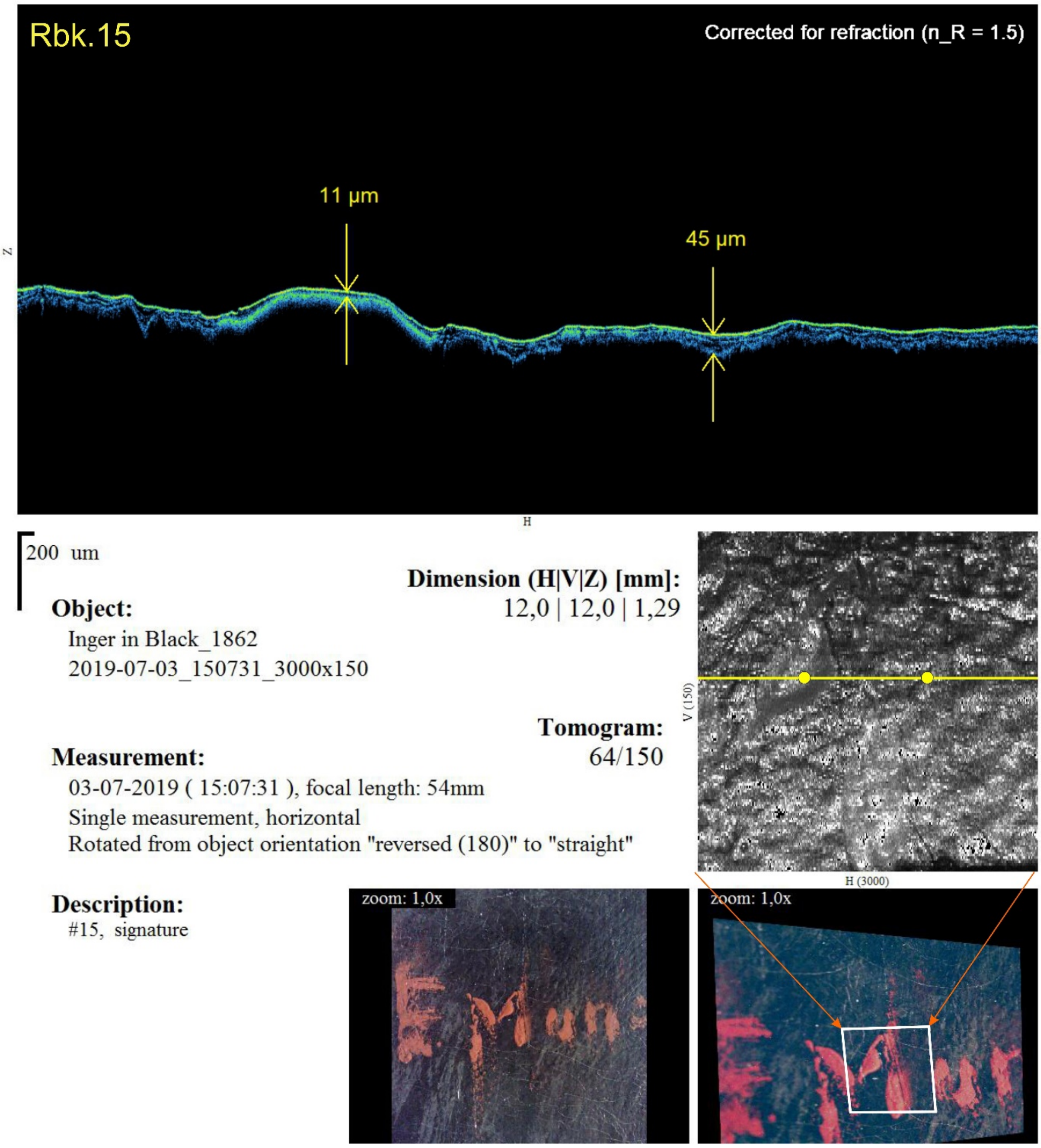

Fig. 1 *Inger Munch in Black* (Woll M 113), OCT tomogram and IR reflectogram from examination spot RBk.15 (red signature under 2 varnish layers)

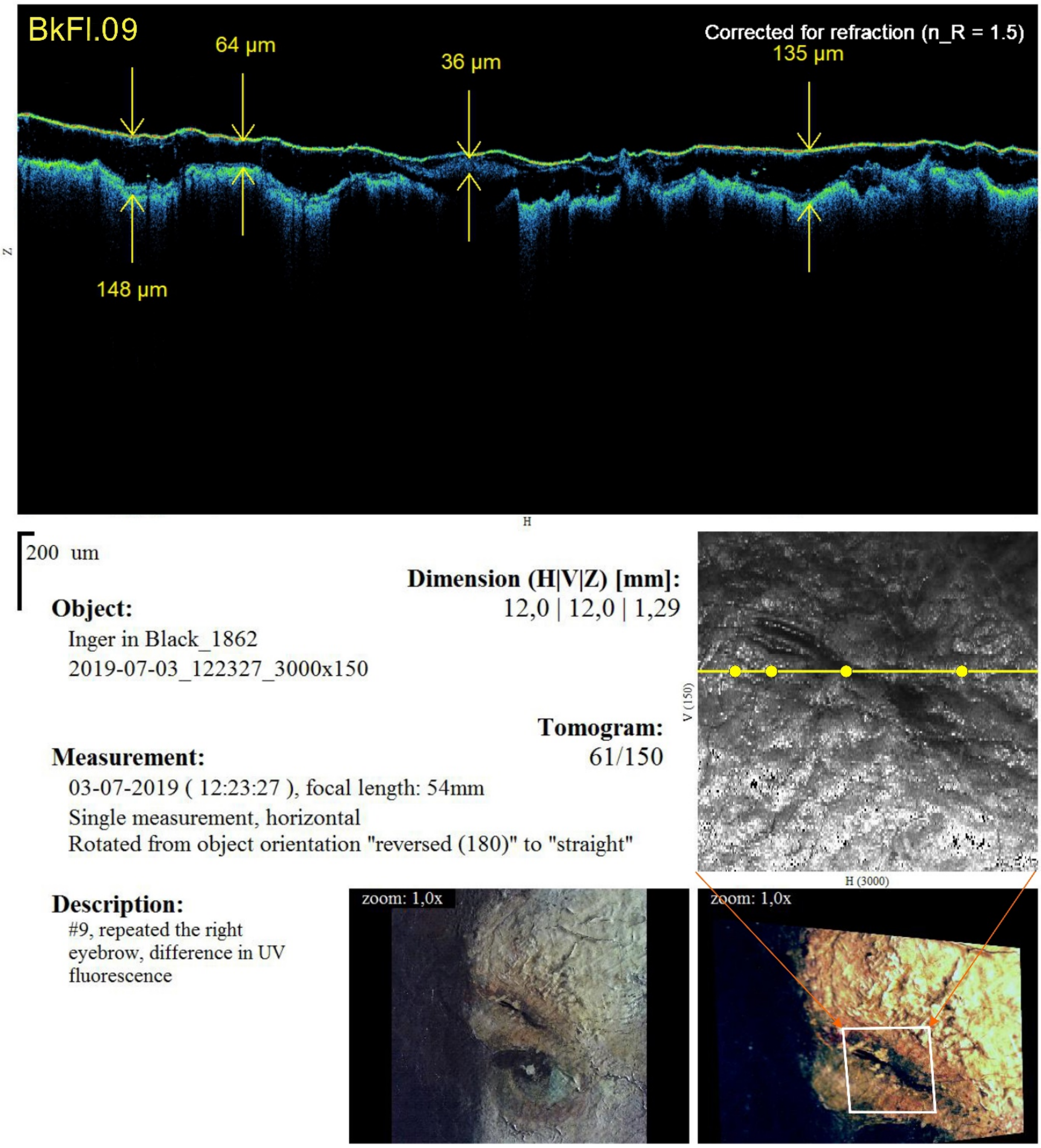

Fig. 2 *Inger Munch in Black* (Woll M 113), OCT tomogram and IR reflectogram from examination spot BkFl.09 (right eyebrow, semi-transparent black paint, artist's alteration)

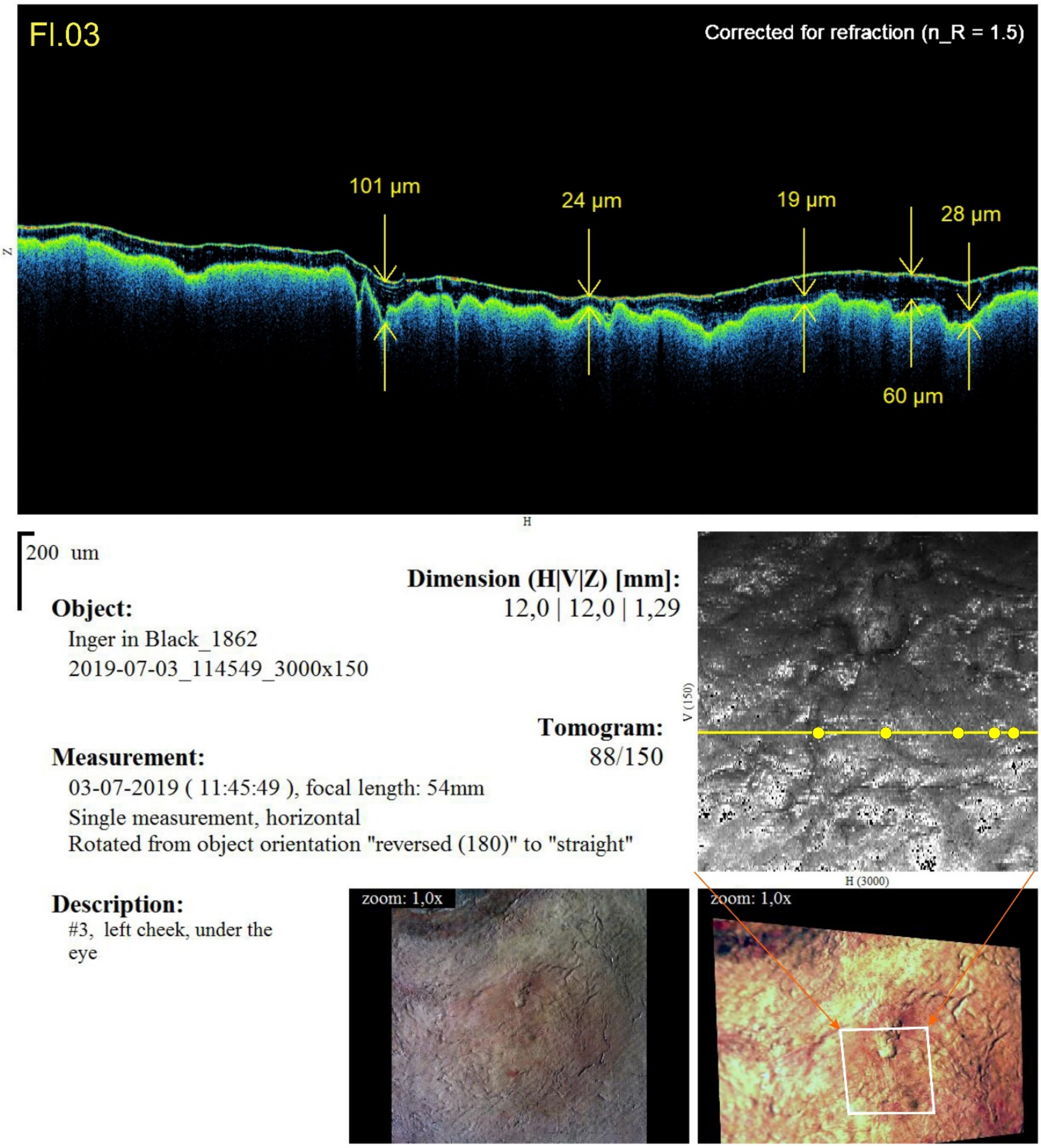

Fig. 3 *Inger Munch in Black* (Woll M 113), OCT tomogram and IR reflectogram from examination spot Fl.03 (left cheek with 4 varnish layers)

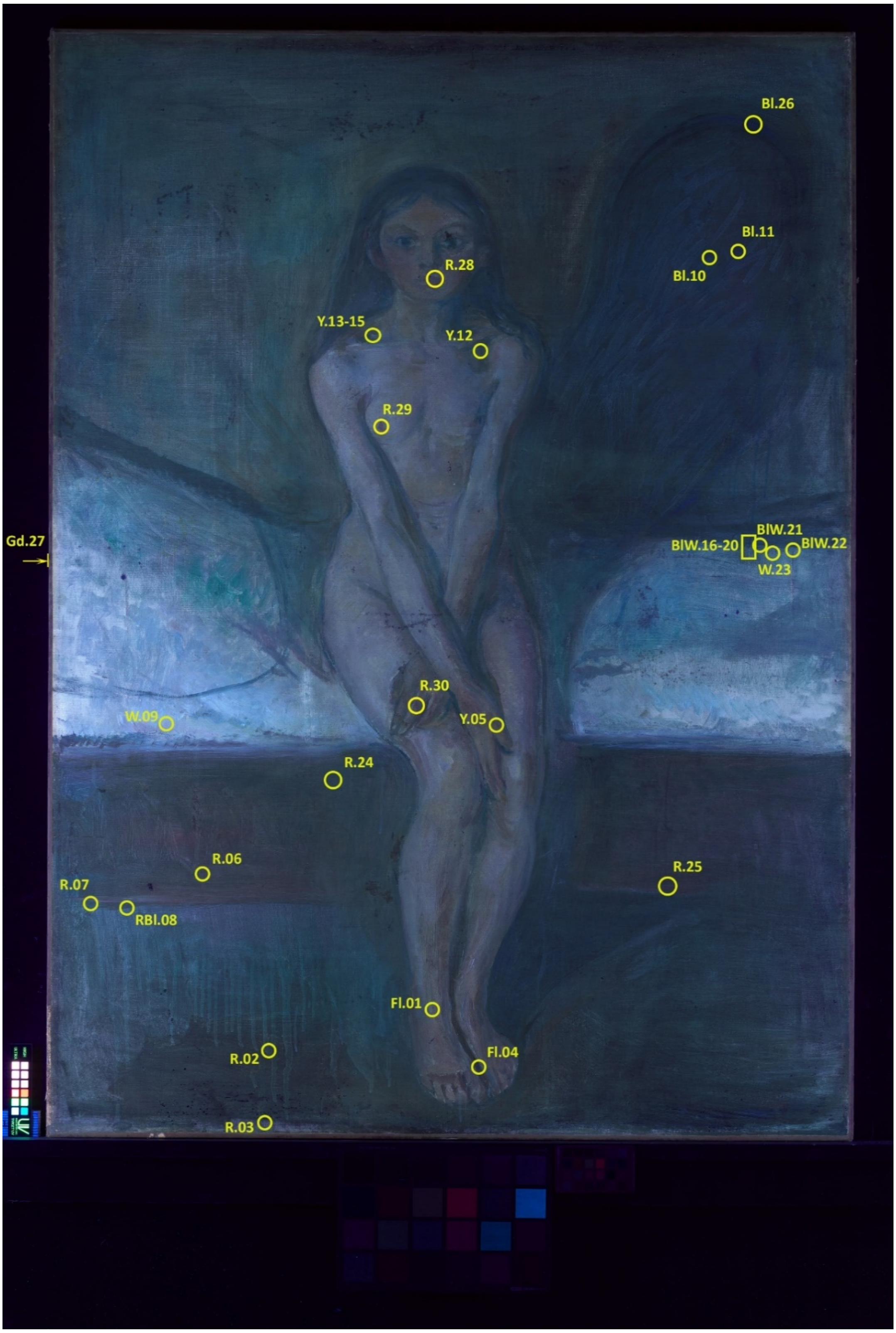

Fig. 4 *Puberty* (Woll M 347), UVA-induced fluorescence photography with location of OCT & pXRF examination spots

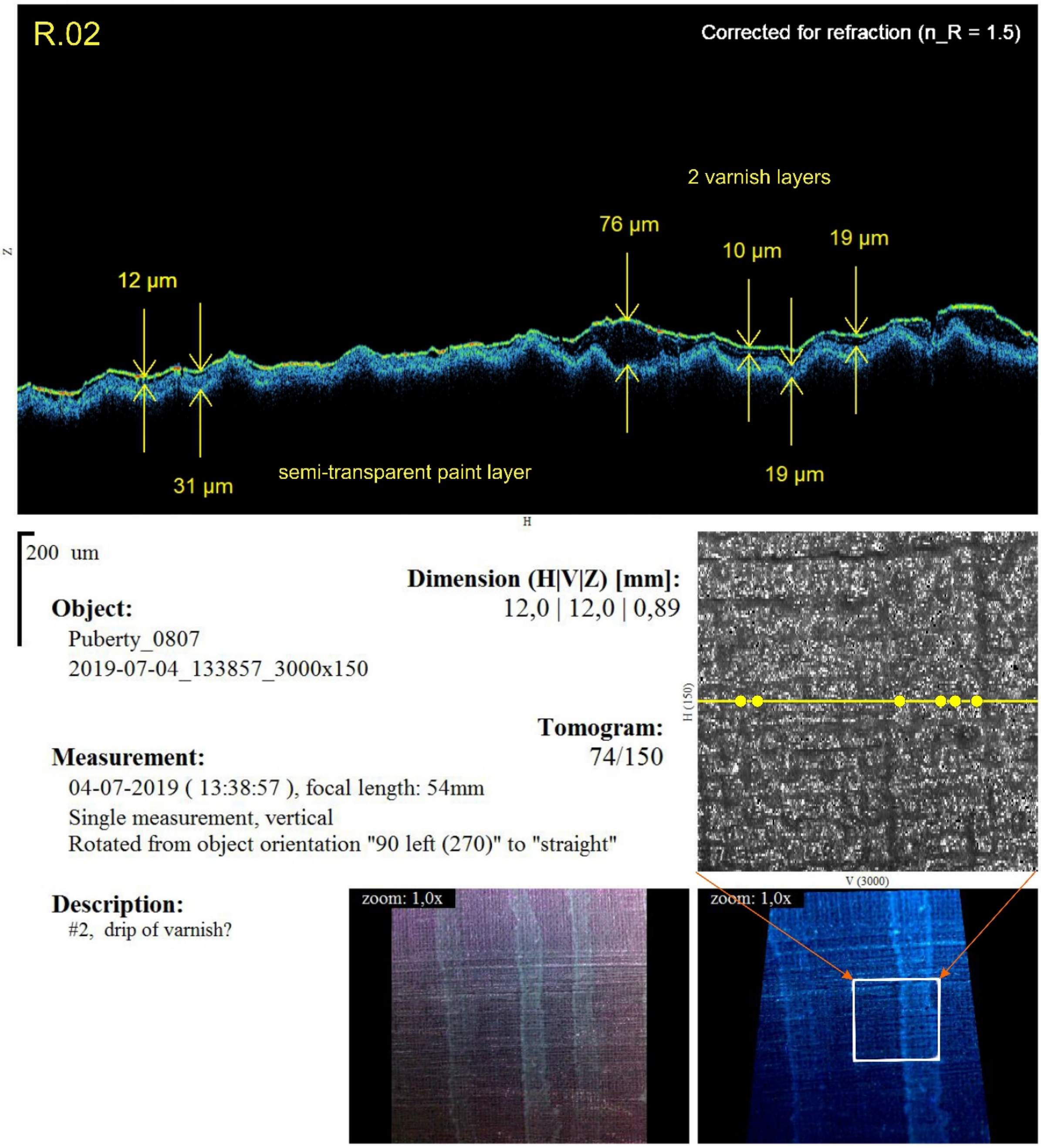

Fig. 5 *Puberty* (Woll M 347), OCT tomogram and IR reflectogram from examination spot R.02 (second transparent layer identified in drips in the red foreground)

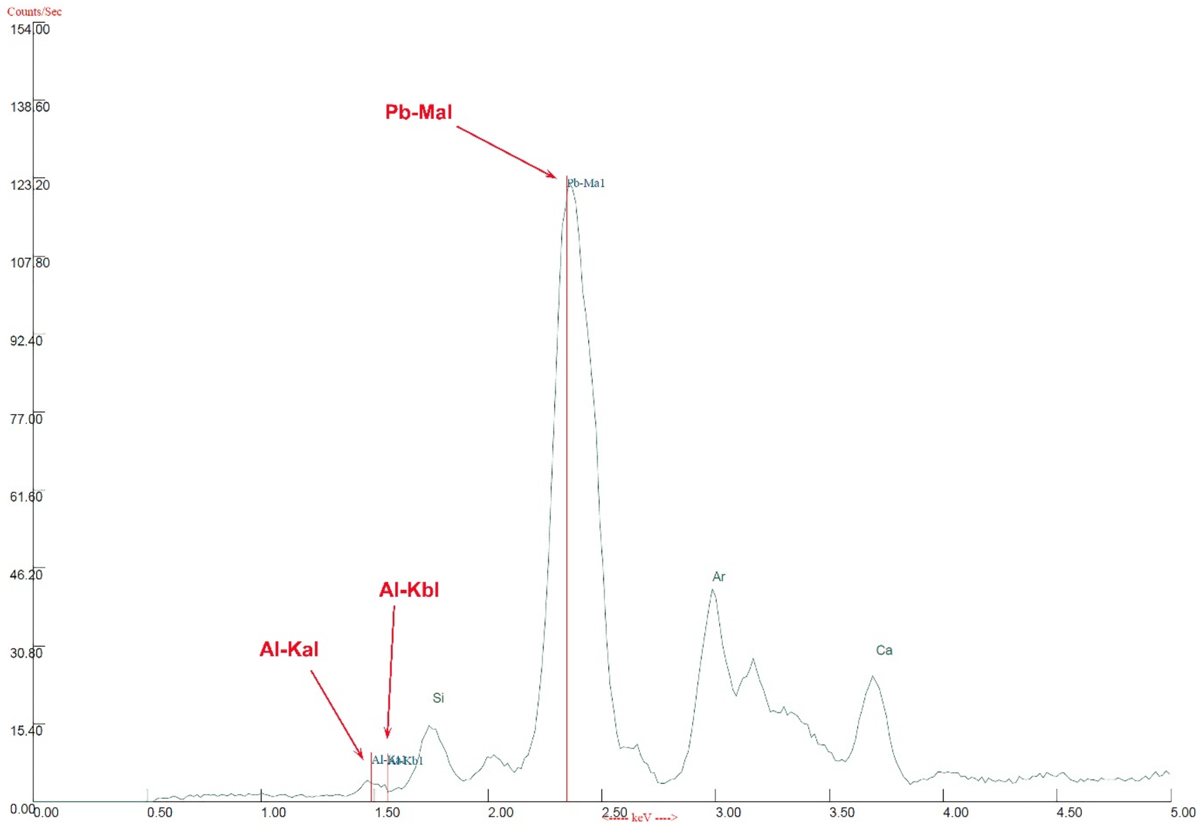

Fig. 6 *Puberty* (Woll M 347), XRF full spectra, spot R.06. The paint layer is thinly applied in this passage and the dominant peaks for Pb are from the commercially prepared lead white ground

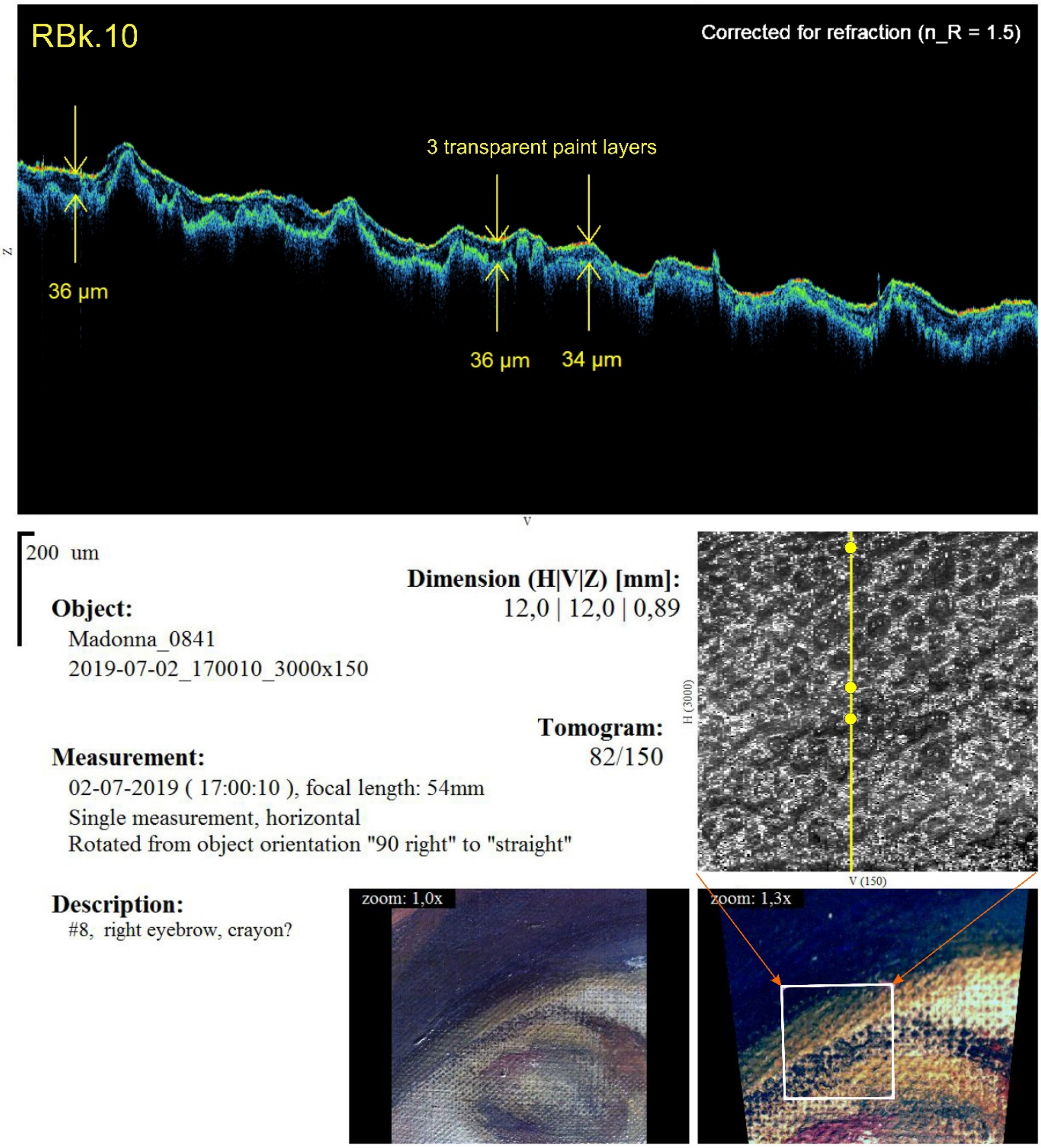

Fig. 7 *Madonna* (Woll M 366), OCT tomogram and IR reflectogram from examination spot RBk10 (lower transparent layer located beneath upper two restoration varnishes and on top of the dark contours)

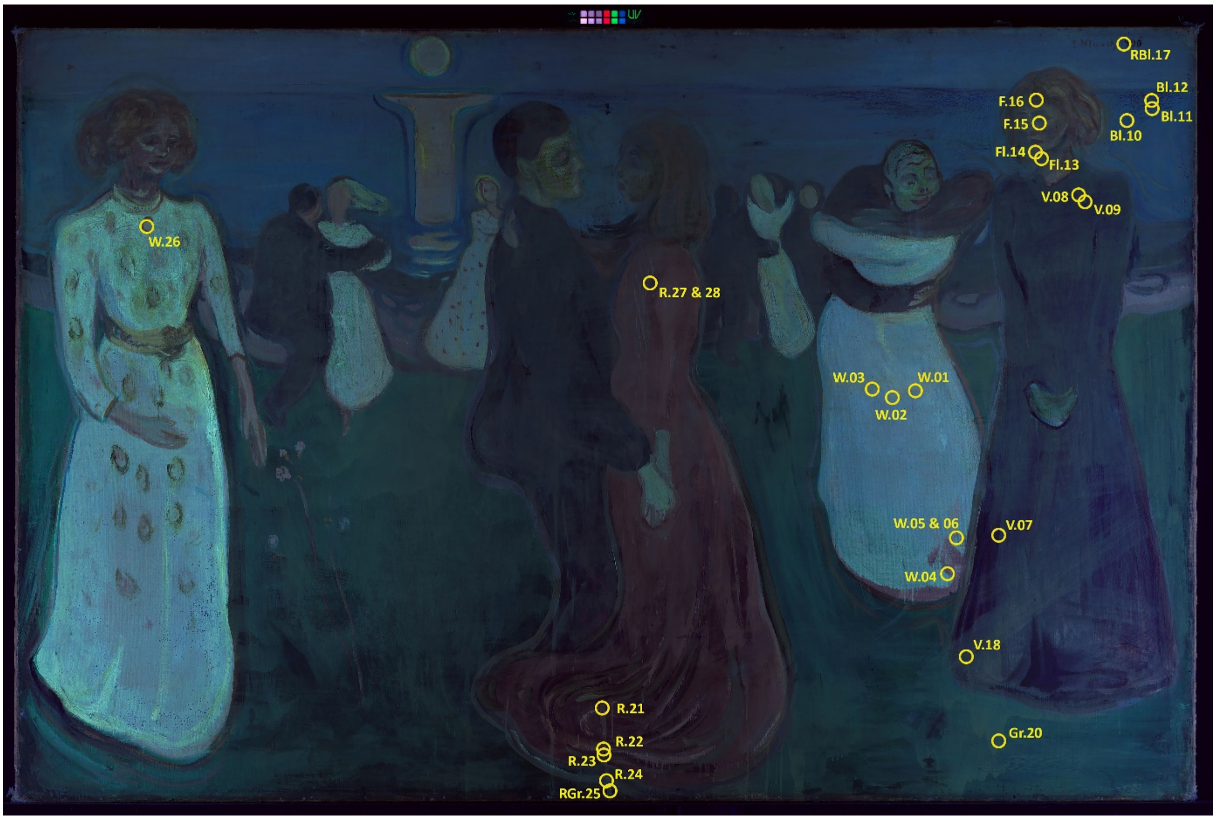

Fig. 8 *The Dance of Life* (Woll M 464), UVA-induced fluorescence photography with location of OCT examination spots

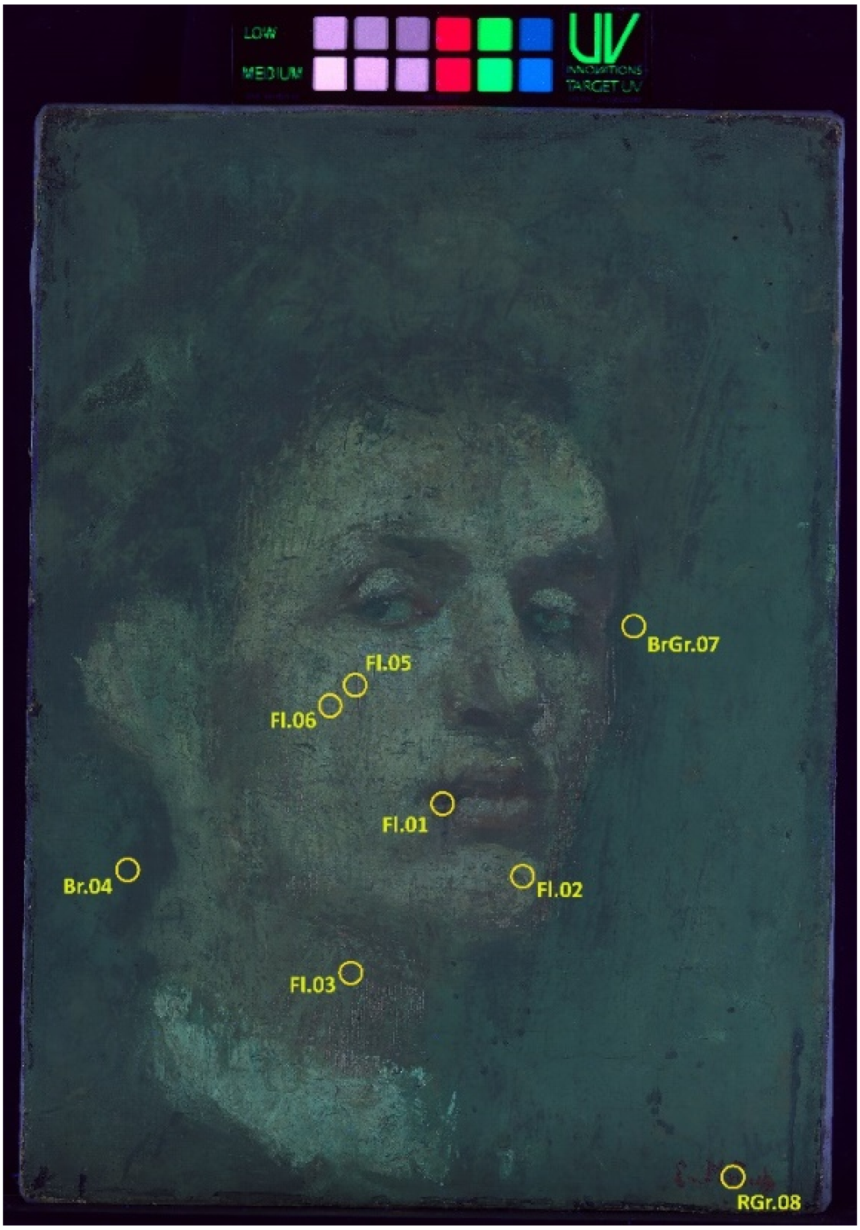

Fig. 9 *Self-portrait* (Woll M 133), UVA-induced fluorescence photography with location of OCT examination spots

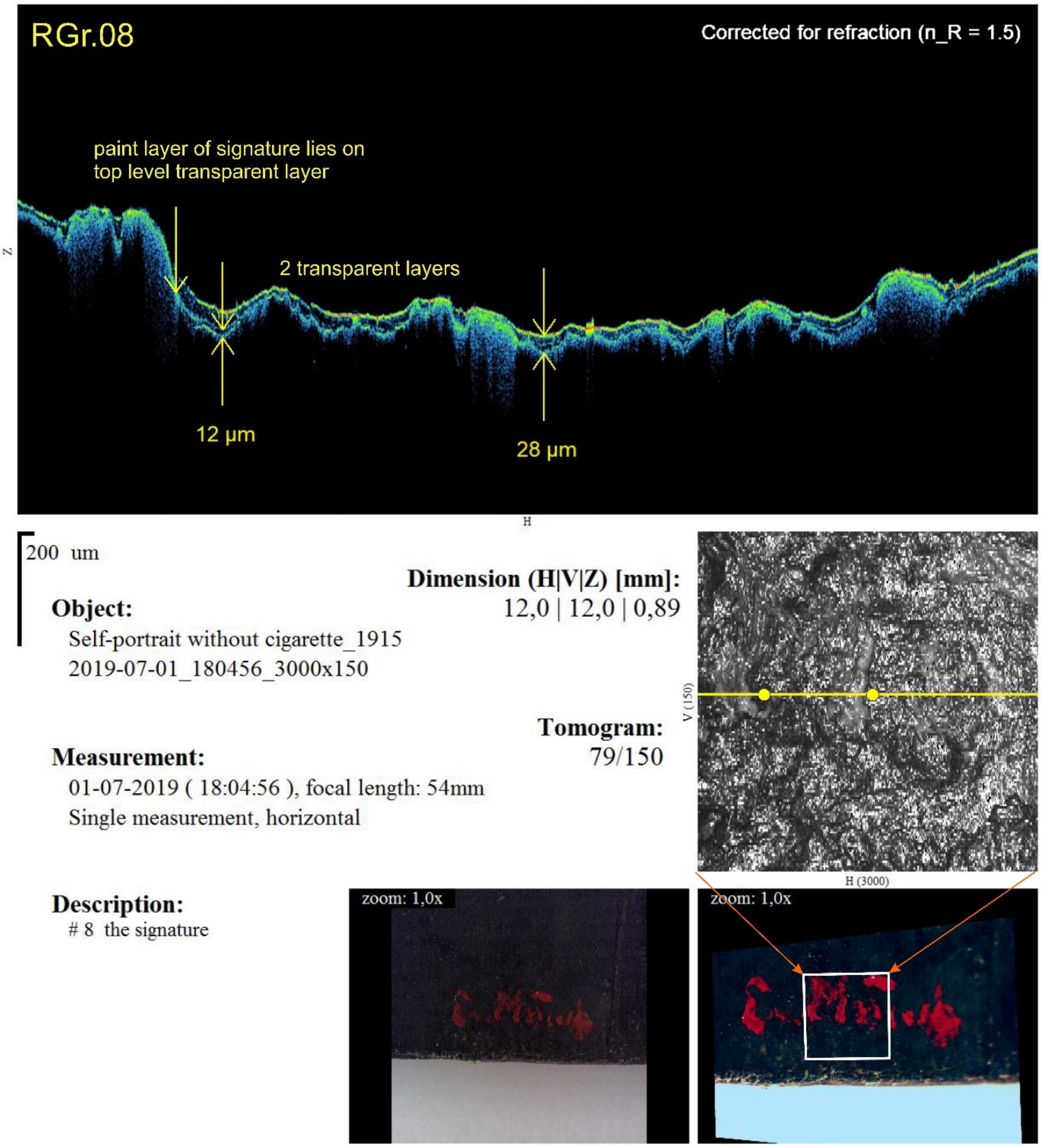

Fig. 10 *Self-portrait* (Woll M 133), OCT tomogram and IR reflectogram from examination spot RGr.08 (red signature lies between two transparent varnish layers)

Fig. 11 *Flowery meadow at Veierland* (Woll M 148), UVA-induced fluorescence photography with location of OCT examination spots

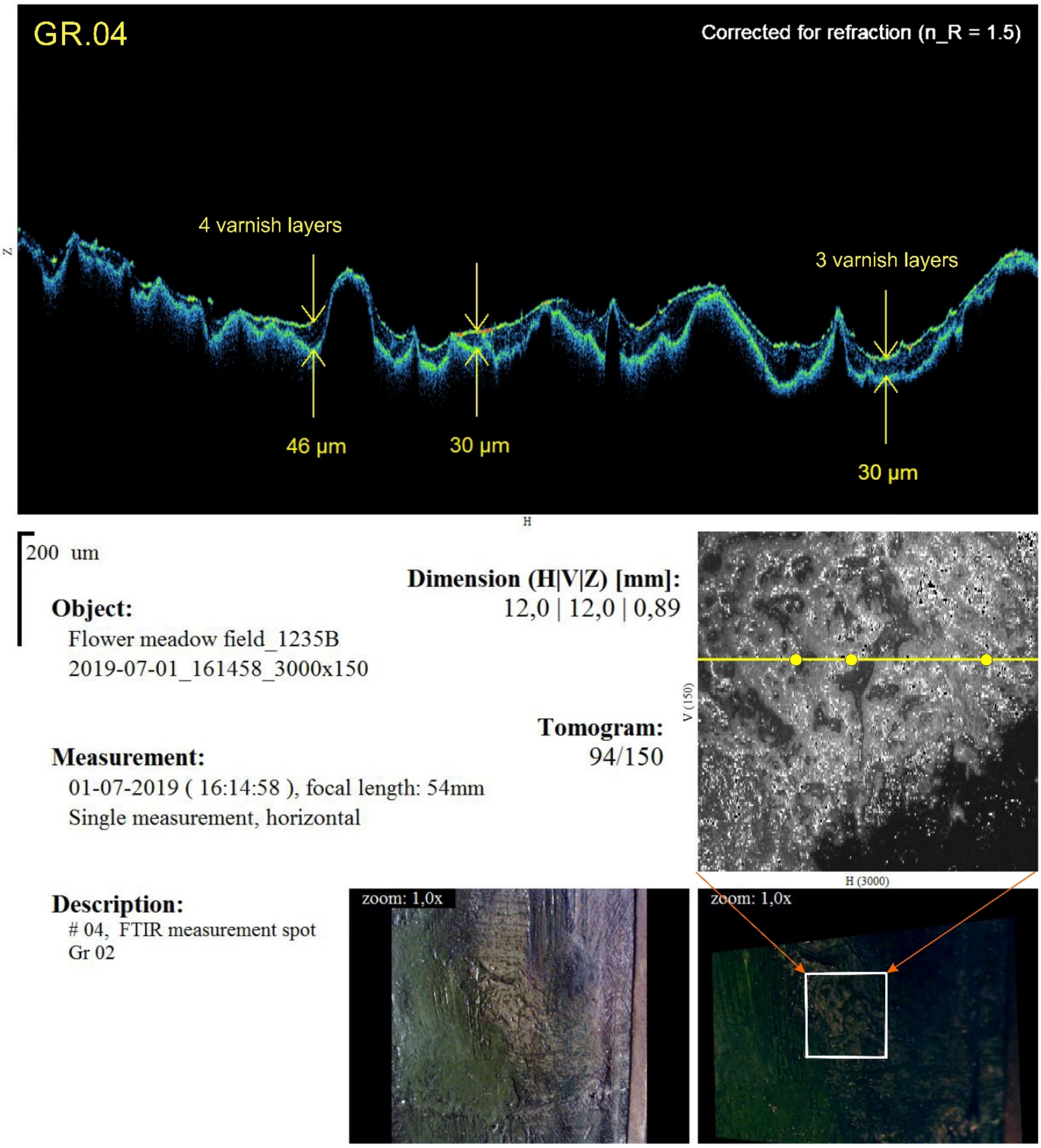

Fig. 12 *Flowery meadow at Veierland* (Woll M 148), OCT tomogram and IR reflectogram from examination spot Gr.04 (Four layers of varnish in the foreground)

Fig. 13 *The Day After* (Woll M 348), UVA-induced fluorescence photography with location of OCT examination spots

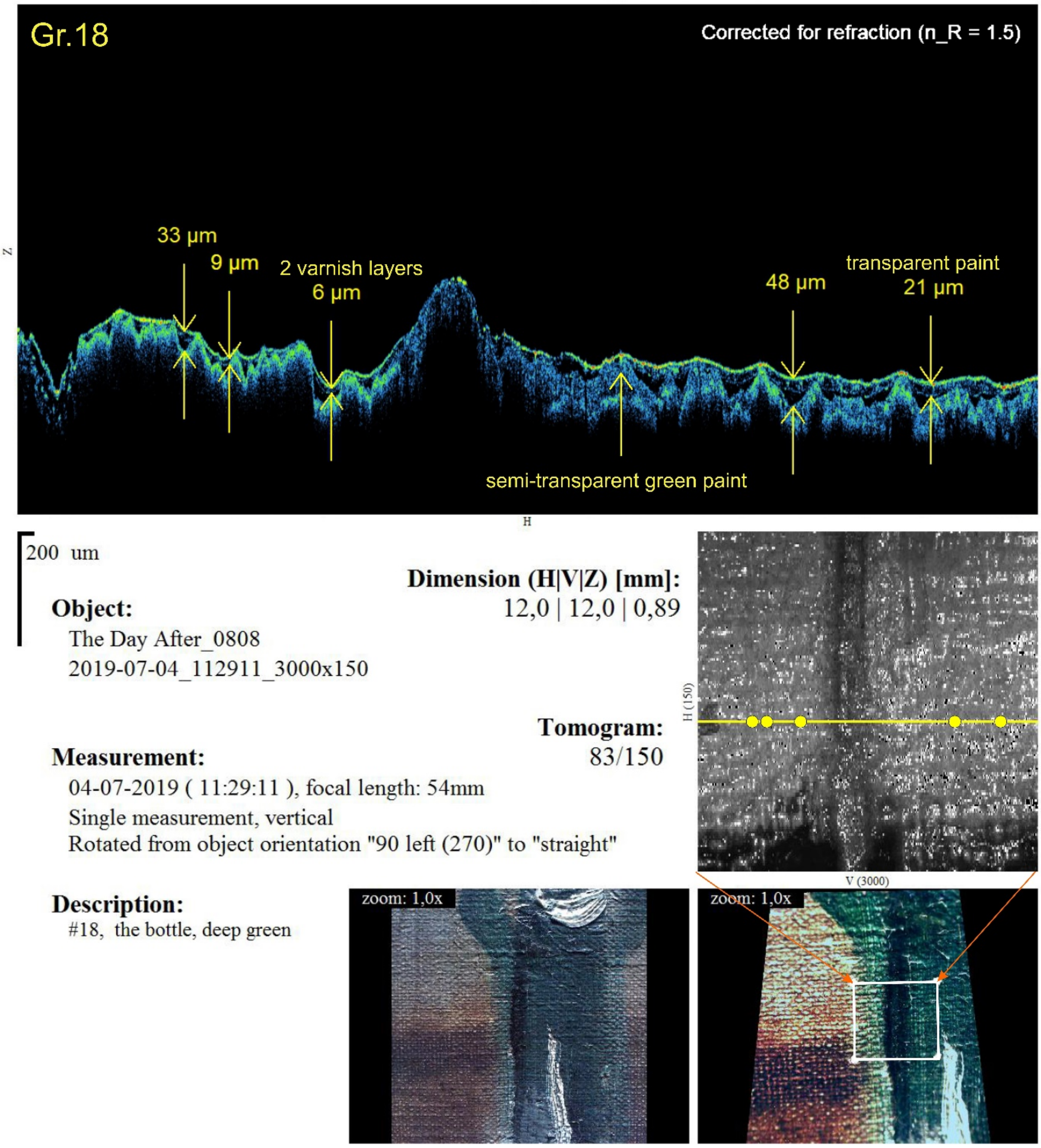

Fig. 14 *The Day After* (Woll M 348), OCT tomogram and IR reflectogram from examination spot Gr.18

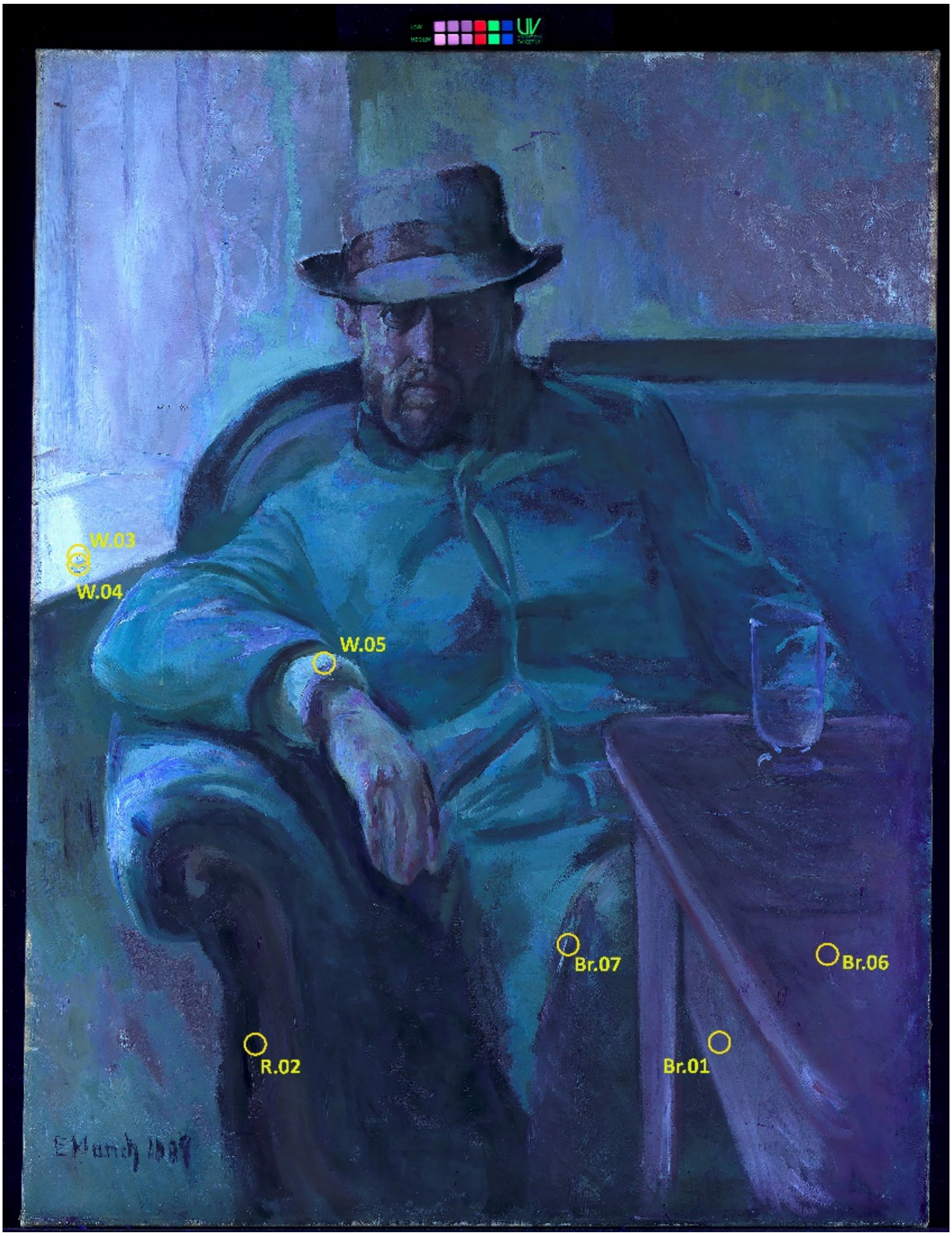

Fig. 15 *Hans Jæger* (Woll M 174), UVA-induced fluorescence photography with location of OCT examination spots

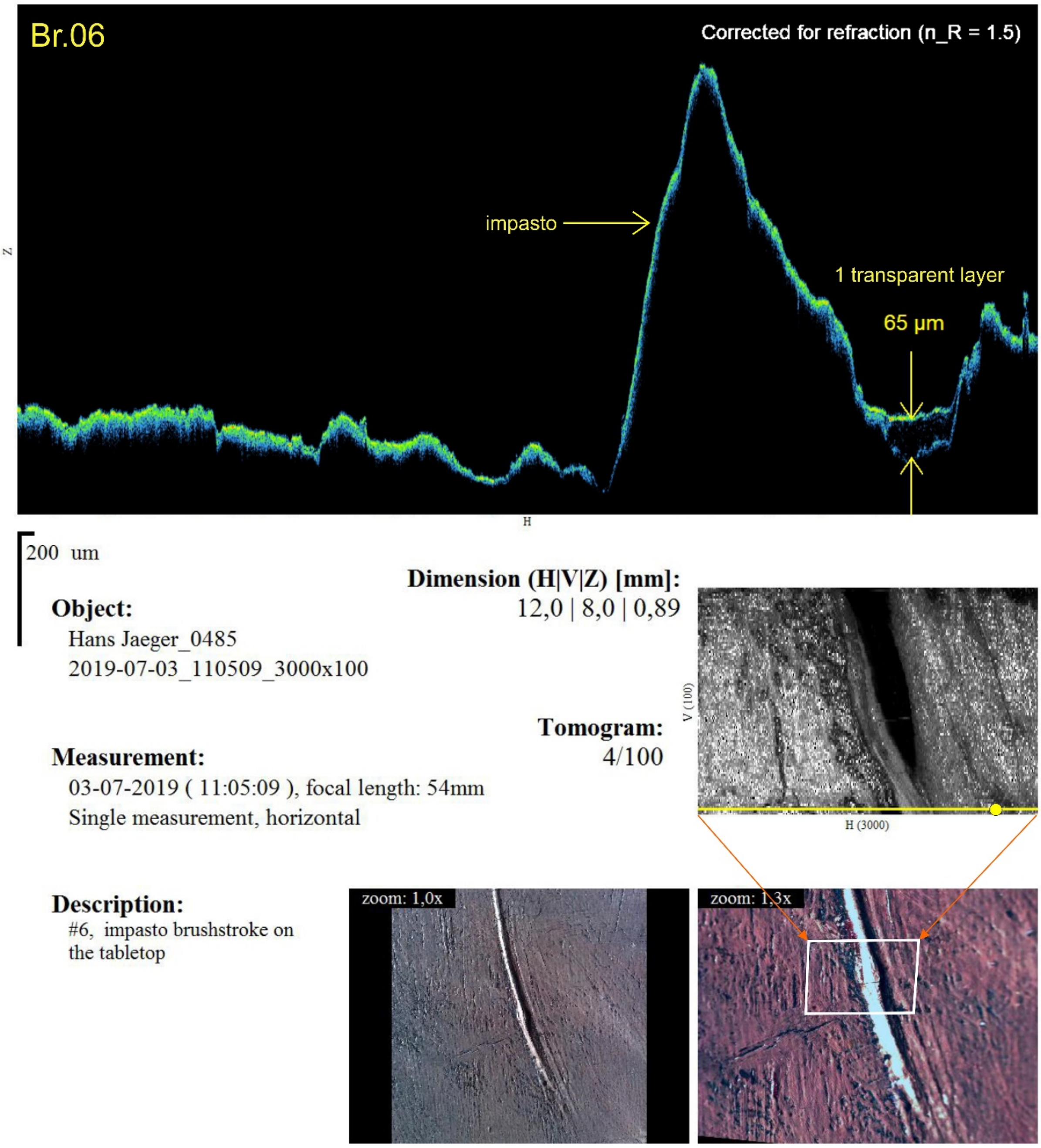

Fig. 16 *Hans Jæger* (Woll M 174), OCT tomogram and IR reflectogram from examination spot Br.06

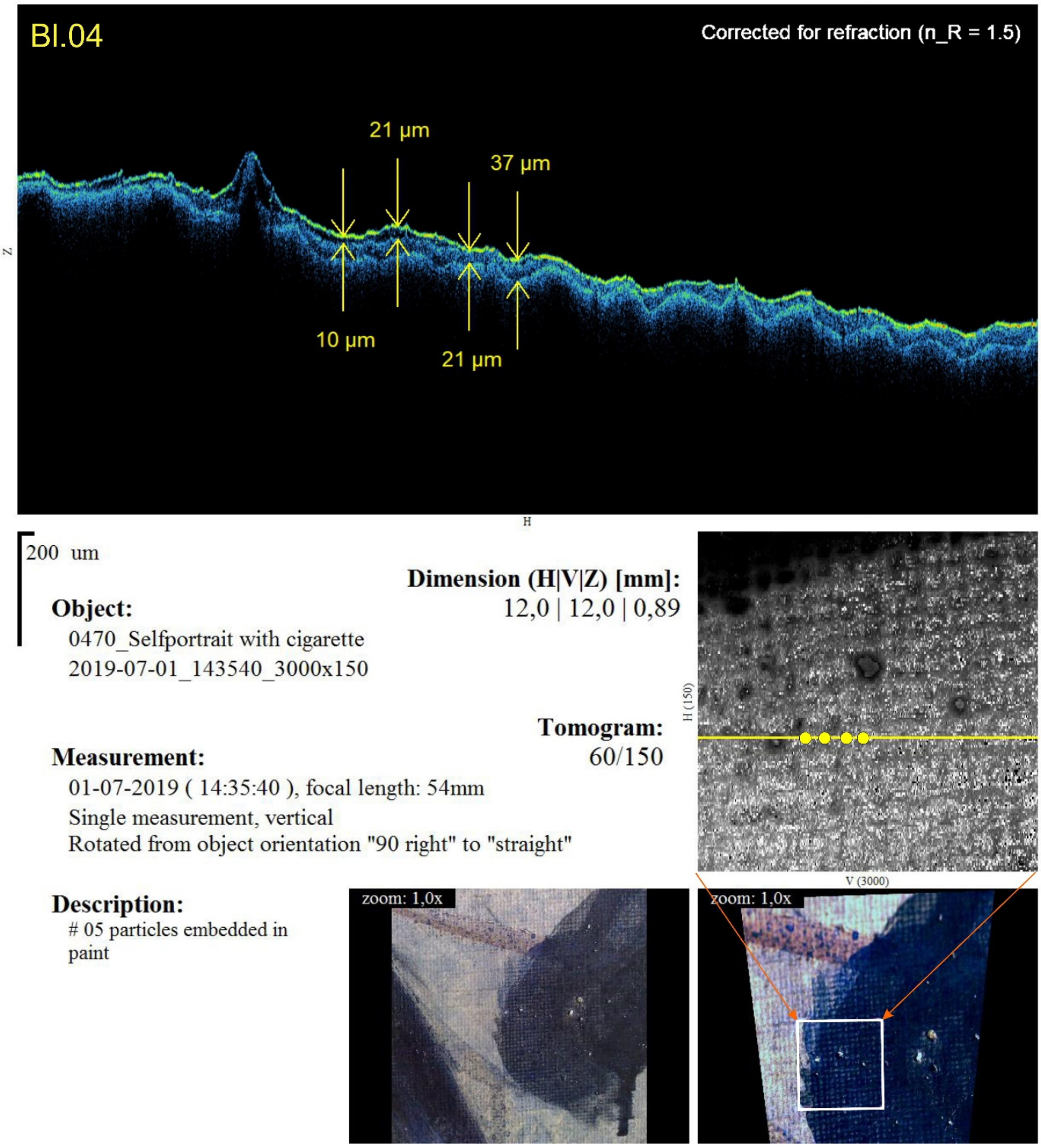

Fig. 17 *Self-portrait with cigarette* (Woll M 382) OCT tomogram and IR reflectogram from examination spot Bl.04 (evidence of semi-transparent paint layers/glazes)

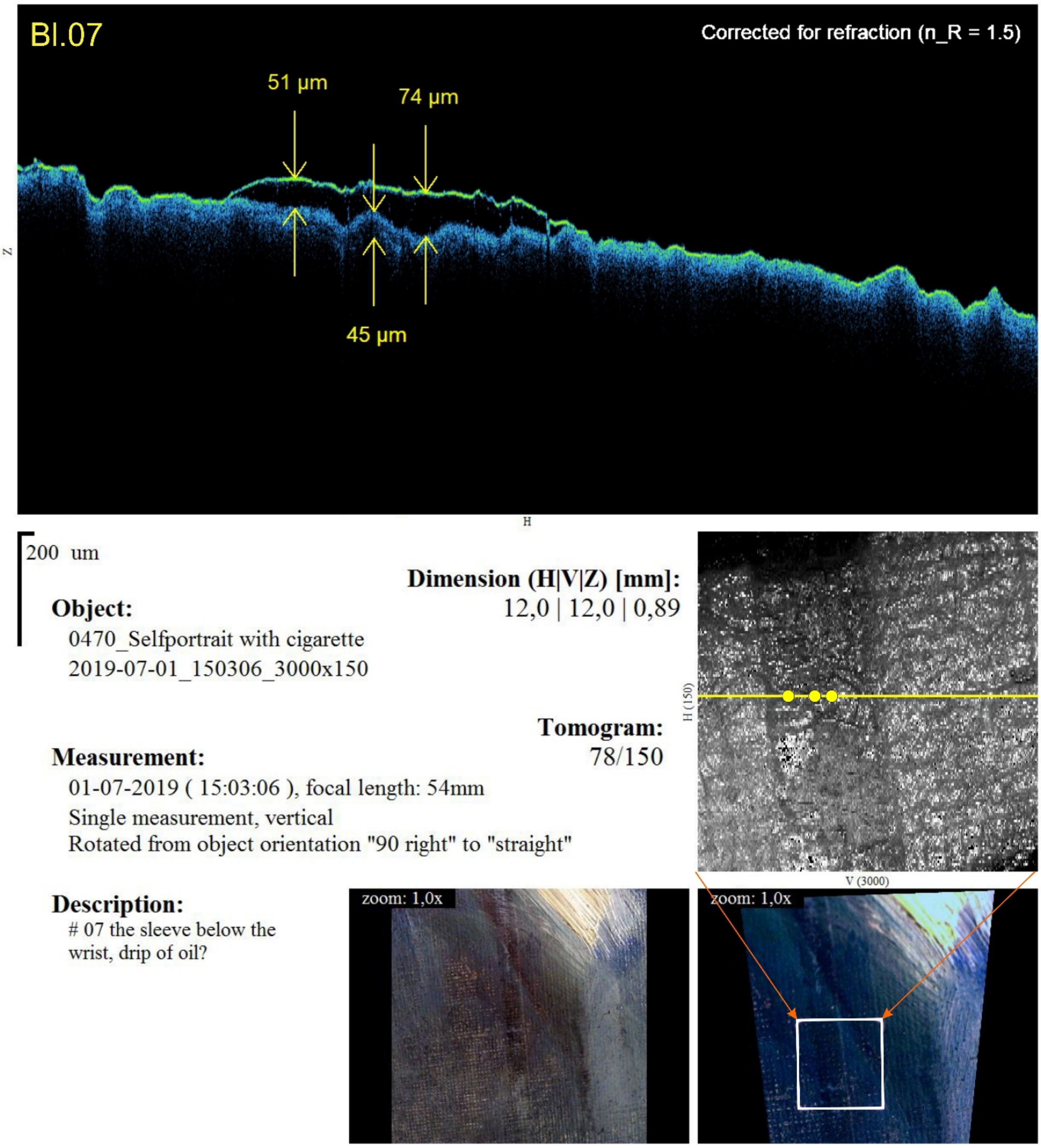

Fig. 18 *Self-portrait with cigarette* (Woll M 382) OCT tomogram and IR reflectogram from examination spot Bl.07 (residues of excess oil)

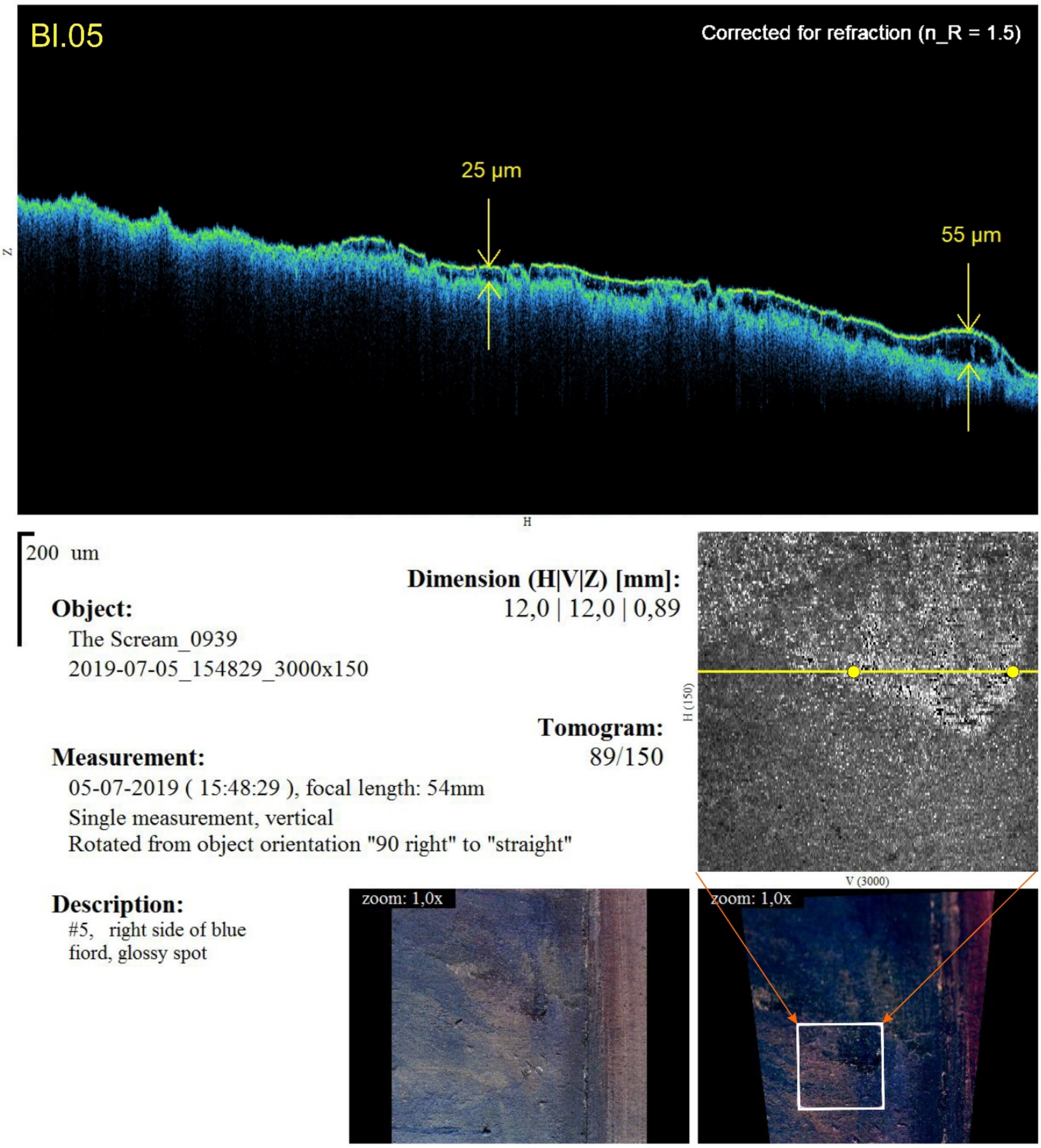

Fig. 19 *The Scream* (Woll M 333) OCT tomogram and IR reflectogram from examination spot Bl.05 (evidence of locally applied transparent layer)

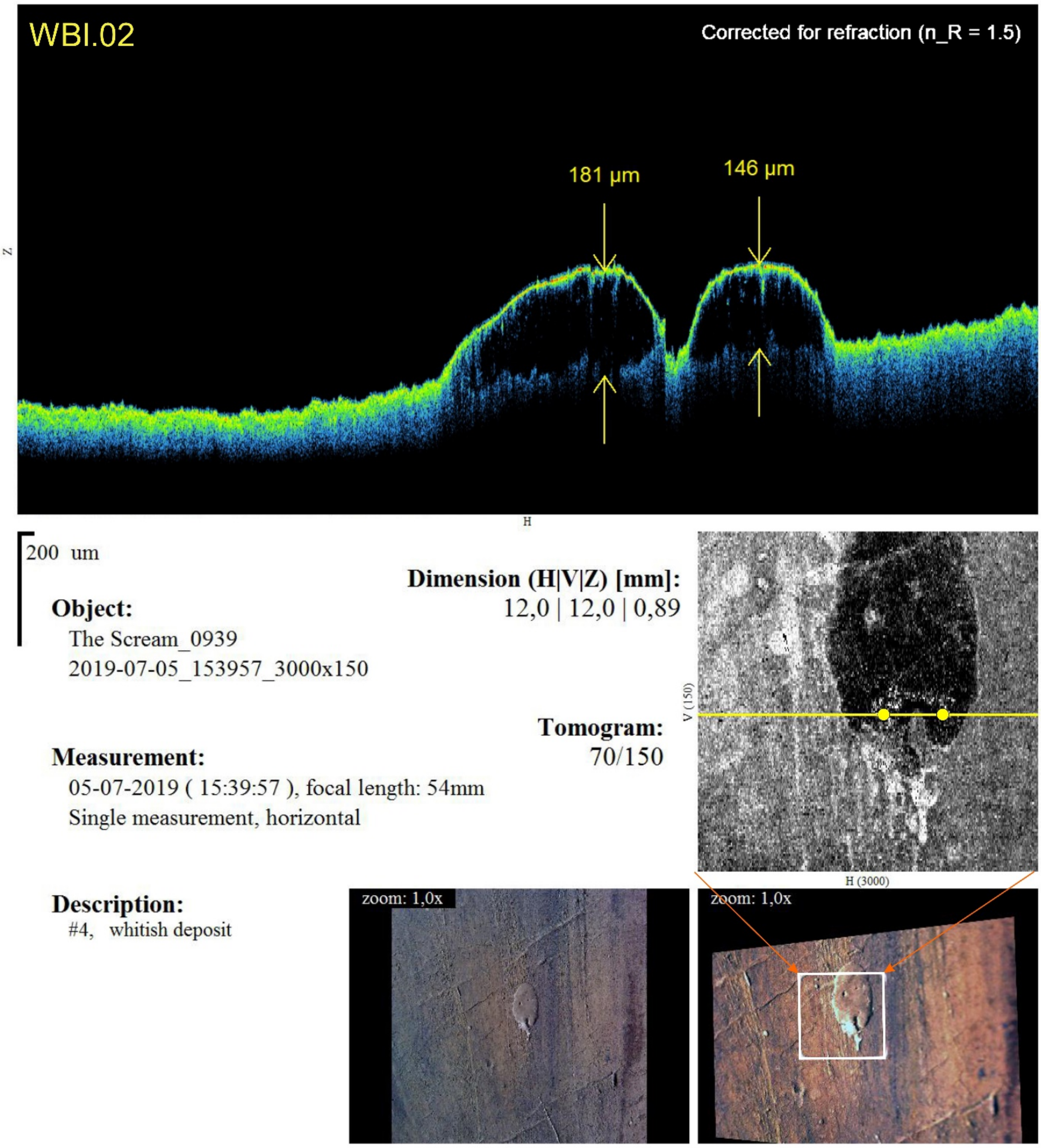

Fig. 20 *The Scream* (Woll M 333) OCT tomogram and IR reflectogram from examination spot WBl.02 (candlewax deposit),

6.4 Paper IV

Bridging the gap between the Munch Room display and the conservation narrative: a decision-making model

Ford, T., Frøysaker, T., and Hendriks, E.
https://www.ijcs.ro/public/Munch2022_Book_of_Abstracts.pdf

Abstract

Since the second half of the 20th century, public museums have witnessed a steady increase in expectations for implementing transparent conservation and preservation strategies for their art collections, balanced with requirements for display and accessibility. Despite their permanent museum status, historical painting collections are not necessarily static as they continue to evolve over time and in tandem with current views and changes in perception. This phenomenon is reflected in the National Museum of Art's collection of 57 Munch paintings, which has a collective display tradition in terms of the Munch Room. The following study addresses the challenges in designing a viable conservation decision-making model for an anachronistically displayed collection of paintings. In terms of conservation, the focus is on the non-original restoration varnish layers. Research methods include the creation of an updated survey of the 57 paintings which revealed that three-quarters of the Munch collection had been varnished by the museum. A proposed decision-making design, based on contemporary art models, incorporates an extra visual overview of each painting's historical trajectory. The theoretical framework of 'object itineraries' was adopted to both interpret and map the shifts in the core display of paintings between 1909 and 2019. This approach helped to highlight the recurring historical patterns related to the application of non-original restoration varnishes and physical damages. Likewise, changes in the painting's iconic status and shifts in popularity in terms of display context and demand (exhibitions and loans) are more easily discernible. Finally, the study accommodates the changing role of the institution's decision-makers and stakeholders over the past 110 years and presents a useful format for the management of change in historic collections.

Introduction

The main aim of this study was to design a suitable conservation[1] decision-making model for a single artist collection with a heterogenous character. The investigation encompassed 57 paintings by Edvard Munch (1863–1944) belonging to the Norwegian National Museum of Art (NM).[2] Emphasis was placed on visual mapping of the conservation histories and movement of each painting within the context of the collective display traditions of the Munch Room. The conservation focus is on the issue of non-original restoration varnish layers. The research methods consisted of a twostep process. The first step includes the creation of an updated survey of the varnishes in the entire NM Munch collection. This overview is derived from a fusion of earlier research studies and their associated findings (Ford et al. 2019; Ford 2021; Ford et al. 2021) and was instrumental for the design process and creation of the model. The second step is the design for a decision-making model. The overall format is based on existing conservation decision-making models but incorporates a workflow framework specifically tailored for the Munch collection. The model was tested with four Munch paintings.

The Munch Room and collection history

The Munch paintings were acquired over a period of 79 years (1891–1970) and represent the first public collection of the artist's earlier and mid-career masterpieces (1881–1920) including important motifs from his *Frieze of Life* (Skedsmo and Waaler 1998; Messel 2012). Furthermore, many of the paintings are Munch's first painted versions of reused iconic motifs, which give them added art historical significance. These include *The Sick Child* (Woll M 130), *The Scream* (Woll M 333), *Madonna* (Woll M 366), and *The Dance of Life* (Woll M 464). Since 1909, highlights from the Munch collection have been displayed as a specific group and in 1937 they were allocated a permanent exhibition space known as the Munch Room in the former National Gallery of Art (NG) building (Willoch 1937; Messel 2012). Traditionally, the Munch Room has consisted of a typical core (18–20 works) of Munch's most representative motifs from the collection. Display variations have been dependent on the

[1] The umbrella definition of conservation used here accords with ICOM's terminology and encompasses preventive conservation, remedial conservation, and restoration. https://www.icom-cc.org/en/search?searchstring=conservation%20definition
[2] Hereafter referred to as NM Munch collection. The paintings formerly belonged to the National Gallery of Art (NG) which, on 1 July 2003, became part of the NM.

director and/or curatorial staff. Additional disruptions to the core display, caused by either exhibition, loans or conservation requirements, have resulted in the temporary display of other motifs from the remaining Munch paintings in storage. In 2019, the NG building closed its doors to the public. The Munch Room concept will be historically recreated in the new museum building due to open in June 2022.

It was not until the appointment of the first director, Jens Thiis (1908–1941) that the Munch paintings gained prominence as a specific group in terms of display (Messel 2012; Messel 2022). From June 1909, Thiis was consistent in his promotion of Munch and the collective display of his works in the museum (Ford 2021). Historically, their collective display can be categorised into four phases (A(i), A(ii), B and C), which run parallel to the various extensions and refurbishments made to the National Gallery building **(Figure 1)**.

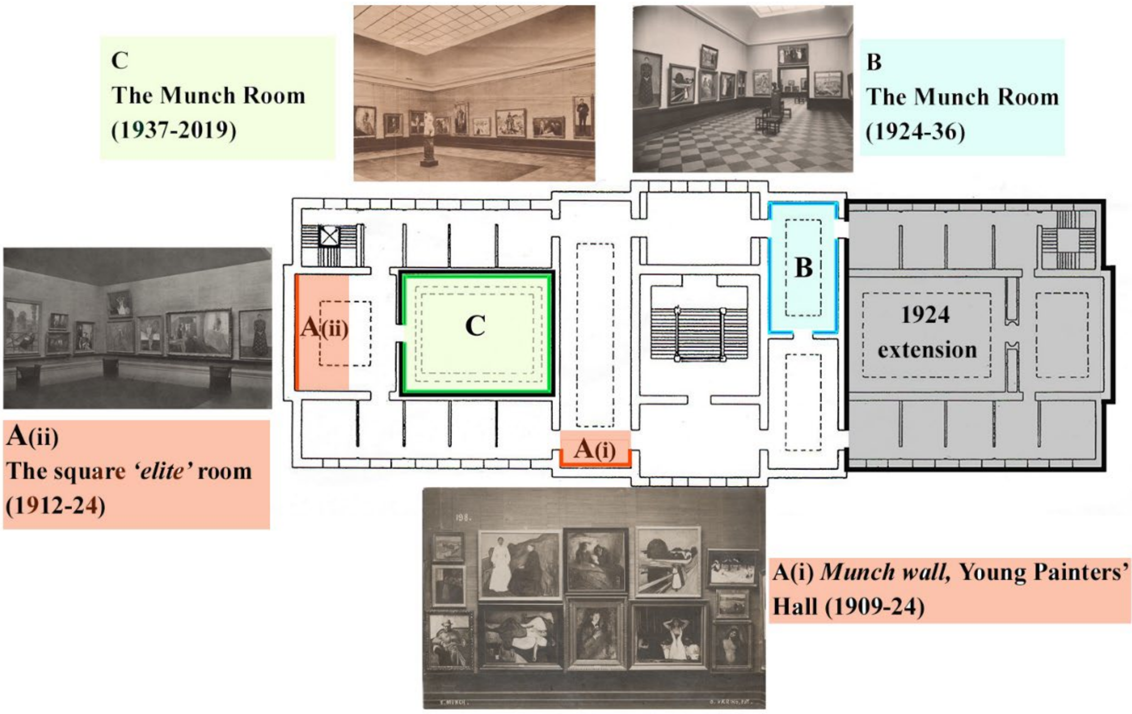

Figure 1. Overview of the Munch Room's four phases and locations, 2nd-floor plan, National Gallery (1909–2019). C The Munch Room (1937–2019), B The Munch Room (1924–1936), A(i) The Munch wall, Young Painters' Hall (1909–1924), A(ii) The square 'elite' room (1912–1924)

During the first phase (1909–1924), the majority of the newly acquired paintings were initially displayed together on one wall (Munch wall) in the Young Painters' Hall **(Figure 1, A(i))**.[3] As the collection increased, the Munch display became split between the Munch wall and the south wall of the square 'elite' room (1912–1924) **(Figure 1, A(ii))**.[4] However, in 1924, the Munch collection was reunited in one room **(Figure 1, B)**. This was possible due to the completion of the much-needed north extension and the general refurbishment of the galleries.[5] Nevertheless, director Thiis was not satisfied and continued to lobby for a grander and more exclusive exhibition space for Munch's paintings (Messel 2012; Berman 2013). In 1937, the south courtyard was converted into exhibition spaces with a large room dedicated to Munch on the second floor **(Figure 1, C)**. At present, no systemised study exists of the Munch Room's development and shifts in the core display of paintings between 1909 and 2019. Historically, there have only been three disruptions to the 1937 room since its establishment and closure in 2019: the first was linked to the evacuation of the paintings between 1940 and 1946 to safeguard them from physical danger during WWII (Kongssund 2006); the second was in 2005, when the existence of the Munch Room as a concept came under threat with a controversial rehanging;[6] and the third was in conjunction with the 150-year Munch anniversary exhibition (2013) which involved a recreation of Munch's *Frieze of Life* display (Guleng et al. 2013; Iranowska 2017).[7] Despite these disruptions and its dismantling with the closure of the NG, the NM has continued to uphold the historic display legacy by recreating the Munch Room in the new museum building (Ustvedt and Yvenes 2022).

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[3] In 1909, the NM's existing collection of 8 Munch paintings was supplemented with an extra 12 paintings (5 purchased with the Houens fund and 7 donated by Olav Schou). It increased again to a total of 23 with 3 more donations from Schou in 1910. The earliest photographic documentation from 1909 shows 15 works displayed on the Munch wall (Messel 2022).

[4] It is difficult to ascertain as to when exactly Thiis split the paintings between the two rooms. However, the earliest surviving records, photographs taken in 1912 of both rooms, document 18 from a total of 24 paintings on display.

[5] The earliest photographic documentation of the 1924 room dates from 1930 (*Dagbladet*, Tuesday 8th April 1930) and again it is difficult to get a complete overview of the whole display as the west wall is not visible. A 1932 photograph shows a similar display variation but with the inclusion of *The Dance of Life* above the door.

[6] Between February 2005 and June 2006, many of the paintings from the Munch Room that were loaned to an exhibition at MOMA, were replaced with artists other than Munch (Picasso, Matisse etc.). https://www.dagsavisen.no/kultur/2006/06/17/munch-salen-er-tilbake/https://www.aftenposten.no/kultur/i/z7vJ1/slik-blir-det-nye-nasjonalgalleriet

[7] For the 2013 exhibition, the Munch Room was used to recreate Munch's 1902 Berlin sequence of paintings forming his *Frieze of Life*, but only 6 of the NM's Munch paintings were featured: the remaining missing motifs were loaned-in, and the paintings were temporary reframed in special display cases for the exhibition period.

A group case study approach

Until now, a discrepancy has existed between the art historical display legacy of the Munch Room and approaches to conservation. Despite the tradition of a group display, the paintings have never been assessed collectively in terms of conservation issues. Historically, only six of the 57 paintings have been investigated by previous conservators, and all as individual case studies (Plahter 1999; Aslaksby 2009; Aslaksby 2015; Plahter and Plahter 2015; Ford 2021). Furthermore, there exists only one varnish overview of the NM Munch collection which is incomplete in terms of methodology (Stein and Rød 2015). This overview is based solely on the interpretation of 49 conservation reports and contemporary written sources and does not include any visual or scientific methods of investigation. Therefore, there was a need for an integrative, decision-making model for the Munch collection that would address these shortcomings. The main aim was to find a solution to the current mismatch between the soloist approach focusing on conservation decisions for each work versus art historical regard for the collection as an ensemble, bringing both aspects into alignment. In addition, the new model should facilitate the need to redress the balance in appearance of a collection comprised of paintings in a disparate state due to past uncoordinated and, arguably, inappropriate varnish interventions (Stein and Rød 2015).

Decision-making models: background

Since the second half of the 20th century, public museums have witnessed a steady increase in public expectations for implementing transparent conservation and preservation strategies for their art collections, balanced with requirements for display and accessibility (Appelbaum 2010; Muñoz Viñas 2020). There is also growing attention being paid to the wishes of other stakeholders in relation to those of the custodian (Laurenson 2004; Scholte and Wharton 2011; Van Saaze 2013; Henderson and Nakamoto 2016). Together, these developments have encouraged conservation professionals to reflect more critically in their design and choice of suitable decision-making models for complex artefacts. There exists a recent body of research which has focused specifically on the decision-making challenges posed by contemporary art (Giebeler et al. 2021). However, the applicability of the models and approaches developed for contemporary art has yet to be tested properly for more traditional and historical collections (Tom 2019), such as the Munch collection.

Methods

Updated varnish survey of the NM Munch collection

Renewed interest in the conservation of the NM Munch collection was prompted by unanswered questions regarding the museum's past controversial varnishing practices (Ford 2021). New research into the non-original restoration varnishes (Ford et al. 2019; Ford et al. 2021) provided valuable information for the creation of a revised and updated varnish survey of the entire collection. This updated survey was undertaken prior to the design of the decision-making model and was necessary as background for the model's structure and workflow design. Furthermore, the model needed to be tested using examples from the collection.

The updated varnish survey was based on the systemised visual examination of 56 paintings undertaken between January 2018 and June 2021 **(Table I)**.[8] This was supplemented by a comprehensive overview of relevant archival sources, studio recipe books, 57 conservation dossiers and surviving historic varnish resin samples.[9] Additional scientific results obtained from two non-invasive diagnostic studies were also incorporated. These included the testing of portable Fourier transform infrared spectrometry (pFTIR) used to identify the varnish resins on three paintings (Ford et al. 2019) and the extra pFTIR spectra from three of the four test paintings. Findings from optical coherence tomography (OCT), tested on 13 paintings (Ford et al. 2021a), were employed for the layer identification, distribution and thickness of the varnishes.

A total of 44 out of 57 paintings were found to have at least one varnish layer and 14 were left unvarnished. Seven different varnish types and mixtures were also documented including

[8] The varnish survey is a summary of relevant data collected from a larger PhD study on the NM Munch collection by Thierry Ford (2018–2022). It is essentially comprised of the physical inspection of 56 paintings and conservation records and NM varnish-related archival material. The survey also includes the conservation reports made prior to the 1993 theft of the painting *Betzy Nilsen* (Woll M 144). All 56 paintings were taken out of their frames in the NG conservation studio and their surfaces examined with optical microscopy combined with ultraviolet light for the detection of resinous varnish coatings.
[9] NM Archives: NMFK/NG-0007/E/L0002; for the historical resin samples see, NMFK/NG-malerikonserveringsarkiv.

mastic, dammar, Wilhelm Becker's matt *tavel* varnish,[10] Laropal K 80, MS2A, MS2B and Lefranc Bourgeois' Ceronis[11] picture varnish. Chemically, this only represents three main classes of varnish resins: two natural (mastic and dammar) and one synthetic (ketone).[12] One type of varnish was applied to 26 paintings, whereas six paintings have two different varnish resin types and only one painting has three (Woll M 340). The original surfaces of four paintings were matted down locally with the Ceronis wax-varnish paste. According to the conservation reports, all 43 paintings appear to have been either varnished or revarnished by the NM.

The Munch conservation decision-making model

Design format

The design of the Munch conservation decision-making model combines elements borrowed from contemporary art models with background information provided from the revised varnish survey. The design format is based on the recently revised flow diagram for contemporary art, hereafter referred to as the Köln model (Giebeler et al. 2021) **(Figure 2)**. This formed the model's initial backbone and necessary adjustments were made to incorporate various institutional and collective requirements. Hence, the Munch Room features as an integral part of the process, assisting contextualisation of the group's identity and the mapping of similarities and differences within the group.

Theoretical background

The systematic processing of each individual painting in context to the whole group and the Munch Room through a conservation decision-making model required a theoretical framework for the interpretation of the various historical trajectories. In this case, a theoretical approach, developed by Joyce and Gillespie, of 'object itineraries' was chosen. Essentially, its perspective builds on the theory of object biographies, by 'tracing the paths along which

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[10] Wilhelm Becker's (Stockholm) matt *tavel* varnish (*ceramatt*/matt *tavelfernissa*) was used on 6 paintings between March and May 1950. The Swedish picture varnish is a mixture of dammar and mastic with bleached beeswax in balsam turpentine (Becker 1955; Becker 1965).

[11] LeFranc Bourgeois' Ceronis is a matt wax-varnish paste for paintings sold in 60 ml tubes. The exact content has not been chemically confirmed but, from undated sales catalogues, the varnish appears to be 28% wax (drying extract) dissolved in petroleum (unknown quantity). See, Lefranc's Technical Guide for Oil Painting: Retouching Varnishes, Picture Varnishes, https://fliphtml5.com/mjoa/gfiy/basic (accessed 14.01.2022).

[12] Laropal K 80, MS2A and MS2B are all low molecular weight ketone resin varnishes (Samet 1998)

things live' in terms of the their interactions over time (Joyce and Gillespie 2015). For the Munch collection, this facilitated representation of the broader narratives connected to each painting in the various decision-making steps. It helped to evaluate the material and non-material factors to be considered, in line with the institution's past, present and future display policies, both for individual paintings and as a group.

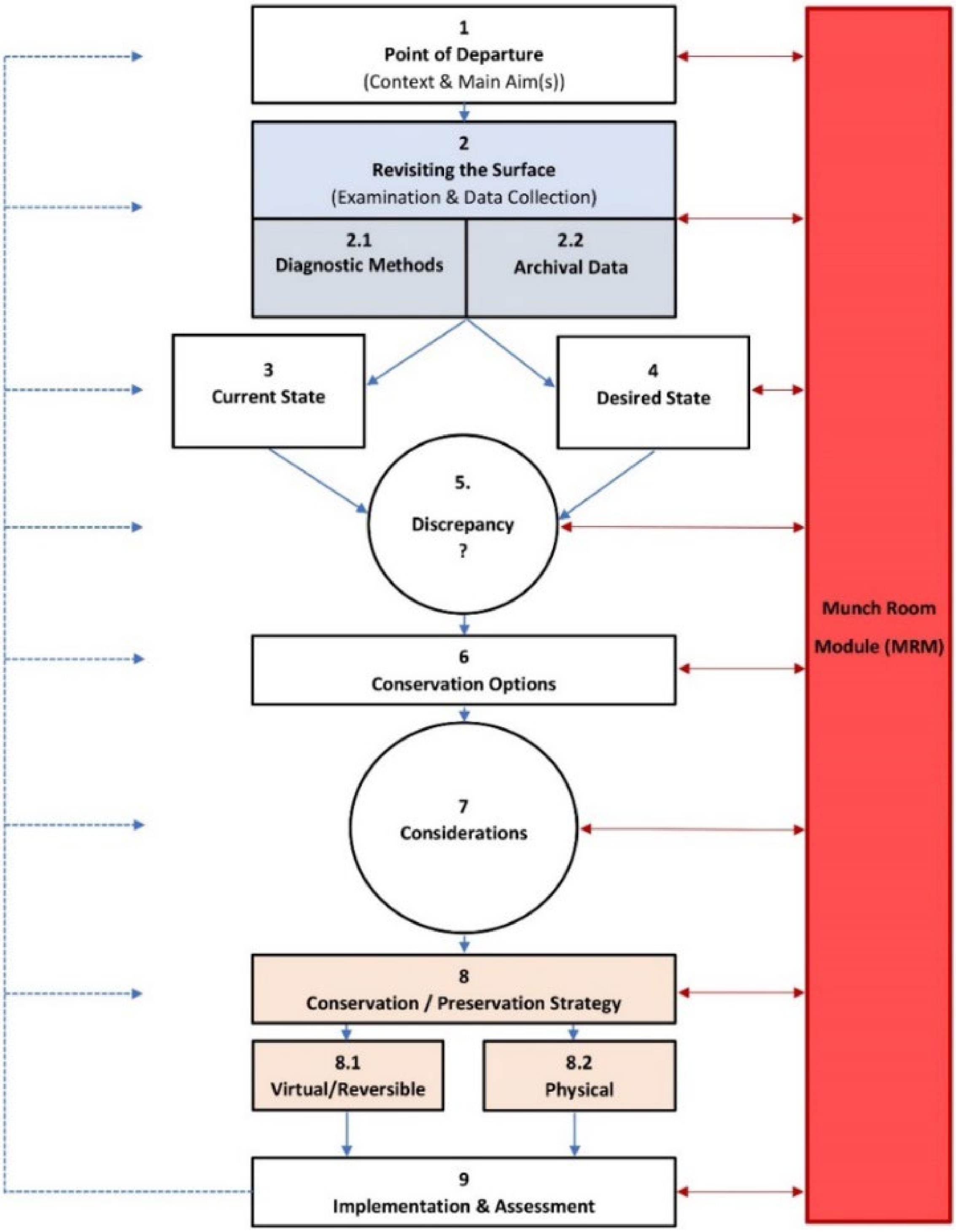

Figure 2. Flowchart showing the Munch conservation decision-making model

The Munch Room module (MRM)

Today's ever-increasing abundance of visual imagery, characterised by our reliance on (digital) images, influenced the inclusion of the additional Munch Room module (MRM) in the overall design of the model **(Figure 3)**. The aim was to explore the benefits of visually mapping the various movements and itineraries of each painting over time. The MRM therefore runs vertically as a parallel parameter for each painting and interacts with the various decision-making steps. Historical knowledge of an artefact's past will help to shape future conservation management (Appelbaum 2010) and, with the Munch paintings, there is an additional and intertwined art historical and collective aspect to the decision-making process (Ford 2021). This is apparent with the more iconic motifs. Initially, certain paintings may have acquired more active historic itineraries through exhibition loans, leading to an increase in iconic status, as in the case of *The Scream*.[13] Tracing the movements of key works from Munch's *Frieze of Life*, in and out of the permanent display of the Munch Room, could also play an important role in the conservator's evaluation of the paintings as a group. For example, having had a permanent exhibition status within the Munch Room, some paintings, such as *The Dance of Life* and *Death in the Sick Room* (Woll M 329), may have received little or no conservation treatments due to lack of accessibility. Similarly, the frequency of exhibition loans for certain paintings might have impacted the occurrence and types of treatments and preventive measures undertaken during specific timeframes.

The MRM is essentially a fusion of two recent conceptual tools applied to contemporary art conservation which have been modified for this study. Firstly, design elements are borrowed from Stigter's 'slide rule' behaviour index (Stigter 2017) for the visualisation of the movements of each Munch painting as they shift status and display, in and out of the Munch Room **(Fig. 3)**. Stigter employs a 3-zone slide rule system (contained, installed, and performed) to illustrate the timeline analysis for behavioural shifts present in contemporary artworks. This successfully allows for museum professionals to visually map active processes within complex artworks when addressing decision-making options. The MRM employs a

[13] *The Scream* gained an increased international iconic status during the 1970s and was only loaned post-WWII. It travelled extensively to over 40 different exhibition venues between 1954 and 1993. After its return from the theft in 1994, it remained in the National Gallery until moving to the new building (24 August 2021).

similar visual concept but instead uses a two-zone chart to trace the paths of each painting through time. Each Munch painting is colour coded and plotted according to its specific display history represented by the horizontal lines. The multiple stacked timelines essentially reveal the movements of each painting (if any) between the Munch Room core display and other exhibition rooms or storage.

The second source of inspiration is taken from Lawson and Marçal's *Map of Interactions*, a visual tool created for the documentation and conservation of performance art (Lawson and Marçal 2021). This documentation tool is used to examine the institutional lifecycle of artworks regarding changes in context and the mapping of new biographical paths. The notion of visually representing the institutional interactions of an artwork over time is also included in the MRM. These types of visual timelines can often be difficult to extract from the confusion of drop-down menus in traditional collection management databases.

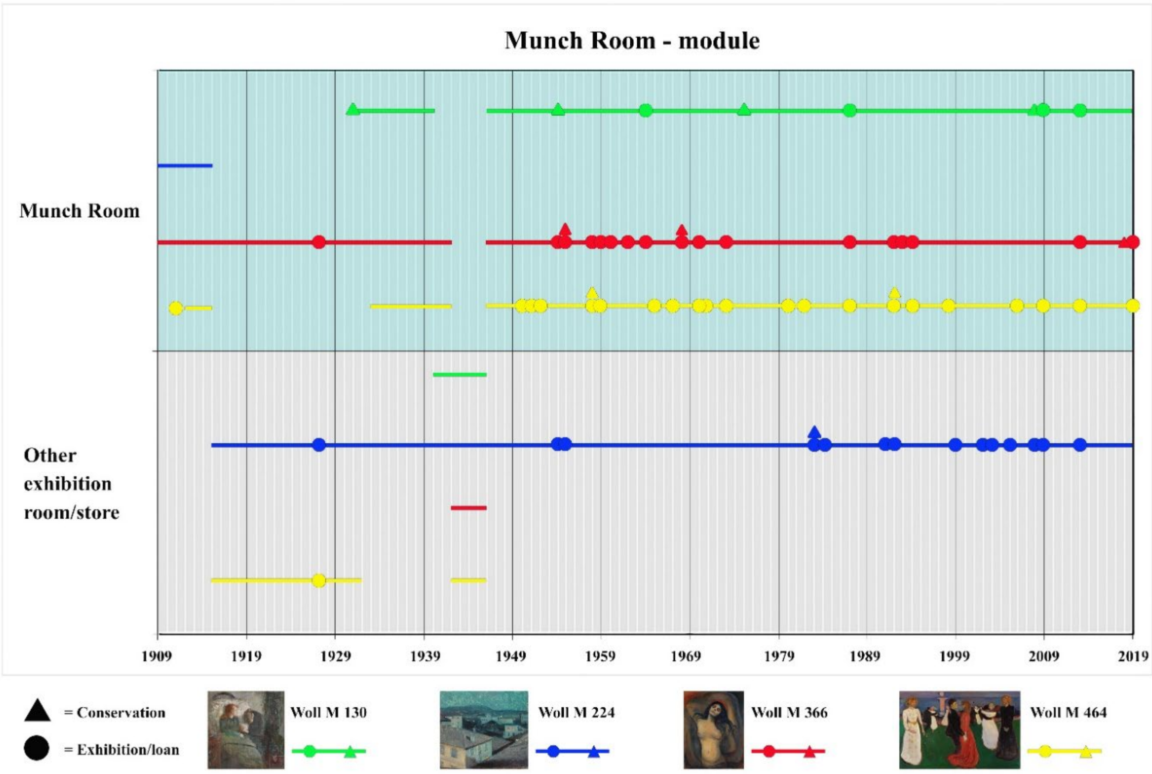

Figure 3. Munch Room module with the 4 test paintings' trajectories plotted

In the MRM, a conservation treatment (such as varnishing) and/or a short-term exhibition loan activity for each painting can be plotted along the horizontal timeline of a painting according to the relevant date. A triangular marker is used to depict a conservation treatment and a circle for a loan **(Figure 3)**.

The integration of a visual element into the decision-making model helps to simultaneously trace and map the unique display trajectories for each Munch painting parallel to shifts in status, demand (exhibition loans) and conservation history. As with the slide rule system and the *Map of Interactions*, the MRM addresses the option for process-based decision-making (Stigter 2019) in addition to more traditional object-based considerations.

As a preliminary test, the following four paintings from the collection were plotted to assess the suitability of the model's workflow: *Night in Nice* (Woll M 224), *The Sick Child*, *Madonna* and *The Dance of Life* **(Figure 3** and **Table II)**. The test paintings were chosen according to their different acquisition timeframes, varnish history and iconic status.

Point of departure: Step 1

The starting point of the model begins with the same format as outlined in the Köln model, **step 1 (Figure 2)**, It is the point of departure and consists of a presentation of the initial aim(s) in the context of the current circumstances and relevance to the various stakeholders and custodians.

The NM's 2020–2025 strategic vision incorporates ethical core values of inclusion, increased accessibility, and openness,[14] therefore, the requirements from a wider audience are an important part of the equation. Decision-making questions need to address the balance between the requirements of the stakeholders (the public and the ministry of culture) and the guardians (museum curators and conservators). In the case of the four test paintings, the initial aims and questions that concern the identification, overview and future of the non-original

[14] https://www.nasjonalmuseet.no/om-nasjonalmuseet/styret-organisasjon-og-ansatte/nasjonalmuseets-strategi-2020-2025/ (accessed 20.03.2022).

varnish layers applied are presented. These can be assessed in the context of past and current display traditions plotted in the parallel MRM **(Figure 3)**.

Revisiting the surface: Step 2

In **step 2**, the conservation history of the painting is assessed with the renewed visual examination of the surface provided by information supplied from the updated varnish survey **(Table I)**. In contrast to the Köln model, this part has been further divided into two sub-steps: **step 2.1**, diagnostic methods (with an emphasis on a non-invasive approach) and **step 2.2**, archival data.

In the case of the four Munch paintings tested, pFTIR and OCT were used as the initial non-invasive 'screening methods' for the identification of the varnishes present. Individual and collective assessments can be made according to a painting's history in terms of (1) the presence of non-original restoration varnish layers and/or (2) evidence of original surface finishes (i.e. Munch's use of localised varnish to saturate certain passages of paint). This section allows for a preliminary non-invasive and non-destructive overview of the varnishes present in the 57 paintings. Furthermore, it facilitates a clear assessment of each painting's current state with reference to its historical narrative and past.

Current state: Step 3

From the information gathered in **steps 2, 2.1** and **2.2**, a painting's current physical state (condition) is summarised according to the information provided in the varnish survey **(Table I)** and the recommended checklists as outlined in the Köln model (Giebeler et al. 2021). The focus is on the authenticity of the existing surface varnish(es) present.

Desired state: Step 4

Step 4 also follows the guidelines and recommendations from the Köln model. In this section, arguments for the desired state for each painting are presented by both the stakeholders and custodians. Linked to the MRM, this step considers the key question(s) to be critically assessed alongside historical context and the removal of non-original restoration varnish layer(s). The identity and meaning of each of the 57 paintings within the group in terms of their historical trajectories and itineraries is explored.

A critical and contextual review of the NM's past restoration varnishing practices is required.

1) How controversial was the restoration varnish layer(s) in context to its time of application?
2) To what extent has the restoration varnish layer(s) altered the visual effect of the painting?
3) What is known about the original state of Munch's painted surface underneath the restoration varnish layer(s)?
4) What are the historical shifts in meaning over time regarding the restoration varnish layer(s)?

Discrepancy: Step 5

The present physical condition of each painting noted in **step 3** is weighed against the arguments regarding the desired state of the varnished surface discussed in **step 4**. The decision-making uses the following core values as recommended by the Köln model:

- Authenticity
- Aesthetic and artistic values
- Historicity
- Functionality
- Artist's intent and anticipation of potential future development/changes

In terms of the Munch collection, the overarching question is whether a non-original restoration varnish should be removed. For each painting, the historicity of the physical varnish layer(s) can be loaded with valuable meaning as noted in **step 4**. Which story (varnish layer) to preserve and which to remove? The varnish dichotomy is central to the final decision-making process and planning of future conservation/preservation options, and remains interlinked with the group display aspect in terms of the Munch Room.

Conservation options: Step 6

In this section, conservation options can be developed for each individual painting, for the whole collection, or sections of the group. However, each option will remain intertwined with the collection in terms of the Munch Room display. The main aim of **step 6** is to establish realistic and ethical options that address the varnish issue. These are dependent on a painting's current condition, documented in **step 3**, balanced with a casuistry approach to conservation (Van de Vall 2005; Marçal et al. 2013; Wharton 2018), as advocated in the Köln model.

The following conservation options are listed below:

1. No action
2. No action with dissemination
3. Partial removal of restoration varnish layer(s) – selective cleaning
4. Complete removal of restoration varnish layer(s)

Option 2, 'No action with dissemination', can be achieved through the visible presentation of the varnish layers and historical context to the public using technical means and without intervening in the object. For example, Munch's original varnish streaks running down the surface of *The Sick Child* (witnessed at The Autumn Exhibition, Oslo in 1886) have lost their gloss over time and become further matted down through past restoration. However, the original varnish streaks are still clearly visible in the UVA photograph **(Figure 4)**.

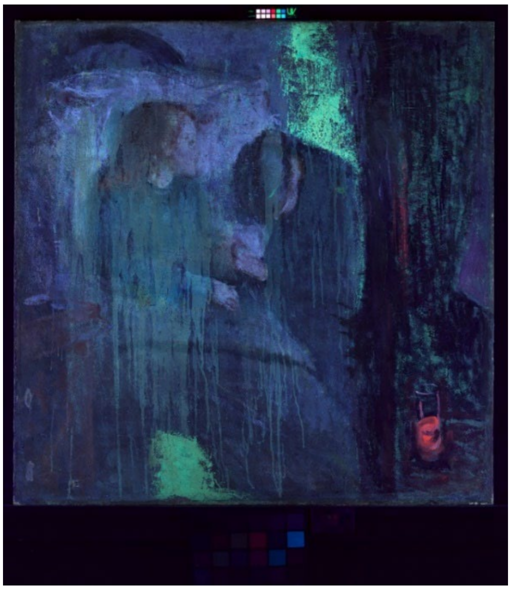

Figure 4 ***The Sick Child*****: UVA photograph showing the green fluorescence of the original varnish streaks running down the surface in the main figure**

Considerations: Step 7

In **step 7**, the four conservation options proposed in **step 6** are critically evaluated by the decision-makers. The following assessment criteria, used in the Köln model, can also be incorporated into the Munch model:

- Aesthetic and artistic values
- Authenticity
- Historicity
- Functionality
- Financial limitations
- Technical limitations
- Restoration/conservation ethics

Conservation/preservation strategy: Step 8

In contrast to the Köln model, **step 8** is subdivided into two sections, **8.1** and **8.2**, which relate to the choice of either a virtual simulation (varnish removal) (Kirchner et al. 2018) or a physical conservation approach, or combinations of both.

Implementation and assessment: Step 9

The final step follows the recommendations of the Köln model in terms of both the monitoring and assessment of the chosen strategy. The flow diagram also provides routes for the revision of any difficulties or uncertainties represented by the set of blue arrows **(Figure 2)**.

Discussion

The integration of the MRM essentially acts as a useful conceptual tool that facilitates analysis and visualisation of the timeline of paintings. Despite their permanent museum status, historical painting collections are not necessarily static as they continue to evolve over time in conjunction with current views and changes in perception (Hölling 2016). In this study, the MRM is used to demonstrate the potential of tracing the interlinking historical trajectories of the four paintings within the context of their conservation issues. It ensures the possibility of simultaneously tracing the display sequences of the various paintings in tandem with their conservation histories for each decision-making step. However, the MRM visual timeline remains a prototype with limitations. The current format cannot include the whole collection on one visual map and requires customised improvements to incorporate all the 57 paintings. Although originating as a standalone idea, the concept of the MRM presents a design which can potentially be further developed to function as an interactive digital tool incorporating even more comparative data.[15]

Plotting both the conservation and exhibition/loan data for each of the four test paintings in the MRM produces an important comparative visual data overview which can be relevant for decision-making **(Figure 3)**. All four paintings have at least one record of conservation treatment: for example, four documented treatments were carried out on *The Sick Child* at regular intervals between 1931 and 2019. This indicates a fragile paint surface with a history

[15] For example, the MRM timeline format could be adapted and developed digitally with specialised software developed for a KronoGraph and include all the extra data summarised in **Table II** (https://cambridge-intelligence.com/kronograph/).

of recurring conservation issues.[16] The fragility of the paint surface might also be an explanation for the painting's limited post-WWII exhibition/loan activity compared to that of *Madonna* and *The Dance of Life*. In contrast, the paintings *Night in Nice, Madonna* and *The Dance of Life* share a history of conservation treatments and varnishing corresponding with exhibition/loans.[17]

Both *The Sick Child* and *Madonna* have a similar exhibition history in terms of their permanent display in the Munch Room. They also both featured in Jens Thiis's earlier collective Munch display configurations (see **Figure 1, A(i)**, **A(ii)** and **B**) in addition to the 1937 Munch Room;[18] in comparison, *The Dance of Life* only became part of the core display after its creation in 1937. Furthermore, the NM's first Munch acquisition in 1891, *Night in Nice*, was removed from the permanent and core Munch display as early as 1915. These variations are relevant for the discussions in **step 1** concerning the conservation of non-original restoration varnish layers. A collective conservation decision would appear to be appropriate for three varnished paintings with a history of permanent display. However, decisions made by the stakeholders and custodians might differ for *Night in Nice*. The painting does not appear to have been given the same historical display status in terms of having been part of the core display of the Munch Room. Thus, the decision to remove a restoration varnish could be more easily be taken outside the collective considerations of the room.

The physical examination of the paint surfaces in **steps 2, 2.1** and **2.2** helps to integrate all the relevant forms of information into the decision-making equation (visual, archival, imaging, and non-invasive diagnostic techniques). The display concept of the Munch Room and the importance of physically examining the paint surfaces act as the two main prerequisites for the overall decision-making process. The model allows each painting's individual complex varnish history (presented in **Table II)** to be fused with data from the NM Munch collection's

[16] Munch's second version of *The Sick Child* (Woll M 392) was initially given to the NM in 1909. In 1931, the painting was swapped with Munch's first version (Woll M 130). The first version is documented in this study. NM conservation dossier: NG.M.00839.
[17] NM conservation dossiers: NG.M.00394, 00841 and 00941.
[18] *The Sick Child* was evacuated between 1940 and 1946 and *Madonna*, between 1942 and 1946.

110-year varnish history (1909–2019). The result produces a more general, collective, and comparative approach as demonstrated by the example of the four test paintings.

The Sick Child has a complex surface, heavily reworked by Munch, and includes residues of the artist's varnish (Aslaksby 2009) **(Table II)**. There is both physical evidence (from OCT) and documentation of tampering with the original surface in terms of a locally applied restoration varnish (Ford et al. 2021). In comparison, *Night in Nice* has a smoother surface topography and two documented restoration varnish layers **(Table II)**. Both the pFTIR and OCT investigations could only confirm the presence of one natural resin layer, which suggests that there is a discrepancy in the written treatment documentation (Ford et al. 2019). The first restoration varnish was also applied while the painting was still in its frame, in line with the early pre-WWII varnish traditions (Willoch 1937).

Madonna is also documented as having two restoration varnish layers corresponding to the two major restorations of 1955 and 1968 **(Table II** and **Fig. 3)**. However, three transparent layers were recorded in the boundaries between the face and hair, lying on top of the preparatory underdrawings. These can be interpreted as the presence of an original medium rich glaze or artists' varnish applied as a saturated finish along the contours of the figure (Ford et al. 2021). *The Dance of Life* shows documentary evidence and physical confirmation of Munch's partial varnishing, which was later modified through extensive restoration post-WWII **(Table II)**.

The information generated from **steps 1–2** can be carefully processed in **steps 3–5** in terms of the historical varnish context of the collection. For example, the presence of a pre-WWII varnish applied to *Night in Nice* whilst still in its frame is a relevant part of the NM's conservation history. This finding is an important physical documentation of the NM's earlier periodic restoration practices. Moreover, it demonstrates how a high-profile collection can act as an important historical marker for an institution's conservation development in terms of changing attitudes and practices (Ford 2021).

In the newly recreated Munch Room, the five paintings – *Ashes* (30), *Madonna* (29), *The Dance of Life* (40), *The Scream* (23) and *Death in the Sick Room* (22) – that will hang on the end wall form part of Munch's *Frieze of Life* series and represent some of the artist's main and iconic motifs (Guleng 2022) **(Table I** and **Figure 5)**. Conservation decision-making in terms of the removal of non-original restoration varnishes will present challenges with regards to the consecutive display of these paintings. The OCT investigations of both *The Scream* and *The Dance of Life* confirmed evidence of Munch's own transparent surface finishes (varnish?), which have been unevenly applied and have discoloured over time (Ford et al. 2021). Furthermore, *The Scream* and *Death in the Sick Room* have comparatively matt finishes due to their unrestored tempera paint surfaces but in *Madonna,* there are traces of the artist's own surface finishes which lie masked beneath multiple and now discoloured restoration varnishes (Ford et al. 2021) (**Table II**).

Steps 3–5 enable a critical review of the intertwined and layered narratives present in individual paint surfaces and across the NM Munch collection. Given the NM's history of past 'controversial' varnishing practices (Ford 2021), questions concerning which story to document and which varnish layer to conserve for display can be more easily processed. Although individual paintings might appear straightforward in terms of varnish removal decisions on aesthetic grounds, this soloist approach might have consequences for the collective display of the Munch Room. The decision-making model therefore provides a workflow design rationale which can accommodate feasible, cost effective, in-situ, non-contact, and non-invasive assessments across a complex group of historical paintings. As argued by both Muir (2009) and Streeton (2017), adopting a set of paradigms in a methodological framework will guide any further collection of scientific data and help steer future conservation away from a purely clinical decision-making approach. More importantly, it creates a platform for decision-making demands voiced by both the custodians and the stakeholders. This allows for greater flexibility, echoing the advantages put forward for creating a bespoke conservation plan, tailor made to the needs of an institution and its public (Ashley-Smith 2018). The final steps **(6–9)** still require implementation and will be presented in a forthcoming study.

Figure 5. Recreation of the Munch Room showing the end wall (2022, Guicciardini and Magni Architetti)

Conclusion

The background to the decision-making plan was based on the collation of data provided from an updated varnish survey of the NM Munch collection. The model represents a fusion of requirements borrowed from existing conservation decision-making models for contemporary art. These have been adapted into a useful conceptual tool employed to process the multifaceted and complex nature of a historical collection of paintings. The Köln decision-making model for contemporary art conservation and preservation provided the backbone to the overall design. Although the Munch model has yet to be further implemented and tested, the proposed workflow design demonstrated that it is theoretically possible to expand models designed for contemporary art for historic objects. The model is the first example of a systemised and comprehensive overview of the Munch Room's development in terms of shifts in the core display of paintings between 1909 and 2019. Nevertheless, the complexity of dealing with a whole collection and the display specificity of the Munch Room underlines the necessity to tailor existing models to the requirements and historical context of an institution. These two prerequisites influenced the fusion of an additional visual element to the model, the

Munch Room module, which provides the decision-makers with a parallel display of each painting's historical trajectory. Recurring patterns related to non-original restoration varnishes and physical damages become more quickly discernible through the visual mapping. Changes in iconic status and shifts in popularity, in terms of display context and demand (exhibitions and loans), can also be processed quantitatively. In addition, the Munch Room module can be developed to incorporate other related forms of data associated with the movement of individual paintings over time (loans, exhibitions, conservation etc.).

The study also shows the importance of defining a theoretical framework for the model. Despite the NM Munch collection's anachronistic display traditions, the collection is in flux. Adopting a concept of 'object itineraries' helps to facilitate an understanding of the continued shifts, balance and relationships between the paintings and the group and more specifically, a recognition of the changing role of the institution's decision-makers and stakeholders over the past 110 years. Finally, the flexibility of the design allows for the Munch model to be updated over time and duplicated for other similar single artist collections within and outside the institution.

Table I. Updated varnish survey of the NM Munch collection based on archives, conservation dossiers, physical examinations, microscopy, UV, pFTIR and OCT (paintings arranged chronologically by date)

Painting	Mastic	Dammar	Beckers[i]	Ceronis[ii]	Laropal K-80	MS2A	MS2B	Varnished	Unvarnished
(1) Woll M 17 ***From Vestre Aker*** (1881)		x						x	
(2) Woll M 75 ***Thorvald Thorgersen*** (1882)								x	
(3) Woll M 80 ***Andreas Reading*** (1882–1883)					x			x	
(4) Woll M 98 ***Study of a Head*** (1893)						x		x	

(5) Woll M 104 ***Around the Paraffin Lamp*** (1883)			x	x
(6) Woll M 113 ***Inger in Black*** (1884)	x	x		x
(7) Woll M 126 ***Jørgen Sørensen*** (1885)			x	x
(8) Woll M 130 ***The Sick Child*** (1885–1886)		x		x
(9) Woll M 133 ***Self-portrait*** (1886)				x
(10) Woll M 144 ***Betzy Nilsen*** (1887)			x	x
(11) Woll M 148 ***Flowery Meadow at Veierland*** (1887)			x	x

(12) Woll M 173 ***Spring*** (1889)					x	
(13) Woll M 174 ***Hans Jæger*** (1889)	x				x	
(14) Woll M 192 ***Night in St. Cloud*** (1890)		x			x	
(15) Woll M 224 ***Night in Nice*** (1891)					x	
(16) Woll M 232 ***Rue Lafayette*** (1891)			x	x	x	
(17) Woll M 266 ***The Kiss*** (1892)				x	x	
(18) Woll M 274 ***Moonlight by the Mediterranean*** (1892)						x
(19) Woll M 284 ***Melancholy*** (1892)				x	x	

(20) Woll M 294 ***Inger in Black & Violet*** (1892)	x				x	
(21) Woll M 322 ***Moonlight*** (1893)					x	
(22) Woll M 329 ***Death in the Sickroom*** (1893)						x
(23) Woll M 333 ***The Scream*** (1893)						x
(24) Woll M 340 ***Ragnhild Bäckström*** (1894)						x
(25) Woll M 343 ***Julius Meier-Graefe*** (1894)		x	x	x	x	
(26) Woll M 347 ***Puberty*** (1894)	x			x	x	
(27) Woll M 348 ***The Day After*** (1894)	x				x	

(28) Woll M 358 ***Bathing Boys*** (1894)						
(29) Woll M 366 ***Madonna*** (1894/-1895)			x		x	
(30) Woll M 378 ***Ashes*** (1895)	x	x			x	
(31) Woll M 381 ***Moonlight*** (1895)						x
(32) Woll M 382 ***Self-portrait with Cigarette*** (1895)						x
(33) Woll M 387 ***Young Woman Washing Herself*** (1896)				x	x	
(34) Woll M 388 ***Parisian Model*** (1896)		x			x	

(35) Woll M 404 ***Mother and Daughter*** (1897)	x	x	x	
(36) Woll M 439 ***House with Red Virginia Creeper*** (1898–1899)	x		x	
(37) Woll M 445 ***Winter in the Woods*** (1899)			x	
(38) Woll M 457 ***Aase Nørregaard*** (1899)				x
(39) Woll M 458 ***Aase and Harald Nørregaard*** (1899)			x	
(40) Woll M 464 ***The Dance of Life*** (1899–1900)			x	

(41) Woll M 477 ***White Night*** (1900–1901)			x	
(42) Woll M 483 ***The Girls on the Bridge*** (1901)	x		x	
(43) Woll M 495 ***The Fairy-tale Forest*** (1901–1902)				x
(44) Woll M 514 ***Two Nudes*** (1902–1903)				x
(45) Woll M 549: ***On the Veranda*** (1902)			x	
(46) Woll M 578 ***Frenchman Marcel Archinard*** (1904)		x	x	
(47) Woll M 649 ***Self-portrait*** (1905)				x

(48) Woll M 698 ***Mrs. Schwarz*** (1906)		x	x	
(49) Woll M 1083 ***Seated Nude*** (1913)			x	
(50) Woll M 1126 ***Winter on the Fjord*** (1915)	x		x	
(51) Woll 1158 ***Midsummer*** (1915)	x		x	
(52) Woll M 1195 ***Man in the Cabbage Field*** (1916)	x		x	
(53) Woll M 1256 ***Thorvald Løchen*** (1918)		x	x	
(54) Woll M 1284 ***Bathing Men*** (1918)				x

(55) Woll M 1296 ***Self-portrait with the Spanish Flu*** (1919)					x			x	
(56) Woll M 1341 ***Autumn Ploughing*** (1919)			x		x			x	
(57) Woll M 1361 ***Workers Returning Home*** (1920)									x
TOTAL	6	4	6	2	19	2	2	**44**	**13**

i – Wilhelm Becker's matt *tavel* varnish.

ii – LeFranc Bourgeois Ceronis picture varnish.

Table II. Test paintings showing an example of the combined data sourced from archives, conservation dossiers, physical examinations, microscopy, UV, pFTIR and OCT.

Painting details	**Acqui-sition date**	**Documentation of restoration and/or artist's varnish layer(s)**	**pFTIR Main observations**	**OCT Main observations & layer thickness (µm)**	**Summary of varnish type(s) present**
Woll M 130 *The Sick Child*  1885/6 oil on canvas (120 × 118.5 cm)	1931	**1) 1885/6:** Artist's varnish (pine resin). **2) 1931:** Cleaned & restored when acquired – no conservation record (Willoch 1937). **2) 1954:** Partial restoration varnish (Le Franc, Ceronis) applied to glossy/saturated areas.		Transparent, scattering layer over thick varnish drips.	Complex surface. Locally distributed artist's varnish matted down with an upper restoration varnish.

Woll M 224 *Night in Nice*  1891 oil on canvas (48 × 54 cm)	1891	**1) Pre-WWII:** Natural resin restoration varnish layer. **2) 1983:** Synthetic Laropal-K80 (grade 9) applied over the earlier restoration varnish.	Typical bands for oil medium/natural resin varnish. No peaks for synthetic (Laropal K80) varnish layer detected.	Only one varnish layer present (4–17 µm).	Only one restoration (natural resin) varnish layer confirmed. Possibly applied while painting still framed. No evidence of upper Laropal-K80 layer.

Woll M 366 *Madonna*  1894 oil on canvas (90.5 × 70.5 cm)	1909	**1) 1909:** Natural resin restoration varnish layer. **2) 1968:** Synthetic MS2A restoration varnish layer.		2 varnish layers found in most of the spots. Total of 3 transparent layers in the figure.	2- restoration varnish layers present over whole surface. Evidence of locally applied artist's varnish layer underneath restoration varnishes. This is concentrated in contours of the figure.

Woll 464 *The Dance of Life*  1899–1900 oil on canvas (125 × 191 cm)	1910	**1) 1958:** Partial restoration varnish applied to glossy/saturated areas.		Evidence of localised drips & patches of added oil binder. Some of these oil skins are covered by an upper scattering layer. Semi-transparent paint layers.	Complex surface with evidence of a matting restoration varnish applied over Munch’s original surface finishes.

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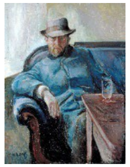
7. Appendices

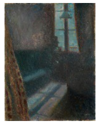
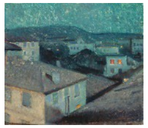
7.1 Overview of paintings

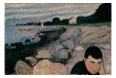
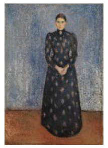
Painting Details				Historical Documentation			Physical Examinations			Summary of Findings
Woll cat. no. NM inventory no. Title	**Medium Dimensions (cm)**	**Painting date**	**Acquisition date** P = Purchased D = Donation	**Conservation history and NM conservation reports**	**Varnish date and type**	**NM varnish period and conservator**	**UVA-induced fluorescence**	**pFTIR**	**OCT**	**Observations**
1.Woll M 17 (NG.M.02442) ***From Vestre Aker*** 	Oil on paper on masonite board (20.5 × 30.5)	1881	P-1958	• Already marouflaged onto masonite board pre-acquisition. • 1950: Cleaned with white spirit/acetone/diacetone alcohol mix prior to varnishing. • Glazed – Mirogard.	1958: **Dammar** + bleached beeswax	2 (LEP)	Overall surface dull orange fluorescence			• Thin matt **dammar** varnish layer. • Evidence of isolated areas with retouches.
2.Woll M 75 (NG.M.01893) ***Thorvald Thorgersen*** 	Oil on cardboard (36.5 × 28)	1882	P-1938	• 7 mm cardboard support. • Varnished pre-war. • X-ray, evidence of woman's portrait underneath (Thurmann-Moe et al.1995). • Glazed – Mirogard.	No record	1 (Unknown)	Overall greenish surface fluorescence			• **Natural resin** varnish.
3.Woll M 80 (NG.M.02810) ***Andreas Reading*** 	Oil on paper on cardboard (51.5 × 35.5)	1882–1883	D-1970 Mustad	• Paper support already glued to cardboard support and varnished pre-acquisition. • 1970: Consolidated with PVA, surfaced cleaned with soap and water, varnished. • 1970: X-ray, evidence of earlier landscape composition underneath. • 1999: Glazed – Mirogard.	1970 Dec: **Ketone**	3 (LEP)	Overall green/purple surface fluorescence			• Matt **ketone** upper layer. • Possibility of underlying varnish layers present as painting only surface cleaned in 1970.
4.Woll M 98 (NG.M.02581) ***Study of a Head*** 	Oil on canvas (60.5 × 46.5)	1883	P-1964	• Glue-paste lined prior to NM acquisition. • Discoloured yellow varnish and isolated areas with discoloured retouches. • 1965: Consolidated, cleaned and revarnished. • 1999: Glazed – Mirogard. • 2015: Refitted in original wooden frame and glazed with Optium	1965 Jan: **MS2A**	3 (LEP)	Overall purple surface fluorescence			• **MS2A** upper layer. • Possibility of underlying varnish layers present from previous restorations.

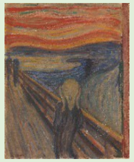
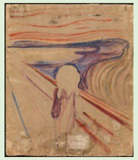
Painting Details				Historical Documentation			Physical Examinations		Summary of Findings
5.Woll M 104 (NG.M.02811) ***Around the Paraffin Lamp*** 	Oil on board (27 × 39.5)	1883	D-1970 Mustad	• 4 mm thick wooden support, no ground. • Reverse side used as palette by Munch. • Already varnished pre-acquisition. • 1970: Surfaced cleaned with mild soap and water. • X-ray: Evidence of earlier composition underneath. • Glazed – Mirogard.	1970 Nov: **Ketone**	3 (LEP)	Overall purple surface fluorescence		• **Ketone** upper layer. • Possibility of underlying varnish layers present as painting was only surface cleaned.
6.Woll M 113 (NG.M.01862) ***Inger in Black*** 	Oil on canvas (97 × 67)	1884	D-1937 Mustad	• 1954: Glue-paste lined and replacement of the stretcher. Damage/loss in left-hand corner repaired with canvas inset. Surface cleaned with soap and water. Previous varnish layers not removed. • 1987: Uneven discoloured thick yellow varnish noted in face and hands – possibility of an original artist's varnish underneath the restoration varnish. • Glazed – Mirogard. • 2019: Glazed – Optium 3 mm.	1954 Sept: **Dammar** + **Ceronis**	2 (JTM)	Overall greenish surface fluorescence	X	• OCT confirmation of two restoration varnish layers present over whole surface. Probably **dammar**. • Lower restoration layer is probably pre-war. • Evidence of locally applied **artist's varnish** in face, neck and hands. • 3–4 transparent/semi-transparent layers (upper two layers are restoration varnishes and lower two layers are artist's varnish).
7.Woll M 126 (NG.M.00472b) ***Jørgen Sørensen*** 	Oil on canvas (36 × 31)	1885	D-1895 Sørensen	• 1956: Wax-lined, cleaned, varnished, original stretcher changed. Waxed with beeswax • 1983: Surface cleaned and re-varnished. • 2008: Glazed – Mirogard.	1956 Mar: **Beeswax** 1983: **Ketone** grade 5	2 & 3 (JTM & LEP)	Overall purple surface fluorescence		• Upper semi-matt **ketone** layer. • Possibility of earlier underlying natural wax layer present.

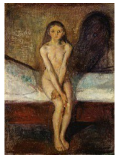
Painting Details				Historical Documentation			Physical Examinations		Summary of Findings
8.Woll M 130 (NG.M.00839) ***The Sick Child*** 	Oil on canvas (120 × 118.5)	1885–1886	D-1931 Schou	• 1886: Criticised for artist's use of varnish – *streaks running down the surface*. Complex and heavily reworked thick paint and fragile surface. • 1931–37: Painting cleaned when swapped with later version (Thiis 1933: 138). •1954: Wax-lined, new stretcher, surface cleaned and localised varnishing. • 1974: X-ray, artist's alterations and earlier underlying motif (Plahter 1974). • 2008: Microinvasive analysis (Aslaksby 2009). • 1997: Glazed – Mirogard. • 2019: Glazed – Optium 4.5 mm.	1885–86: **Artist's varnish** (pine resin) 1954: **Ceronis** used locally	Munch 2 (JTM)	Uneven green surface fluorescence. Original artist's varnish streaks visible	X	•Complex surface with evidence of **artist's varnish** used locally. • OCT confirmation of 1954 locally applied restoration varnish (**Ceronis**) used to dampen down Munch's original varnish. •No evidence to suggest that the painting was varnished after 1931–38 cleaning.
9.Woll M 133 (NG.M.01915) ***Self-portrait*** 	Oil on canvas (33 × 24.5)	1886	P-1938	•Wax-lined, surface texture deformed (flattened) by the process. • 1987: Earliest conservation report. • 1995: Glazed – Mirogard. • 2015: Glazed – Optium 3 mm.	No record	1 (Unknown)	Overall greenish surface fluorescence	X	• OCT, one upper **natural resin** restoration varnish layer and one thinner lower varnish layer. •Signature located between the two varnish layers. • Lining and two restoration varnishes are most probably pre-war due to lack of post-war documentation. • Harald Nørregaard (previous owner) describes the painting restored and varnished by Harald Brun, post-1938 (MM K 794). • 1927: Painting catalogued as unsigned in NG Munch exhibition.
10.Woll M 144 (NG.M.03054) ***Betzy Nilsen*** 	Oil on canvas (25.5 × 29)	1887	D-1909 Schou	• 1909–21: Wax-lined and varnished by HB. • 1973: X-ray, earlier composition underneath, canvas previously folded, monogram *EM* found in bottom right-hand corner. • 1983: Cleaned with Exsol D60 and revarnished. • 1993: Stolen – 20 August.	1983 October: **Ketone** grade 9	1 & 3 (HB & LEP)	Not examined		• Painting not examined – still missing. • Documented matt **ketone** varnish. • Possibility of natural resin underneath.

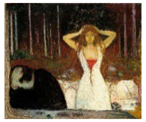
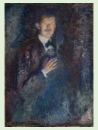
Painting Details				Historical Documentation			Physical Examinations			Summary of Findings
11.Woll M 148 (NG.M.01235b) ***Flowery Meadow at Veierland*** 	Oil on canvas on cardboard (66.5 × 44 cm)	1887	D-1921 Woxen	• Post-war marouflage on cardboard varnish. Paint wet when first framed. • 1983: Consolidation, retouches and revarnishing. • 1983: X-ray, evidence of earlier composition underneath. • 1999: Glazed – Mirogard.	1983 Sept: **Ketone** grade 9	1 & 3 (LEP)	Overall purple surface fluorescence	X	X	• pFTIR, upper synthetic (**ketone**) varnish detected. Strong bands noted with spectral features of the synthetic resin **Laropal K 80**. • OCT, multiple restoration varnish layers and partial cleaning of the sky. • 3–4 varnish layers detected in foreground. • 1–2 varnish layers in region of the sky. • 1927: Painting catalogued as oil on cardboard in NG Munch exhibition.
12.Woll M 173 (NG.M.00498) ***Spring*** 	Oil on canvas (169.5 × 263.5)	1889	P-1899 from Munch	• Unlined, wax-resin impregnated canvas, original stretcher, large wax patch to reverse. • 1899–1907: Painting repaired after NM acquisition. Large tear in the right-hand curtain region (Thue 1989). • 1909: Varnish controversy (Stein and Rød 2015). • 1973: Photographic documentation of paint loss – treatment reports missing. • 1973: X-ray, evidence of earlier composition underneath tear mend (Plahter 1974). • 2016: Surface cleaned and glazed with Optium 6 mm.	Reports missing	1 (CB & HB)	Overall greenish surface fluorescence			• Complex surface which appears to have several **natural resin** varnish layers. • Must have been repaired by Christian Brun sometime between 1889 and 1907 according to the repaired photo of 1907 (Thiis 1907). • 1909: Mentioned as one of the newly varnished paintings by HB (MM, LR 537, 15 June 1909).
13.Woll M 174 (NG.M.00485) ***Hans Jæger*** 	Oil on canvas (109 × 84)	1889	P-1897 from Munch	• 1954: Consolidated with beeswax and colophony mix. Glue-paste lined, cleaned with soap and varnished. 1993: X-ray, Munch's alterations to composition (table) (Plahter 1999). • 1997: Glazed – Mirogard.	1954 April: **Mastic**	2 (JTM)	Overall greenish/ yellow surface fluorescence	X	X	• pFTIR and OCT, confirmation of one restoration (**natural resin/mastic**) varnish layer. • No evidence of earlier varnish coatings and/or artist's varnish.

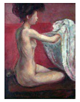
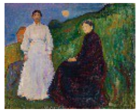
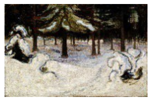
Painting Details				Historical Documentation			Physical Examinations			Summary of Findings
14.Woll M 192 (NG.M.01111) ***Night in St Cloud*** 	Oil on canvas (64.5 × 54)	1890	P-1917 Houens fund	•1915: Restored by Harald Brun (MM K 1548). Original strainer unlined. •1991: Consolidation and spray revarnishing of painting. •2014: Local consolidation, strip-lining, loose lining and pXRF. • 1995: Glazed – Mirogard.	1991 Sept: **Dammar**	1 & 3 (HB & LEP)	Overall greenish surface fluorescence			•Thin spray of **dammar** upper layer. •Possibility of underlying restoration varnish layer(s) present from 1915 restoration. •Visible varnish drip marks along bottom tacking edge from earlier (1915?) brush varnishing.
15.Woll M 224 (NG.M.00394) ***Night in Nice*** 	Oil on canvas (48 × 54)	1891	P-1891	•Unlined canvas (French standard format, 65 × 54 cm), cut down by Munch and restretched onto a new support. Composition present along lower tacking margin edge. •1983: Surface cleaned and revarnished. •1999: Glazed – Mirogard.	1983 Sept: **Ketone** grade 9	1 & 3 (Unknown & LEP)	Overall greenish surface fluorescence	X	X	•pFTIR and OCT confirmation of only one restoration (**natural resin**) varnish layer possibly applied while painting still framed. •No evidence of artist's varnish layer(s). •No evidence of ketone upper layer. •Findings confirmed with microinvasive analyses of cross-sections.
16.Woll M 232 (NG.M.01725) ***Rue Lafayette*** 	Oil on canvas (92 × 73)	1891	P-1933	•Unlined original strainer •1950: Cleaned and varnished. •1983: Cleaned with Exsol D60, consolidated with Beva 371 and revarnished. •1996: Glazed – Mirogard. •2015: Glazed – Optium 3 mm.	1950 April: **Beckers** matt *tavel* varnish 1983: **Ketone** matt	2 & 3 (ODH & LEP)	Overall purple surface fluorescence			•Two documented layers of restoration varnish applied, one **Beckers** and one **ketone** resin. •Varnish layer(s) are thinly applied and matt.
17.Woll M 266 (NG.M.02812) ***The Kiss*** 	Oil on canvas (73 × 92)	1892	D-1970 Mustad	•1980: Unlined canvas, strainer, reverse impregnated with Plexisol white spirit (1:4) and revarnished. •1991–92: Consolidation. •2015: Strip-lined, loose lining (Beva film and Saatifil polyester fabric), pXRF examinations. •1992: Glazed – Mirogard. •2015: Glazed – Optium 3mm.	1980 Nov: **Ketone** grade 9	3 (LEP)	Overall yellow surface fluorescence			•Thinly applied matt **ketone** varnish.

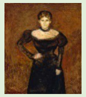
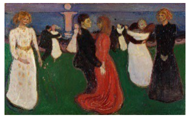
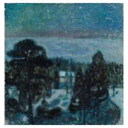
Painting Details				Historical Documentation			Physical Examinations	Summary of Findings
18.Woll M 274 (NG.M.00842) ***Moonlight by the Mediterranean*** 	Oil on canvas (46 × 55)	1892	D-1909 Schou	• No record of restoration. • 2001: Glazed – Mirogard.	**Unvarnished**		Uneven surface fluorescence	• **Unvarnished** surface. • No record of restoration.
19.Woll M 284 (NG.M.02813) ***Melancholy*** 	Oil on canvas (64 × 96)	1892	D-1970 Mustad	• 1970: Surface cleaned and wax-lined, original stretcher and revarnished. • 1970: X-ray, evidence of change in position of head, moved slightly down and to the right. • 1997: Glazed – Mirogard.	1970 Dec: **Ketone**	3 (LEP)	Overall purple surface fluorescence	• Thinly applied **ketone** upper layer. • Possibility of previous varnishes underneath.
20.Woll M 294 (NG.M.00499) ***Inger in Black & Violet*** Oil on canvas 	(172.5 × 122.5)	1892	P-1899 from Munch	• 1949: Marouflaged onto masonite board and varnish partially cleaned. Reparation and retouching of two large tears (14 and 16 cm). • 1991: Minor/localised surface cleaning and retouching. • Glazed – Mirogard. • 2015: Glazed – Optium 4.5 mm.	1949 Dec: **Mastic**	2 (ODH)	Overall greenish surface fluorescence. Large dark areas corresponding to the retouches	• **Mastic** upper layer with isolated residues of previous natural varnish underneath. • Post-war photographs suggest that the portrait must have been either damaged during or after the WWII evacuation.
21.Woll M 322 (NG.M.01914) ***Moonlight*** 	Oil on canvas (140.5 × 137)	1893	P-1938	• 1982: Unlined canvas with old tear mend possibly repaired by Munch. Uneven varnish gloss noted. • 1998: Glazed – Mirogard. • 2017: Glazed – Optium 4.5mm.	**Unknown**	1	Overall purple surface fluorescence	• Thin varnish layer. • **Unknown** varnish date type and application date post-war.
22.Woll M 329 (NG.M.00940) ***Death in the Sickroom*** 	Tempera/ crayon on canvas (152.5 × 169)	1893	D-1910 Schou	• No record of restoration. • Underdrawings visible in IRR (Plahter 1999). • 1993: Glazed – Amiran 6 mm. • 2022: Glazed – Optium 6 mm.	**Unvarnished**			• **Unvarnished** surface. • No record of restoration.

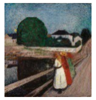
Painting Details				Historical Documentation			Physical Examinations		Summary of Findings
23.Woll M 333 (NG.M.00939) ***The Scream***  	Tempera/ casein/egg/oil/ wax crayon on cardboard (91 × 73.5)	1893	D-1910 Schou	• Unvarnished paint surface. Unprimed 3.5 mm support with first sketch of motif applied to reverse. • 1974: ×4 – XRD. • 1992: Glazed – Mirogard. Minor local spot consolidation with sturgeon glue. • 1994: Stolen 12 Feb–7 May. • 2001–2015: Microinvasive analysis. • 2012: Hirox. • 2013: Hyperspectral imaging. • 2016: MAXRF. • 2018: XRD and Raman. • 2019–2020: Micro-fading tests.	**Unvarnished**		Uneven fluorescence	**X**	• **Unvarnished** paint surface. • OCT, confirmation of Munch's locally applied **transparent layer/surface finish**.
24.Woll M 340 (NG.M.02814) ***Ragnild Bäckström*** 	Tempera and pastel on canvas (87 × 70)	1894	D-1970 Mustad	• Repaired and retouched small puncture in upper mid-section of painting prior to NM acquisition. • 1993: Glazed – Mirogard.	**Unvarnished**		Uneven fluorescence		• **Unvarnished** matt surface. • Underdrawings visible in normal light and IRR. • Damage seen in photo – 1930.
25.Woll M 343 (NG.M.00995) ***Julius Meier-Graefe*** 	Oil on canvas (100 × 75)	1894	D-1912 Julius Meier-Graefe	• 1950: Unlined canvas on original stretcher. Cleaned and varnished in conjunction with tear mend. • 1983: Surface cleaned and spray revarnished. • 1995: Local retouches. • 2006: Local consolidation. • 1996: Glazed – Mirogard. • 2015: Glazed – Optium 4.5 mm.	1950 March: **Beckers** 1983 Sept: **Ketone** grade 9 + **Dammar**	2 & 3 (ODH & LEP)	Overall dull green surface fluorescence		• Three different matt varnishes, **Beckers, ketone** and **dammar**. • Varnish layer(s) appear to be thinly applied.

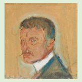
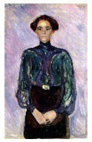
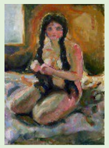
Painting Details				Historical Documentation			Physical Examinations		Summary of Findings
26.Woll M 347 (NG.M.00807) ***Puberty*** 	Oil on canvas (151.5 × 110)	1894–1895	P-1909 Houens fund	• 1909: Varnish controversy. • 1950: Glue-paste lined, cleaned and varnished. • 1979: Local consolidation, surface cleaned and revarnished. • 1997: Glazed – Mirogard. • 2014: Glazed – Optium 4.5 mm.	1909: **Unknown natural resin** 1950 January: **Mastic** 1979 October: **Ketone**	1, 2 & 3 (HB, ODH & LEP)	Overall purple surface fluorescence	X	• OCT confirmation of one restoration (**ketone**) varnish layer present over whole surface. • Evidence of locally applied **artist's varnish** (up to three layers) underneath restoration varnish and concentrated in contours of the figure. • Second transparent layer identified in red drips, left foreground.
27.Woll M 348 (NG.M.00808) ***The Day After*** 	Oil on canvas (115 × 152)	1894	P-1909 Houens fund	• 1909: Varnish controversy and letter to Munch, Harald Brun (MM K 1445). • 1956: Relining (glue-paste) cleaned and revarnished. • 1986–2004: There has been some localised consolidation. • 1997: Glazed – Mirogard. • 2019: Glazed – Optium 4.5 mm.	1909: **Unknown natural resin** 1956 June: **Mastic**	1 & 2 (HB & JTM)	Overall greenish surface fluorescence. Large areas with retouches	X	• OCT confirmation of two restoration natural resin (**mastic**) varnish layers. • Previous restorations also detected. • No evidence of artist's varnish.
28.Woll M 358 (NG.M.01866) ***Bathing Boys*** 	Oil on canvas (92 × 150)	1894	D-1937 Mustad	• No record of restoration. • 1997: Glazed – Mirogard.	**Unvarnished**		Uneven fluorescence		• **Unvarnished** surface.
29.Woll M 366 (NG.M.00841) ***Madonna*** 	Oil on canvas (90.5 × 70.5)	1894–1895	D-1909 Schou	• 1968: Wax-lined after history of consolidation of flaking paint along edges and in the background, original stretcher. Revarnished. • 1997: Glazed – Mirogard. • 2020: IRR.	1968 Sept: **MS2A**	3 (JTM)	Overall dull purple surface fluorescence	X	• OCT, confirmation of two restoration varnish layers present over whole surface. Upper layer is **MS2A**. • Evidence of locally applied **artist's varnish** layer underneath restoration varnishes. Layer found concentrated in the contours of the figure and follows the crayon underdrawings detected in IRR.

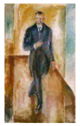
Painting Details				Historical Documentation			Physical Examinations		Summary of Findings
30.Woll M 378 (NG.M.00809) ***Ashes*** 	Oil on canvas (120.5 × 141)	1894	P-1909 Houens fund	• 1909: Varnish controversy. • 1950: Relined (glue-paste) and varnished. • 1979: Consolidation, surface cleaning and revarnishing. • 1983: Consolidation and revarnished. • 1997: Glazed – Mirogard. • 2019: Glazed – Optium 3 mm.	1909: **Unknown natural resin** 1950 January: **Mastic** 1979 October: **Ketone** 1983: **Ketone**	1, 2 & 3 (HB, ODH & LEP)	Overall purple surface fluorescence		• Upper layer appears to be synthetic **ketone**. • Possibility of underlying restoration and/or **artist's varnish.**
31.Woll M 381 (NG.M.02815) ***Moonlight*** 	Oil on canvas (93 × 110)	1895	D-1970 Mustad	• 1970: Unvarnished and unlined painting on original stretcher. Three large repaired tears, scratches and small holes noted. • 1993: Glazed – Mirogard. • 2015: Glazed – Optium 3mm.	**Unvarnished**		Uneven fluorescence and dark areas with retouched damages		• **Unvarnished** surface. • Difficult to ascertain whether the old reparations are by Munch or from previous restoration?
32.Woll M 382 (NG.M.00470) ***Self-portrait Cigarette*** 	Oil on canvas (120.5 × 141)	1895	P-1895 from Munch	• Unrestored. • 1997: Glazed – Mirogard. • 2017: Glazed – Optium 4.5 mm.	**Unvarnished**		Uneven fluorescence	**X**	• Unrestored and **unvarnished** surface. • OCT, overall uneven surface gloss, locally applied semi-transparent paint layers. • Artist's surface finish/effect – interplay between matt and glossy passages of paint.
33.Woll M 387 (NG.M.00843) ***Young Woman Washing Herself*** 	Oil on board (74.5 × 59)	1896	D-1909 Schou	• Painted on A2 drawing board (poplar with beechwood edges), no ground. • 1969: Varnished in conjunction with treatment of surface blemishes. • Glazed – Mirogard.	1969 June: **MS2B**	3 (LEP)	Overall purple surface fluorescence		• Thin layer of **MS2B** varnish.

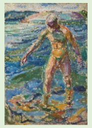
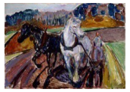
Painting Details				Historical Documentation			Physical Examinations		Summary of Findings
34.Woll M 388 (NG.M.02816) ***Parisian Model*** 	Oil on canvas (80 × 60)	1896	D-1970 Mustad	• 1970: Wax-lined, cleaned and revarnished. • 1970: X-ray. • 1999: Glazed – Mirogard.	1970 Dec: **Ketone**	3 (LEP)	Overall purple surface fluorescence		• Thin layer of **ketone** varnish.
35.Woll M 404 (NG.M.00840) ***Mother & Daughter*** 	Oil on canvas (135 × 163)	1897	D-1909 Schou	• 1966: Relined (wax-resin), retouched with matt tempera colours and revarnished. • 1983: Removal of pencil marks, retouched and revarnished. • 1998: Glazed – Mirogard. • 2015: Glazed – Optium 4.5 mm.	1966 Dec: **MS2B** 1983 Oct: **Ketone** grade 9	3 (LEP)	Overall purple surface fluorescence		• Thin layer of matt synthetic varnish (**MS2B** and/or **ketone**). • Possibility of older restoration varnishes underneath as painting was relined in 1966.
36.Woll M 439 (NG.M.01894) ***House with Red Virginia Creeper*** 	Oil on panel (32.5 × 48)	1898–1899	P-1938	• 1984: 4 mm thin unprimed panel. Panel damaged during reframing. Horizontal split glued, surface cleaned, retouched and varnished. • 2005: Glazed – Mirogard.	1984 May: **Ketone** matt	3 (LEP)	Overall purple surface fluorescence		• One thin layer of matt **ketone** varnish. • Underdrawings visible in IRR and writing on reverse of panel.
37.Woll M 445 (NG.M.00570) ***Winter in the Woods*** 	Oil on cardboard/ wooden board (60.5 × 90)	1899	P-1901	• Support: wooden core sandwich between 2 pieces of cardboard. Unprimed. Discoloured/yellow thick varnish layer. • 1999: Glazed – Mirogard. • 2015: Glazed – Optium 3 mm.	No record	1 (Unknown)	Overall dull yellow/green surface fluorescence	**X**	• OCT, confirmation two restoration (**natural resin**?) varnish layers present. • Evidence of a varnish applied while painting still framed. • Artist's fingerprints visible in paint.

Painting Details				Historical Documentation			Physical Examinations		Summary of Findings
38.Woll M 457 (NG.M.01793) ***Aase Nørregaard*** 	Oil on canvas (110.5 × 85.5)	1899	D-1935 Nørregaard	•Unlined and unvarnished. •No treatment records. •2004: Glazed – Mirogard.	**Unvarnished**		Uneven surface fluorescence		•**Unvarnished** surface with few signs of previous restorations. •Interplay between matt and glossy passages of paint.
39.Woll M 458 (NG.M.01794) ***Aase & Harald Nørregaard*** 	Oil and crayon on cardboard (49.5 × 75)	1899	D-1935 Nørregaard	•No treatment records. •Unprimed cardboard support, varnished. •2019: Glazed. •Glazed – Optium 3 mm.	No record	1 (Unknown)	Overall greenish surface fluorescence		•**Unknown** thin varnish layer present over whole surface – possibly a **natural resin**. Varnish stops 1– 2 cm in from edges.
40.Woll M 464 (NG.M.00941) ***The Dance of Life*** 	Oil and crayon on canvas (125 × 191)	1899–1900	D-1910 Schou	•1958: Glue-paste lined, new stretcher, reverse impregnated with ketone resin, partial varnishing with mastic + beeswax. •1992: Local consolidation and retouching. •1998: Glazed – Mirogard. •2019: Glazed – Optium 4.5 mm. •2020: IRR.	1956 March: **Mastic** + beeswax	2 (LEP)	Uneven green fluorescence	**X**	•OCT, complex surface with evidence of a matting restoration varnish (**mastic**) applied over Munch's original surface finishes. •Evidence of locally applied **artist's varnish**. •Drips and patches of added oil binder. Some of these oil skins are covered by an upper scattering layer. •Blue crayon and red signature lie over transparent layer. •Semi-transparent paint layers.
41.Woll M 477 (NG.M.00581) ***White Night*** 	Oil on canvas (115. 5 × 111)	1900–1901	P-1901 from Munch	•Unlined canvas, three small tear mends, varnished. •1992–93: Localised consolidation. •2001: Glazed – Mirogard. •2015: Glazed – Optium 4.5 mm.	No record	1 (Unknown)	Overall greenish surface fluorescence		•Appears to be uneven gloss – **natural resin** restoration varnish layer. •Possibility of underlying layers.

Painting Details				Historical Documentation			Physical Examinations	Summary of Findings
42.Woll M 483 (NG.M.00581) ***Girls on the Bridge*** 	Oil on canvas (136 × 125)	1901	D-1909 Schou	•1956: Relined (glue-paste) and impregnated reverse with varnish (dammar). Cleaned with solvents, retouched and revarnished. •1998: Glazed – Mirogard.	1956 June: **Mastic**	2 (JTM)	Overall greenish surface fluorescence	•**Mastic** upper varnish layer with dammar applied to reverse.
43.Woll M 495 (NG.M.02237) ***The Fairy-tale Forest*** 	Oil on canvas (79 × 106.5)	1901–1902	D-1951 Larsen	•Glazed – Mirogard. •2015: Glazed – Optium 3 mm.	**Unvarnished**		Uneven fluorescence	•**Unvarnished** surface. •Artist prepared ground. •Underdrawings visible in IRR.
44.Woll M 514 (NG.M.01868) ***Two Nudes*** 	Oil on canvas (110.5 × 145.5)	1902 - 1903	D-1937 Mustad	•Unlined and unvarnished, stretcher replaced. •1966: Cleaned with petroleum ether, stretcher replaced and retouched with matt tempera colours. •1994: Removal of pencil graffiti.	**Unvarnished**		Uneven fluorescence	•Unvarnished surface with large areas of exposed ground. •Painting unglazed.
45.Woll M 549 (NG.M.00810) ***On the Veranda*** 	Oil on canvas (86.5 × 115.5)	1902	P-1909 Houens fund	•Unlined canvas, glossy varnish. • 2000: Glazed – Mirogard. • 2014 Glazed – Optium 4.5 mm.	No record	1 (Unknown)	Overall greenish surface fluorescence	•Appears to have a post-war glossy **natural resin** restoration varnish.

Painting Details				Historical Documentation			Physical Examinations	Summary of Findings
46.Woll M 578 (NG.M.00811) ***Frenchman Marcel Archinard*** 	Oil on canvas (185 × 70)	1904	P-1909 Houens fund	• Unlined canvas, original stretcher. • 1909: Varnish controversy (LR 537, 27.12.1909). • 1983: Consolidation and revarnished. • 2004: Glazed – Mirogard. • 2015: Glazed – Optium 3mm.	1909: **Unknown natural resin** 1983 Oct: **Ketone** grade 9	1 & 3 (HB & LEP)	Overall dull purple surface fluorescence	• Restoration varnish – possibly **mastic** (LR541, 02.09.1910). • Existing upper layer probably **ketone** from 1983.
47.Woll M 649 (NG.M.01229) ***Self-portrait*** 	Watercolour, pastel and gouache on cardboard (44 × 41.5)	1905	P-1921	• No record of restorations. • 1981: Glazed – Plexiglass with UV filter. • 1993: Glazed – Mirogard.	**Unvarnished**			• **Unvarnished** work on unprimed cardboard – extremely light sensitive.
48.Woll M 698 (NG.M.02817) ***Mrs. Schwarz*** 	Oil on canvas (99.5 × 60.5)	1906	D-1970 Mustad	• Unlined painting on original stretcher. • 1970: Surface cleaned (white spirit and soap) and rearnished. • Glazed – Mirogard. • Glazed – Optium 3 mm.	1970 Nov: **Ketone**	3	Overall purple surface fluorescence	Thin upper **ketone** varnish layer.
49.Woll M 1083 (NG.M.02818) ***Seated Nude*** 	Oil on canvas (103 × 72.5)	1913	D-1970 Mustad	• Unlined canvas, original stretcher. • No record of restoration. • 1999: Glazed – Mirogard. • 2019: Glazed – Optium 3 mm.	**Unvarnished**		Uneven fluorescence	• **Unvarnished** surface with few signs of previous restorations. • Interplay between matt and glossy passages of paint.

Painting Details				Historical Documentation			Physical Examinations	Summary of Findings
50.Woll M 1126 (NG.M.01864) ***Winter on the Fjord*** 	Oil on canvas (103 × 128)	1915	D-1937 Mustad	• Unlined canvas, original stretcher. • 1950: Cleaned and varnished. • 1999: Glazed – Mirogard. • 2006: Localised consolidation. • 2019: Glazed – Optium 4.5 mm.	1950 April: **Beckers** matt *tavel* varnish	2 (ODH)	Overall greenish surface fluorescence	• Appears to have only one thin layer of matt **Beckers** varnish.
51.Woll M 1158 (NG.M.01864) ***Midsummer*** 	Oil on canvas (103 × 128)	1915	D-1915 Schou	• Unlined canvas, original stretcher. • 1950: Cleaned and varnished. • 1998: Localised consolidation and retouches. • 2001: Glazed – Mirogard. • 2013: Glazed – Optium 4.5 mm.	1950 April: **Beckers** matt *tavel* varnish	2 (ODH)	Overall greenish surface fluorescence	• Appears to have only one thin layer of matt **Beckers** varnish.
52.Woll M 1195 (NG.M.01865) ***Man in the Cabbage Field*** 	Oil on canvas (136 × 180)	1916	D-1937 Mustad	• 1950: Cleaned and varnished. • 1970: Wax-lined but not revarnished. Retouched with matt colours. • 1999: Glazed – Amiran.	1950: **Beckers** matt *tavel* varnish	2 (ODH)	Overall greenish surface fluorescence	• Appears to have only one thin layer of matt **Beckers** varnish.
53.Woll M 1256 (NG.M.02080) ***Thorvald Løchen*** 	Oil on canvas (200 × 120)	1918	D-1946 Løchen	• 1958: Surface cleaned. • 1978: Reparation of two holes after accident, surface cleaned, retouched and varnished.		3 Mille Stein	Overall dull purple surface fluorescence	• Matt surface with unvarnished appearance. • Thin matt **ketone** varnish layer. • Painting unglazed.

Painting Details				Historical Documentation			Physical Examinations	Summary of Findings
54.Woll M 1284 (NG.M.01699) ***Bathing Man*** 	Oil on canvas (160 × 110)	1918	D-1927 Munch	• Unvarnished surface, original stretcher. • 1998: Localised consolidation and retouches. • 2002: Glazed – Mirogard. • 2016: Glazed – Optium 4.5 mm.	**Unvarnished**		Uneven surface fluorescence	**Unvarnished** surface with few previous restorations.
55.Woll M 1296 (NG.M.01867) ***Self-portrait with Spanish Flu*** 	Oil on canvas (150 × 131)	1919	D-1937 Mustad	• Unlined canvas on new stretcher. • 1993: Consolidation, surface cleaned, spray varnished and retouched. • 1999: Glazed – Amiran. • 2017: Glazed – Optium 4.5 mm.	1993 June: **Ketone** grade 9 (sprayed)	3 (LEP)	Overall purple surface fluorescence	• Thin layer of **ketone** over whole surface. • Painting documented as unvarnished prior to 1993 varnishing.
56.Woll M 1341 (NG.M.01863) ***Autumn*** 	Oil on canvas (110.5 × 145.5)	1919	D-1937 Mustad	• Unlined canvas, original stretcher. • 1950: Cleaned and varnished. • 1983: Localised consolidation and revarnished. • 2022: Glazed – Optium 4.5 mm.	1950 May: **Beckers** matt *tavel* varnish 1983 Oct: **Ketone** grade 9	2 & 3 (ODH & LEP)	Overall purple surface fluorescence	• Upper layer of **ketone**. • Possibility that **Beckers** matt *tavel* varnish is still present underneath.
57.Woll M 1361 (NG.M.01867) ***Workers Returning Home*** 	Oil on canvas (150 × 131)	1920	D-1970 Mustad	• Unlined canvas on original stretcher. • 2002: Glazed – Mirogard.	**Unvarnished**		Uneven fluorescence	• **Unvarnishe**d surface with few previous restorations.

7.2 Photography

Figure 17. IRR photograph showing Munch's underdrawings and compositional process for *Madonna* (Woll M 366) (2020, Nasjonalmuseet)

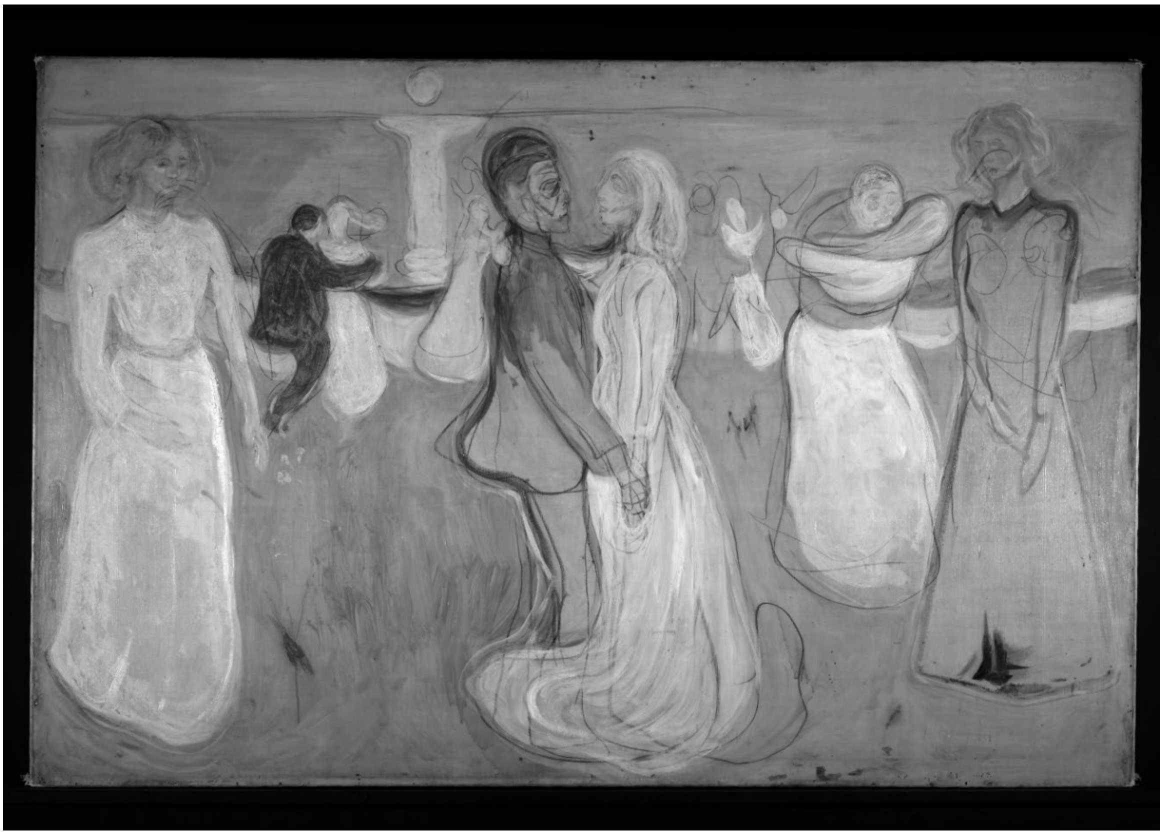


Figure 18. IRR photograph showing Munch's underdrawings and compositional process for *The Dance of Life* (Woll M 464) (2020, Nasjonalmuseet)

Figure 19. Example of high-resolution digital microscope image, spot location R.02, left foreground in *Puberty* (Woll M 347) (normal light 20×, 2020, Ford)

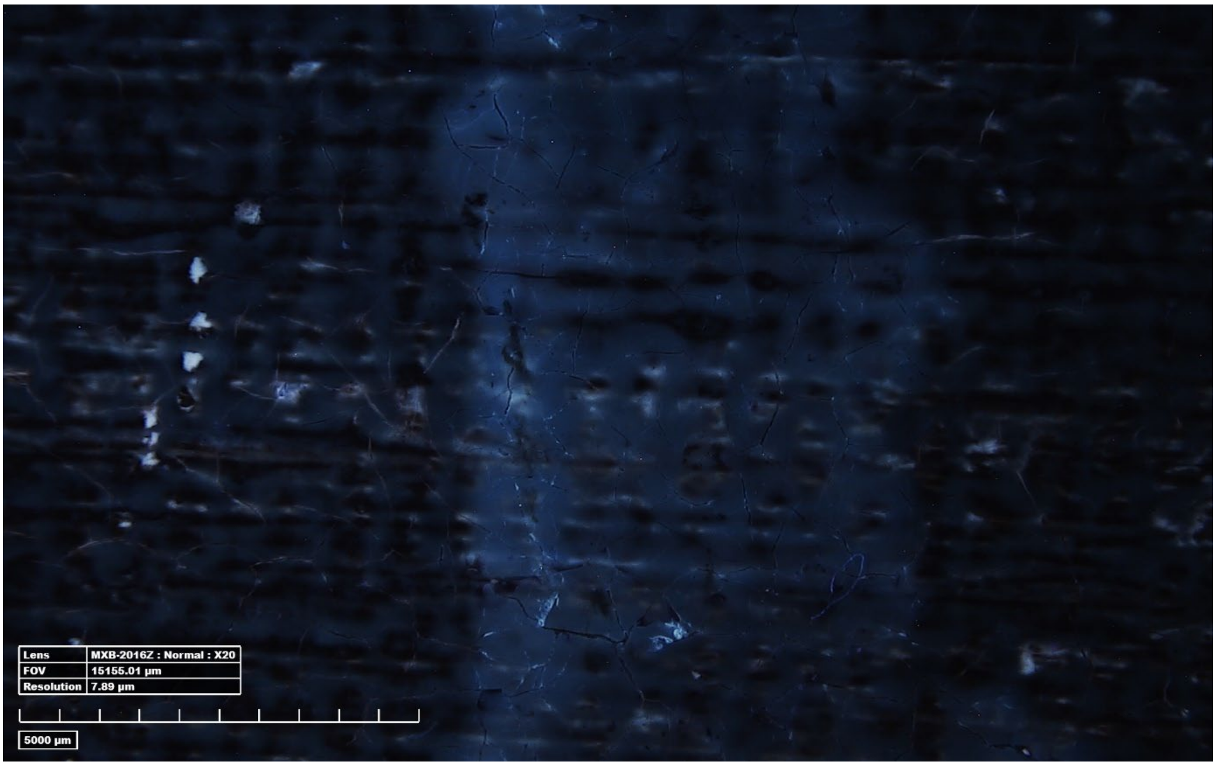


Figure 20. Example of high-resolution digital microscope image, spot location R.02, left foreground in *Puberty*. Fluorescence of Munch's original varnish drips is visible under the restoration varnish layer (Woll M 347) (UVA-induced fluorescence light 20×, 2020, Ford)

7.3 Munch Room configurations

Period 1909

Figure 21. Jens Thiis's first Munch group hanging on a wall in the Young Painters' Hall (Autumn 1909, O.Væring, Nasjonalmuseet)

15 out of a total of 20 paintings are documented in the 1909 photograph.

(*The Sick Child* is the 2nd version before its replacement with the 1st version in 1931).

Period c.1912

Figure 22. The Munch wall in the Young Painters' Hall showing a slightly different configuration with Olav Schous's 1910 donations and 1912 acquisition of *Julius Meier-Graefe* (Woll M 343) (c.1912, O. Væring, Nasjonalmuseet)

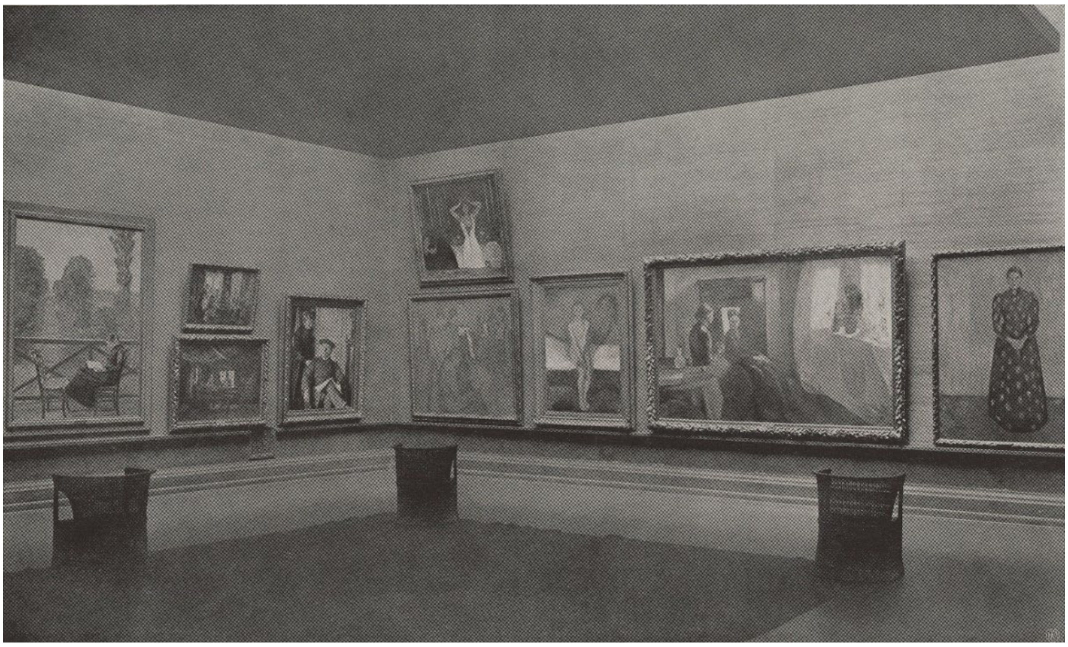


Figure 23. Munch paintings were also hung in the Square Room (c.1912, O. Væring, Nasjonalmuseet)

18 out of a total of 23 paintings are documented in the two 1912 photographs.

Period 1915–1924

Figure 24. Munch wall in the Young Painters' Hall showing the new configuration with Olav Schous's latest 1915 donation of *Midsummer* (Woll M 1158) (c.1915–1920, O. Væring, Nasjonalmuseet)

Figure 25. Larger Munch paintings hung in the Square Room (c.1920, O.Væring, Nasjonalmuseet)

18 out of a total of 25 paintings are documented in the two photographs.

Period 1924–1936

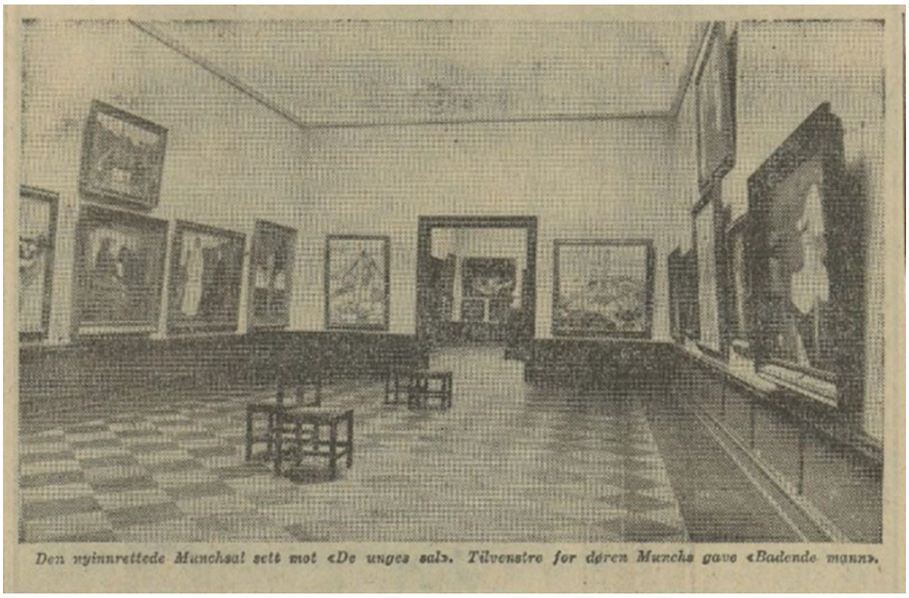


Figure 26. First entire room dedicated to Munch with *Bathing Man* (Woll M 1284) donated by Munch to the NM after the 1927 exhibition (Tuesday 8 April 1930, *Dagbladet*)

Figure 27. The Munch Room showing a slight change in the configuration with *The Dance of Life* (Woll M 464) hung over the door arch (c.1930, O. Væring, Nasjonalmuseet)

Figure 28. The Munch Room, west wall (c.1930, O. Væring, Nasjonalmuseet)

18 out of a total of 26 paintings are documented in the three 1930 photographs.

Period 1937

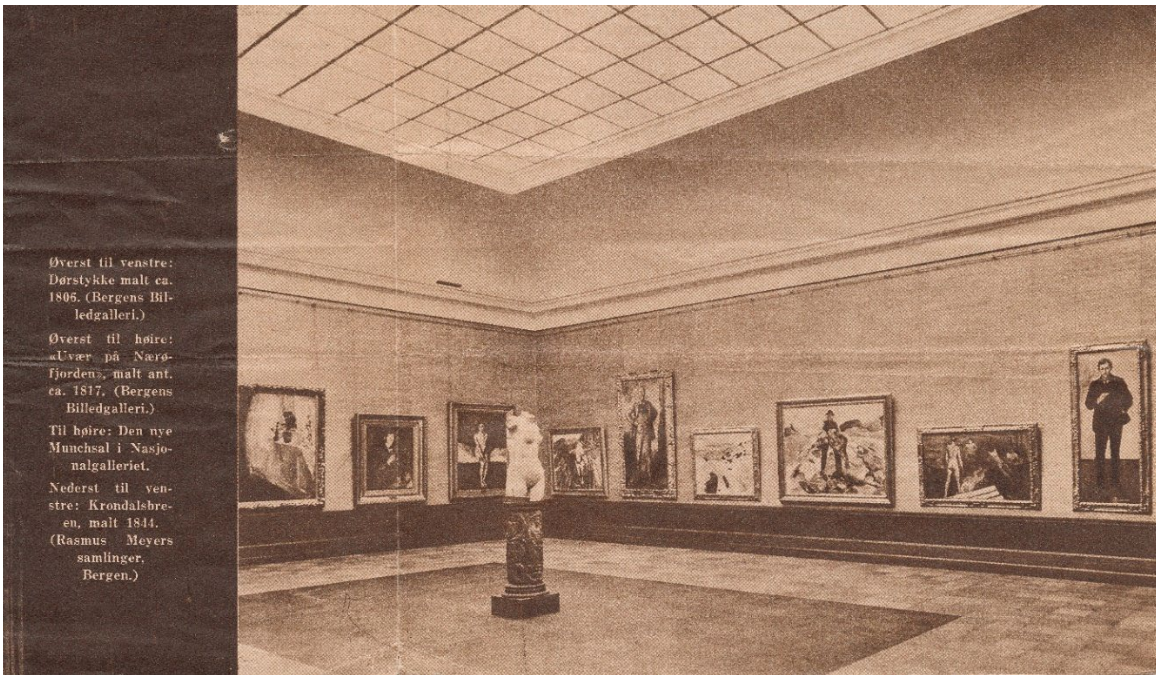


Figure 29. 1937 Munch Room showing some of the Mustad donations
(15 May 1937, Oslo *Illustrerte*)

In 1937 the NM owned 36 Munch paintings.

Period 1938–1940

Figure 30. The Munch Room pre-WWII evacuations with loaned portrait of *Dr Daniel Jacobsen* (Woll M 822) (O. Væring)

Period 2014–2019

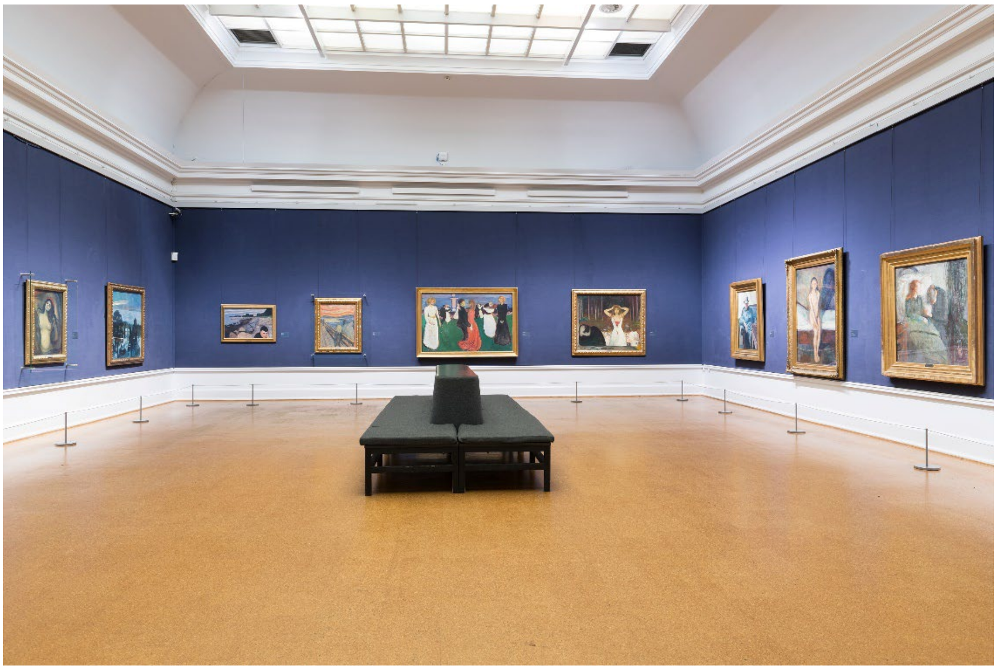


Figure 31. The Munch Room (December 2018, Nasjonalmuseet)

7.4 WWII Evacuation

Table (v). Table of evacuation priority (location, dates and crate numbers)

Evacuation priority and destination	Crate no.	Painting	NM inventory no. (NG.M.)	Woll cat. no
1. Hadeland Folkmuseum 07.03.1940	11	*Ashes*	00841	378
		Aase Nørregaard	01793	457
		Winter on the Fjord	01864	1126
	17	*Man in the Cabbage Field*	01865	1195
	20	*Self-portrait with Cigarette*	00470	382
		Hans Jæger	00498	174
		Inger in Black and Violet	00499	294
		Puberty	00807	347
		The Day After	00808	348
	52	*The Sick Child*	00839	126
2. Bagn Bygdesamling museum (Valdres) 22.10.1942	2	*Bathing Boys*	01866	358
	18	*White Night*	00581	477
	21	*Girls on the Bridge*	00844	483
	46	*Thorvald Thorgersen*	01893	75
	55	*Betzy Nilsen*	03054	144
	72	*Night in St Cloud*	01111	192
	73	*Jørgen Sørensen*	00472b	75
		Self-portrait	00839	133
	74	*Night in Nice*	00394	224
	77	*Madonna*	00841	366
		Rue Lafayette	01725	232
		Inger in Black	01863	113
	80	*On the Veranda*	00810	549
3. Hadeland Folkmuseum 09.11.1942	94	*Frenchman Marcel Archinard*	00811	578
	95	*The Dance of Life*	00941	464
4. Bagn Bygdesamling museum (Valdres) 20.11.1942	83	*Aase and Harald Nørregaard*	01794	458
	90	*Winter in the Woods*	00570	445
5. Bagn Bygdesamling museum (Valdres) 06.10.1943	11	*Autumn*	01863	1341
	113	*Julius Meier-Græfe*	00995	343
	114	*Midsummer*	01864	1158
		Self-portrait with Spanish Flu	01867	1296
		Moonlight	01914	322
	115	*Mother and Daughter*	00840	404
	117	*Death in the Sickroom**	00940	329
	118	*Two Nudes*	01868	514
6. Hadeland Folkmuseum 13.10.1943	101	*Moonlight by the Mediterranean*	00842	274
	105	*Flowery Meadow at Veierland*	01235b	148
	141	*Bathing Man*	01699	1284
	146	*House with Red Virginia Creeper*	01894	439
	163	*Self-portrait*	01229	649
	168	*The Scream*	00940	939
	191	*Woman Washing Herself*	00843	387
8. Hadeland Folkmuseum	19	*Spring**	00498	173

*Due to their large size, *Death in the Sickroom* (Woll M 404) and *Spring* (Woll M 173) remained at their first evacuation sites until the end of the war. All remaining crates were thereafter sent to the Kongsberg mines (unknown dates) until the end of the war.

The Scream (Woll M 333) was packed in crate 168 with 2 pastels (including Oda Krogh Japanese lantern NG.M.00879), 2 gouaches and a small still life study.

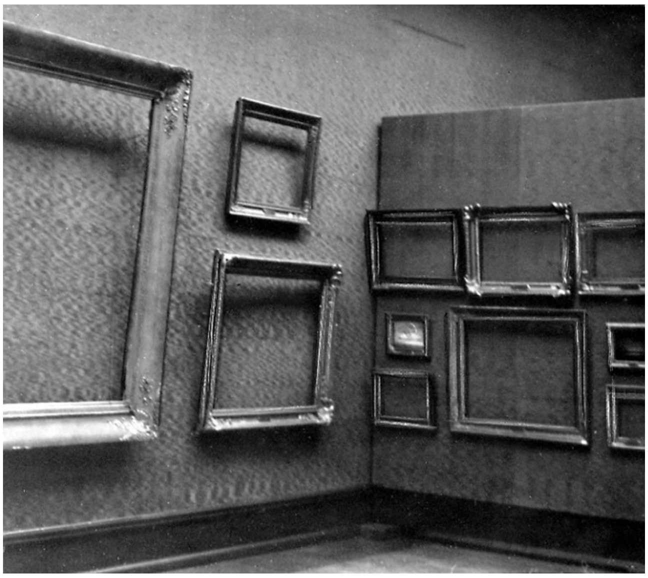
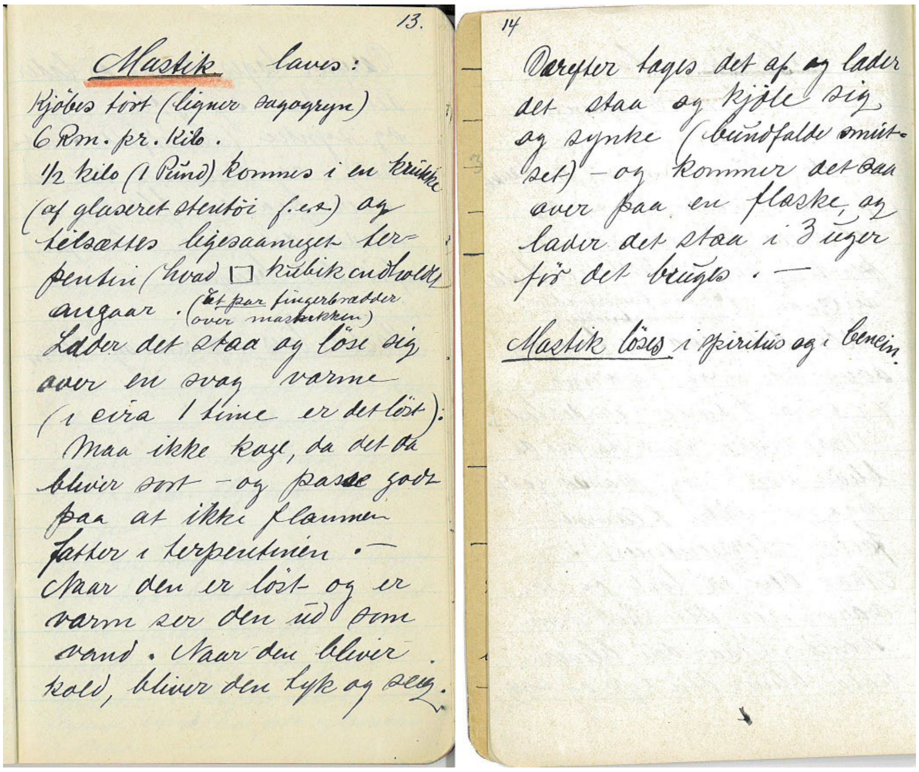


Figure 32. NG frames left hanging in exhibition galleries after WWII evacuation of paintings (1940, unknown photographer, Arbeiderbladet, Arbeiderbevegelsens archive and library, Oslo)

Figure 33. Example of WWII crate with straw packing (2020, Ford)

7.5 Historical varnish recipes & condition reports


13.

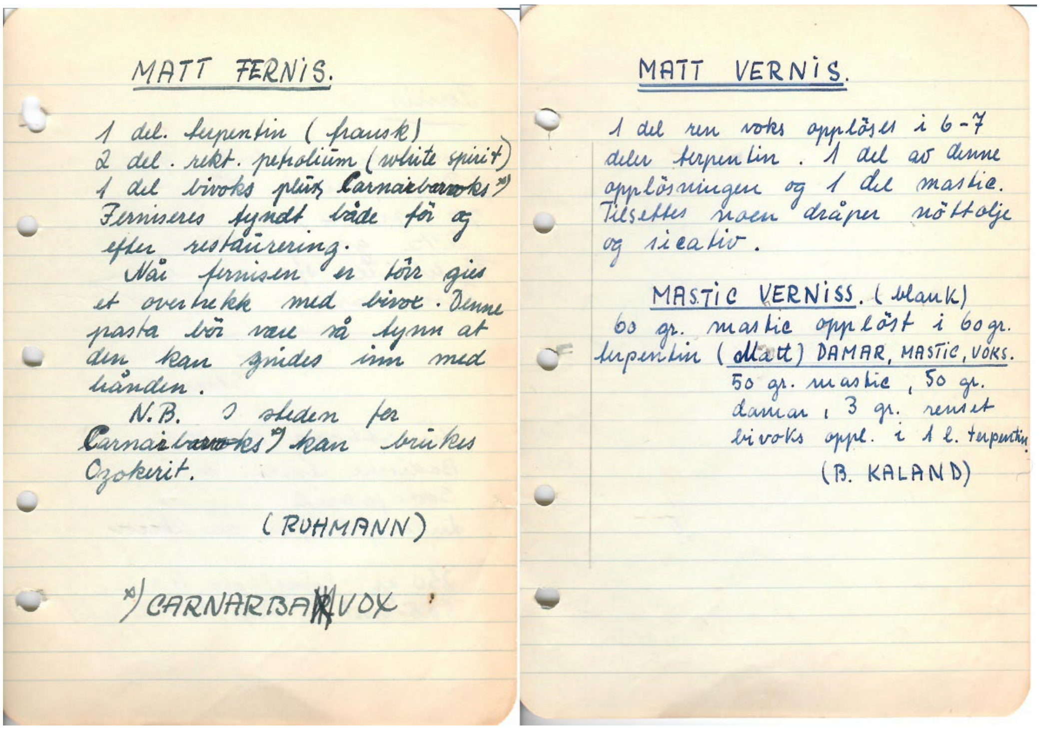
Mastik laves:
Kjöbes tört (ligner sagogryn)
6 Rm. pr. Kilo.
½ kilo (1 Pund) kommes i en krukke
(af glaseret stentöi f.ex.) og
tilsættes ligesaameget ter-
pentin (hvad □ kubikindholdet
angaar. (Et par fingerbredder over mastikken)
Lader det staa og löse sig
over en svag varme
(i circa 1 time er det löst):
Maa ikke koge, da det da
bliver sort — og passe godt
paa at ikke flammen
fatter i terpentinen. —
Naar den er löst og er
varm ser den ud som
vand. Naar den bliver
kold, bliver den tyk og seig.

14

Derefter tages det af og lader
det staa og kjöle sig
og synke (bundfalde smuts-
set) — og kommer det saa
over paa en flaske, og
lader det staa i 3 uger
för det brugis. —

Mastik löses i spiritus og i benzin.

Figure 34. Mastic varnish recipe in turpentine from conservator Harald Brun's studio notebook (pages 13–14, 1906–07, NM Archives: NMFK/NG-0007/E/L0002)


MATT FERNIS.

1 del. terpentin (fransk)
2 del. rekt. petrolium (white spirit)
1 del bivoks pluss Carnaibavoks*)
Fernisseres tynnt både för og
efter restaurering.
Når fernisen er törr gies
et overtrekk med bivox. Denne
pasta bör være så tynn at
den kan gnides inn med
hånden.
N.B. I steden for
Carnaibavoks*) kan brukes
Ozokerit.

(RUHMANN)

*) CARNARBAUVOX

MATT VERNIS.

1 del ren voks opplöses i 6-7
deler terpentin. 1 del av denne
opplösningen og 1 del mastic.
Tilsettes noen dråper nöttolje
og siccativ.

MASTIC VERNISS. (blank)
60 gr. mastic opplöst i 60 gr.
terpentin (Matt) DAMAR, MASTIC, VOKS.
50 gr. mastic, 50 gr.
damar, 3 gr. renset
bivoks oppl. i 1 l. terpentin
(B. KALAND)

Figure 35. Examples of matt varnish recipes post-WWII NM conservator studio recipe book

KETONHARZ N -FERNISSER.

Standardløsning:	Ketonharz N	750 gr.
	White spirit	1200 ml.
	Vegetabilsk terpentin	300 ml.
	Butylacetat	150 ml.
	Standolje	75 ml

Harpiksen fylles i en gaspose ell. lign. i flasken. Løseveskene helles over. Standoljen tilsettes når harpiksen er oppløst.

Retusjeringsferniss:	Standardløsning	400 ml.
	White Spirit	120 ml.
	Vegetabilsk terpentin	30 ml.
	Diaceton alkohol	60 ml.

Matt ferniss:	Standardløsning	400 ml.
	Cosmolloid 60 M	90 ml.
	White Spirit	1300 ml.
	Vegetabilsk terpentin	700 ml.

Sluttferniss, Grad 5:

Standardløsning	1350 ml.
Matt ferniss	750 ml.

Sluttferniss, Grad 9:

Standardløsning	1200 ml.
Matt ferniss	1200 ml.

Vokspasta til sluttcoating på malerier:

600 gr. Cosmolloid 80 H
800 gr. Damar
2500 ml. White Spirit.

Figure 36. Varnish recipes for Ketone N and wax/dammar varnish paste

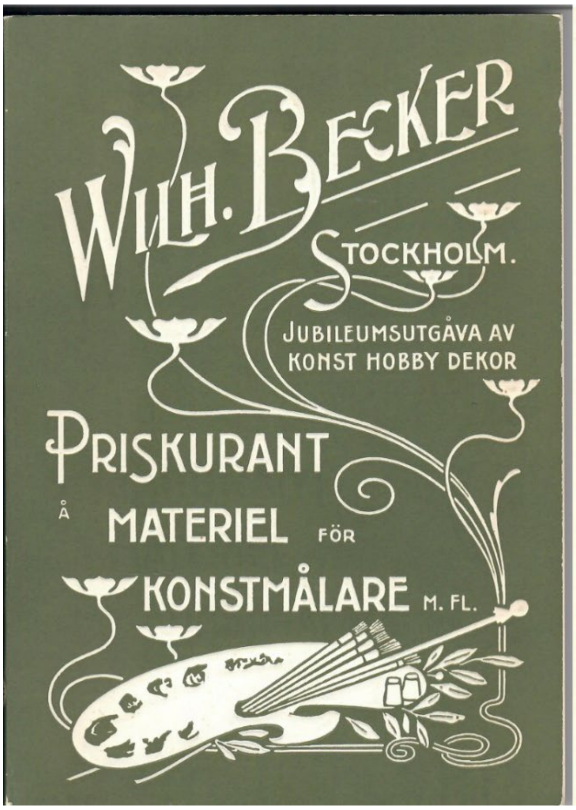
Grade 1: 9 parts standard solution:1 part matt solution.

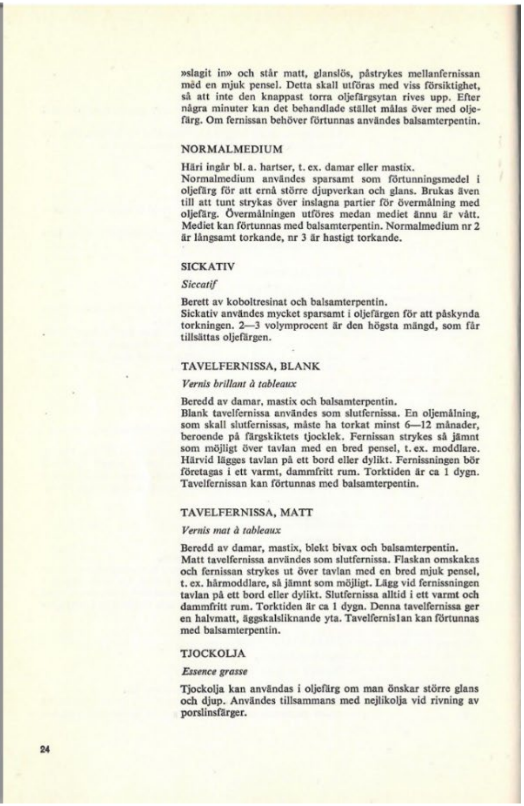
Grade 5: 9 parts standard solution:5 parts matt solution (semi-matt varnish finish).

Grade 9: 1 part standard solution:1 part matt solution (matt varnish finish).

Figure 37. Ceronis (wax varnish paste) Picture Varnish, Lefranc & Bourgeois (2022, Nasjonalmuseet)

Figure 38. Matt tempera retouching colours, Couleurs de Muzii, Lefranc (2022, Nasjonalmuseet)




»slagit in» och står matt, glanslös, påstrykes mellanfernissan med en mjuk pensel. Detta skall utföras med viss försiktighet, så att inte den knappast torra oljefärgsytan rives upp. Efter några minuter kan det behandlade stället målas över med oljefärg. Om fernissan behöver förtunnas användes balsamterpentin.

NORMALMEDIUM

Häri ingår bl. a. hartser, t. ex. damar eller mastix.
Normalmedium användes sparsamt som förtunningsmedel i oljefärg för att ernå större djupverkan och glans. Brukas även till att tunt strykas över inslagna partier för övermålning med oljefärg. Övermålningen utföres medan mediet ännu är vått. Mediet kan förtunnas med balsamterpentin. Normalmedium nr 2 är långsamt torkande, nr 3 är hastigt torkande.

SICKATIV

Siccatif

Berett av koboltresinat och balsamterpentin.
Sickativ användes mycket sparsamt i oljefärgen för att påskynda torkningen. 2—3 volymprocent är den högsta mängd, som får tillsättas oljefärgen.

TAVELFERNISSA, BLANK

Vernis brillant à tableaux

Beredd av damar, mastix och balsamterpentin.
Blank tavelfernissa användes som slutfernissa. En oljemålning, som skall slutfernissas, måste ha torkat minst 6—12 månader, beroende på färgskiktets tjocklek. Fernissan strykes så jämnt som möjligt över tavlan med en bred pensel, t. ex. moddlare. Härvid lägges tavlan på ett bord eller dylikt. Fernissningen bör företagas i ett varmt, dammfritt rum. Torktiden är ca 1 dygn. Tavelfernissan kan förtunnas med balsamterpentin.

TAVELFERNISSA, MATT

Vernis mat à tableaux

Beredd av damar, mastix, blekt bivax och balsamterpentin.
Matt tavelfernissa användes som slutfernissa. Flaskan omskakas och fernissan strykes ut över tavlan med en bred mjuk pensel, t. ex. hårmoddlare, så jämnt som möjligt. Lägg vid fernissningen tavlan på ett bord eller dylikt. Slutfernissa alltid i ett varmt och dammfritt rum. Torktiden är ca 1 dygn. Denna tavelfernissa ger en halvmatt, äggskalsliknande yta. Tavelfernis1an kan förtunnas med balsamterpentin.

TJOCKOLJA

Essence grasse

Tjockolja kan användas i oljefärg om man önskar större glans och djup. Användes tillsammans med nejlikolja vid rivning av porslinsfärger.

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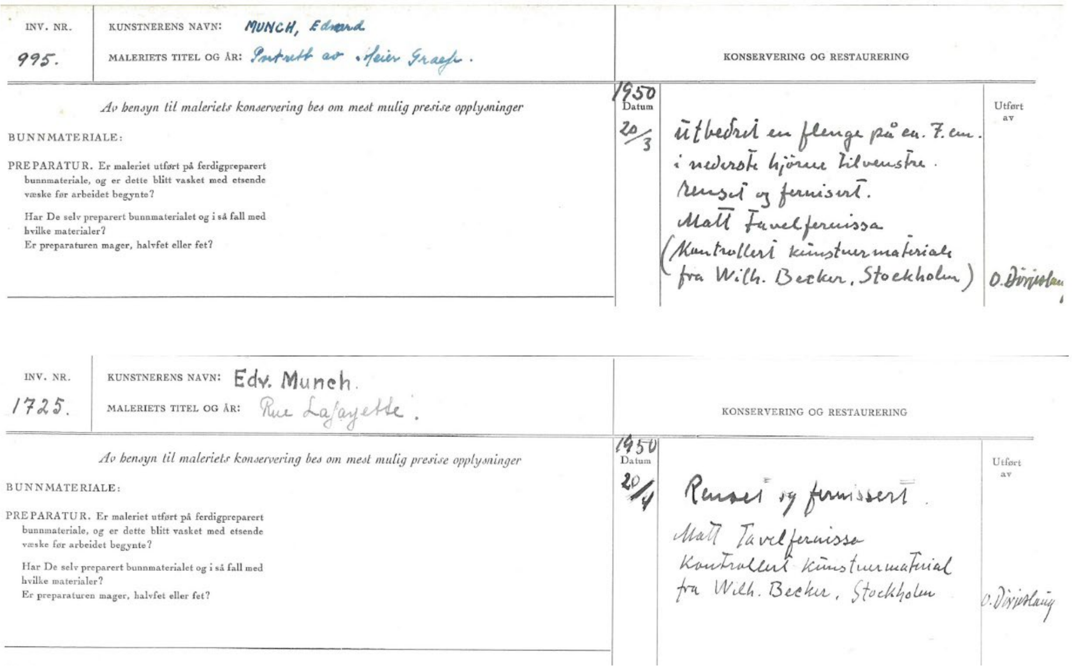
Figure 39. Wilhelm Becker's 1965 artists' material catalogue. Matt (*tavelfernissa*) picture varnish based on a mixture of dammar and mastic with bleached beeswax in balsam turpentine


INV. NR. 995. KUNSTNERENS NAVN: MUNCH, Edvard
MALERIETS TITEL OG ÅR: Portrett av Meier Graefe.

KONSERVERING OG RESTAURERING

Av hensyn til maleriets konservering bes om mest mulig presise opplysninger

BUNNMATERIALE:

PREPARATUR. Er maleriet utført på ferdigpreparert bunnmateriale, og er dette blitt vasket med etsende væske før arbeidet begynte?
Har De selv preparert bunnmaterialet og i så fall med hvilke materialer?
Er preparaturen mager, halvfet eller fet?

Datum 1950 20/3
utbedret en flenge på ca. 7 cm. i nederste hjørne tilvenstre. Renset og fernisert. Matt Tavelfernissa (Kontrollert kunstnermateriale fra Wilh. Becker, Stockholm)
Utført av: O. [illegible]

INV. NR. 1725. KUNSTNERENS NAVN: Edv. Munch.
MALERIETS TITEL OG ÅR: Rue Lafayette.

KONSERVERING OG RESTAURERING

Av hensyn til maleriets konservering bes om mest mulig presise opplysninger

BUNNMATERIALE:

PREPARATUR. Er maleriet utført på ferdigpreparert bunnmateriale, og er dette blitt vasket med etsende væske før arbeidet begynte?
Har De selv preparert bunnmaterialet og i så fall med hvilke materialer?
Er preparaturen mager, halvfet eller fet?

Datum 1950 20/4
Renset og fernissert. Matt Tavelfernissa Kontrollert kunstnermaterial fra Wilh. Becker, Stockholm
Utført av: O. [illegible]

Figure 40. Examples of conservation reports with Becker's matt *tavel* varnish.
Julius Meier-Graefe (Woll M 343) and Rue Lafayette (Woll M 232)

7.6 Varnish reference library

7.6.1 Munch's house retouching varnishes

Figure 41. Mastic varnish bottle, Alf Bjercke, Oslo (MUH.00101) (Roger Berg, Munch hus)

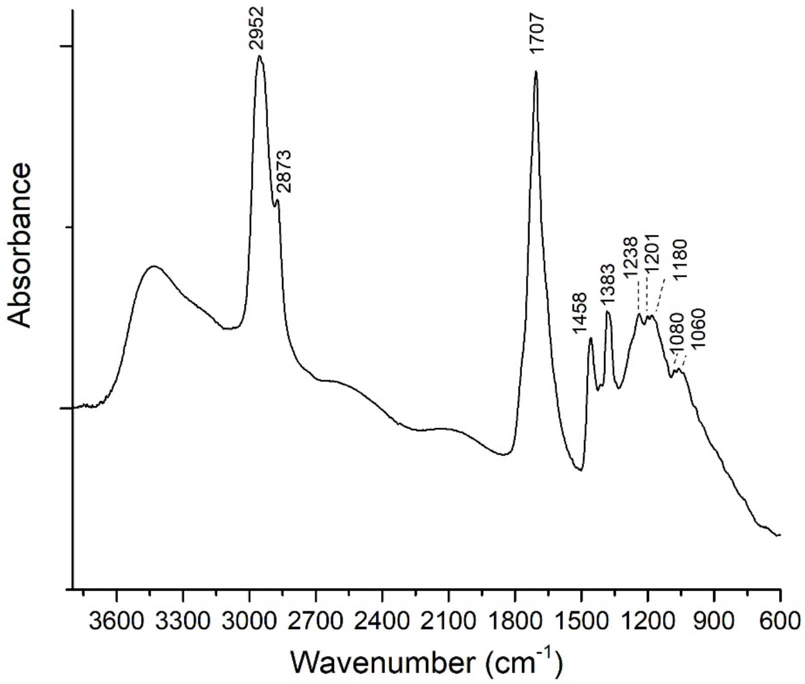


Figure 42. FTIR-(ATR) spectrum from hardened mastic varnish residue taken from MUH.00101 bottle neck

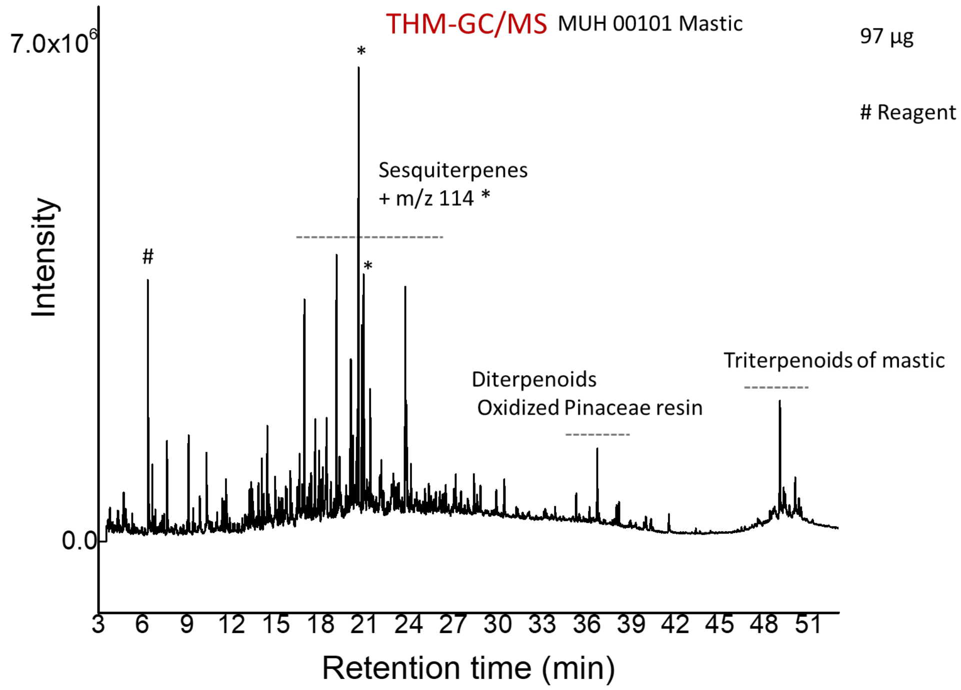


Figure 43. Total ion chromatogram obtained from THM-GC-MS of varnish residue taken from MUH.00101 bottle neck

Figure 44. Bernsteinlack, J.F. Martini, Weimar (MUH.00341) (Roger Berg, Munch hus)

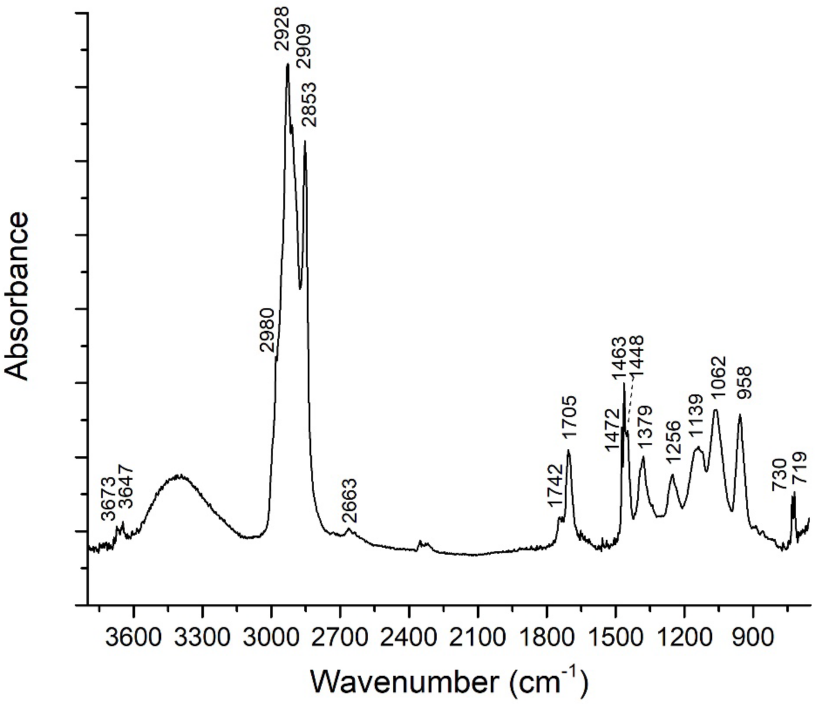


Figure 45. FTIR-(ATR) spectrum from hardened varnish residue taken from MUH.00341 bottle neck

Figure 46. Vernis a l’eau, J. G. Vibert, LeFranc, Paris (MUH.00342) (Roger Berg, Munch hus)

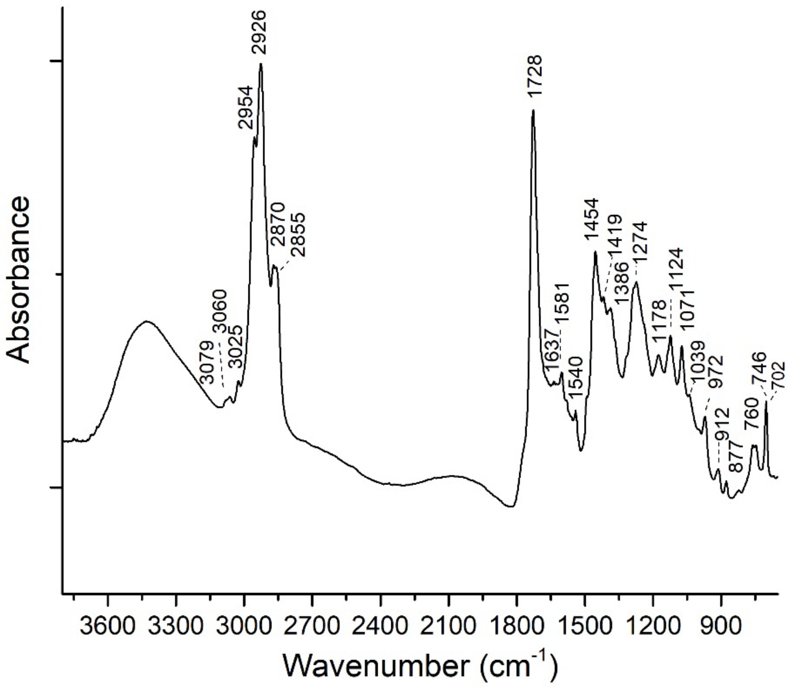


Figure 47. FTIR-(ATR) spectrum from hardened varnish residue taken from MUH.00342 bottle neck

7.6.2 Portable DRIFT varnish reference spectra (Paper II, Table 1)

Selected infrared absorption bands for natural and synthetic resins (cm^{-1})

Mastic:	1714, 1459, 1384, 1265, 1161, 1057
Dammar:	1710, 1459, 1384, 1266, 1157, 1048
Laropal K-80:	1700, 1456, 1375, 1258, 1120, 1054

(Rie and Shedrinsky 1989; Lomax and Fisher 1990)

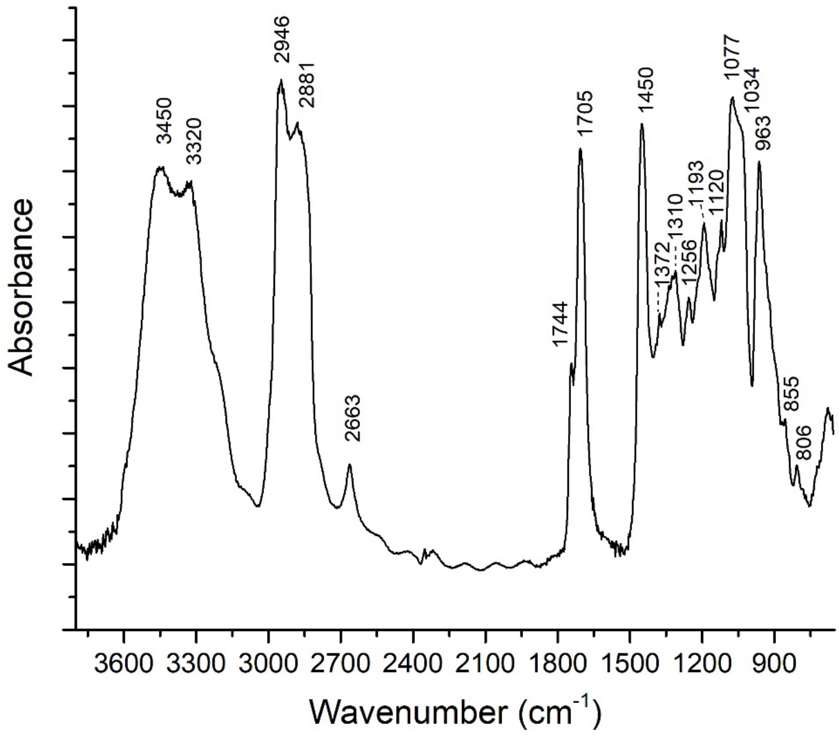


Figure 48. Portable DRIFT spectrum for Mirr02, Laropal K80 standard solution + stand oil (BASF, 2018)

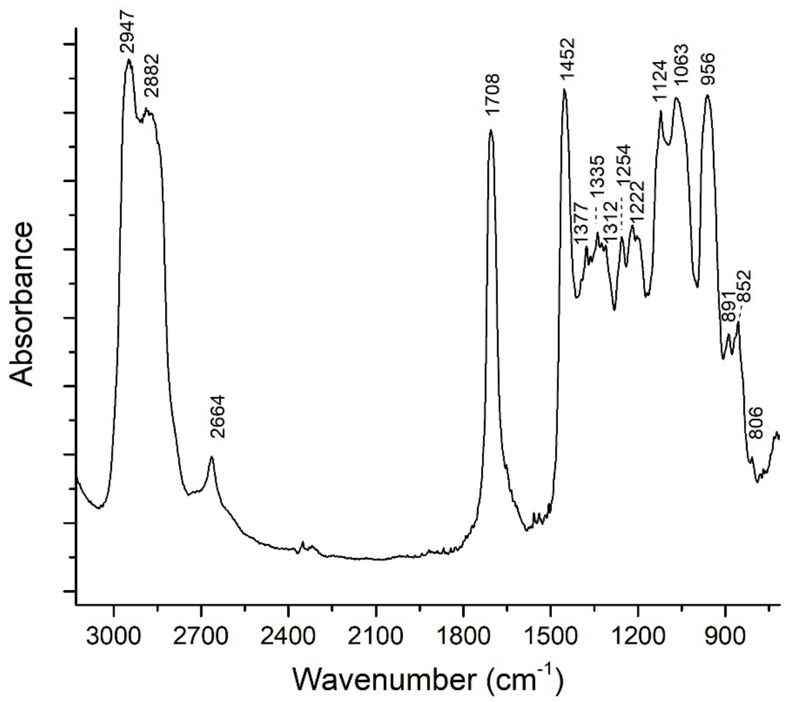


Figure 49. Portable DRIFT spectrum for Mirr08, Laropal K80 standard solution without stand oil (BASF, 2018)

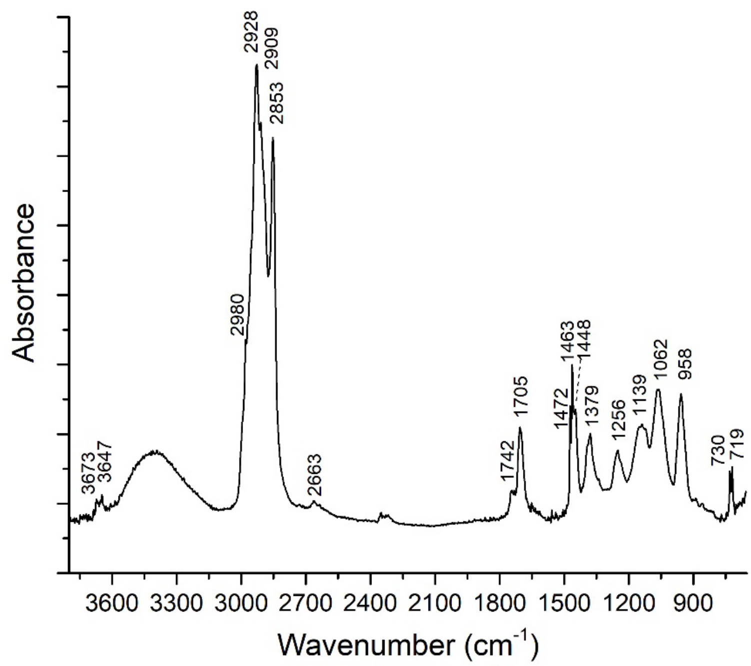


Figure 50. Portable DRIFT spectrum for Mirr03, Laropal K80 matt solution + stand oil and microcrystalline wax (BASF, 2018)

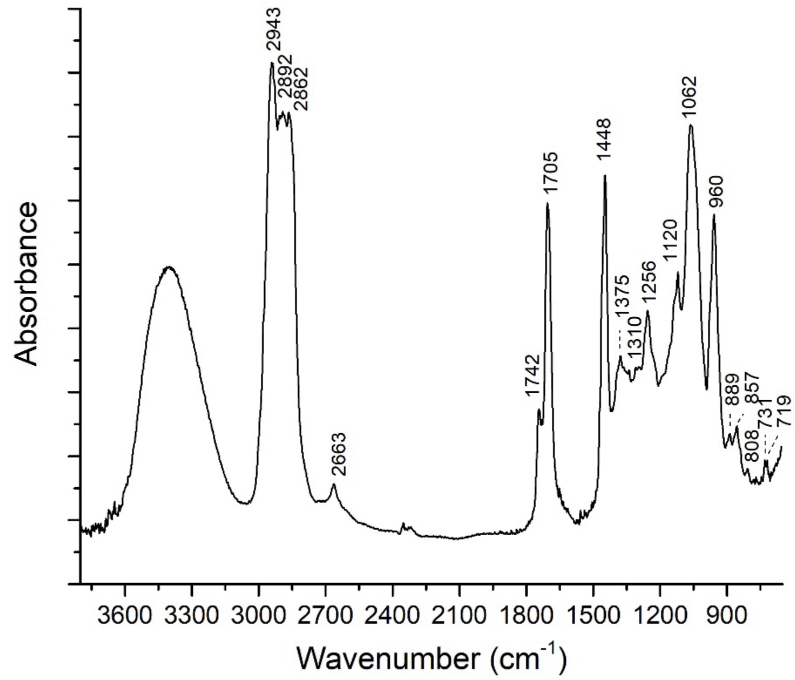


Figure 51. Portable DRIFT spectrum for Mirr04, Laropal K80 Grade 5 solution + stand oil and microcrystalline wax (BASF, 2018)

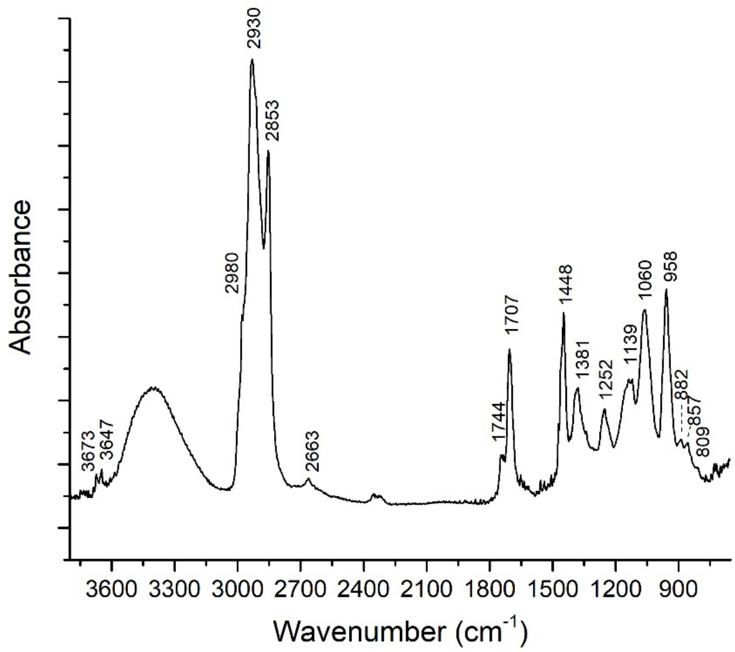


Figure 52. Portable DRIFT spectrum for Mirr05, Laropal K80 Grade 9 solution + stand oil and microcrystalline wax (BASF, 2018)

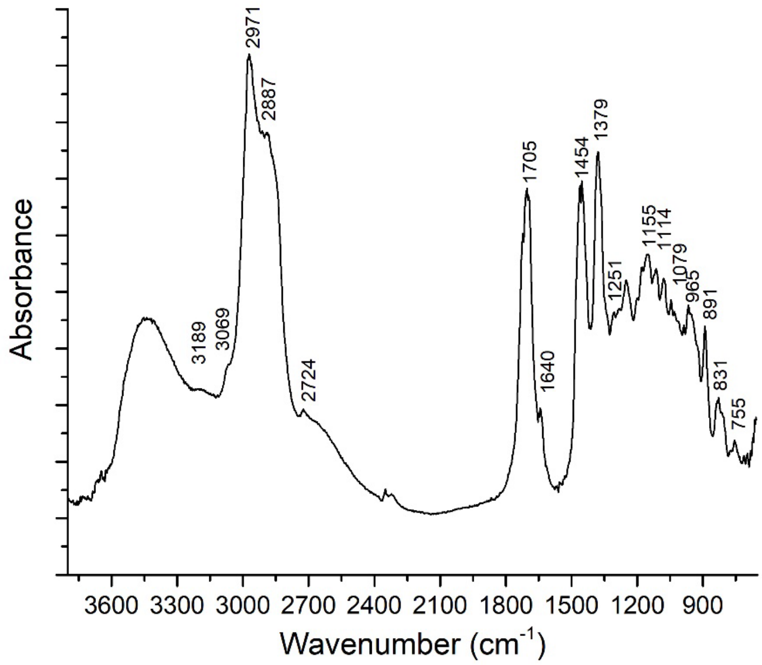


Figure 53. Portable DRIFT spectrum for Mirr06, dammar standard solution (Windsor and Newton)

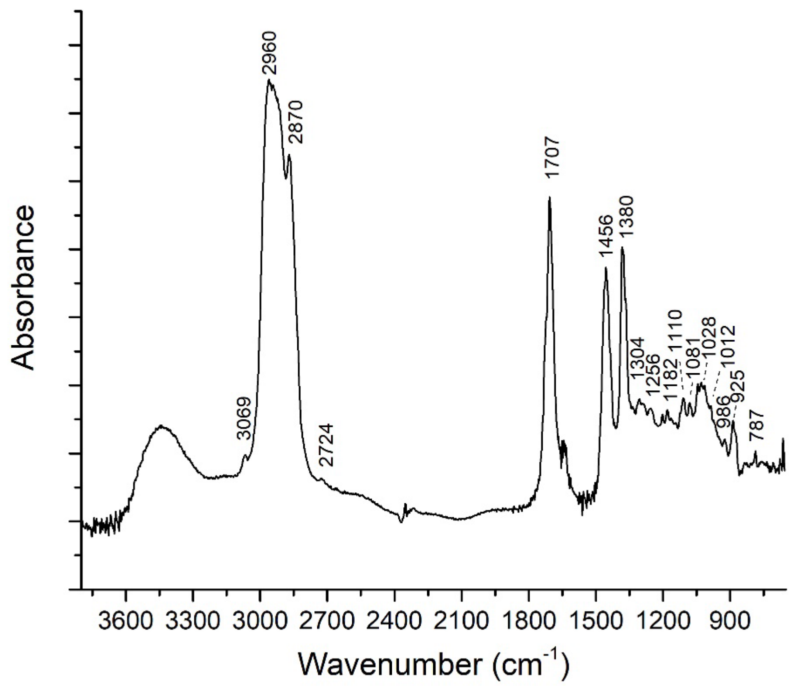


Figure 54. Portable DRIFT spectrum for Mirr13, mastic standard solution (Lascaux)

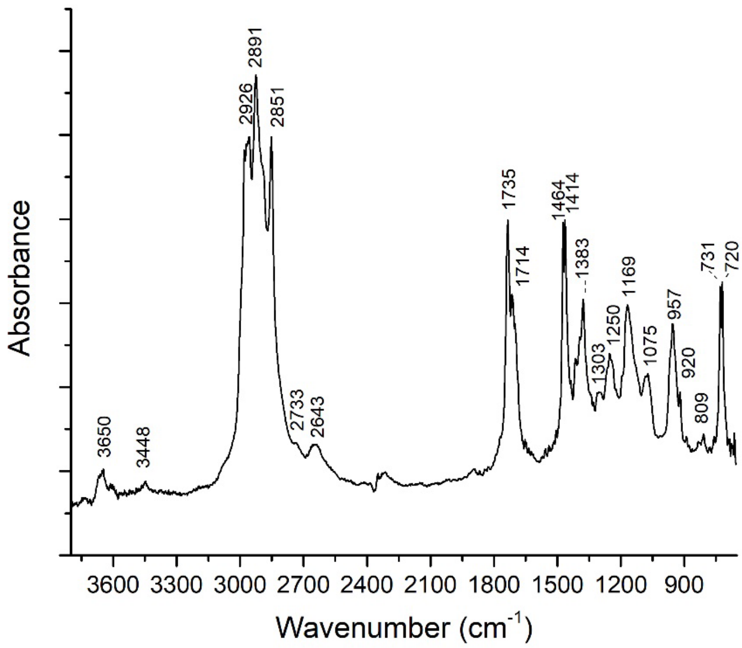


Figure 55. Portable DRIFT spectrum for Mirr15, Ceronis (wax varnish paste) picture varnish, (Lefranc & Bourgeois)

7.6.3 Table (vi) pFTIR depth of penetration tests (Paper II)

Glass slide no.	Varnish thickness (mm)	pFTIR file
DP01S	0,25	DP01_DR256_025S_2019-03-14T21-59-28
DP01R	0,25	DP01_DR256_025R_2019-03 14T22-05-03
DP02S	0,5	DP02_DR256_05S_2019-03-14T22-10-46
DP02R	0,5	DP02_DR256_05R_2019-03-14T22-15-05
DP03S	0,75	DP03_DR256_075S_2019-03-14T22-23-34
DP03R	0,75	DP03_DR256_075R_2019-03-14T22-27-45
DP04S	0,9	DP04_DR256_09S_2019-03-14T22-42-27
DP04R	0,9	DP04_DR256_09R_2019-03-14T22-47-34

The typical Si-O-Si stretch for glass (slide) was not detectable in the varnish thickness of 0.9 mm

7.7 Curriculum Vitae

Thierry-Olivier Ford was born in 1971 and raised in the UK by a British father and Swiss mother. After abandoning his desires to follow the family traditions in horology or to become a painter, Thierry studied the History of Fine and Decorative Arts at Leeds University (1989-1993). It was during his time in Leeds that he was introduced to the field of conservation by the paintings conservator, Jennifer Hack (Leeds Museums and Art Galleries). Before embarking on a career in conservation, Thierry worked as an antique dealer in Switzerland. In 1996, he received his Master's in easel paintings conservation from the University of Northumbria at Newcastle and joined De Beers conservation studios in London until 2001. During this time Thierry gained valuable practical experience with the conservation of Old Master paintings and varnishing. Between 2001 and 2006, Thierry was employed by the Norwegian Institute of Cultural Heritage Research (NIKU) and was involved in a Norwegian development aid project with conservation students: A Preservation Plan for the Shilpakala Academy, Dhaka, Bangladesh (2003–2010). Since 2006, Thierry has worked for the National Museum of Art, Norway but has also had the privilege of lecturing and supervising Master student interns at the University of Oslo. In addition to a 26-year practical career, Thierry has published 14 peer-reviewed papers related to conservation and has been fortunate to research paintings by Gustav Courbet, Gentileschi, Hans Gude, Edouard Manet, Munch, Harald Sohlberg and Picasso. His tasks at the museum have also included numerous public dissemination projects both in Norwegian and English.

Thierry started his PhD study in January 2018 and has undertaken the research part time. During this period, he has also been responsible for several equipment acquisition packages for the new museum building, in particular the design and purchase of the digital X-ray system.

Outside of conservation, Thierry likes to travel, hiking in the mountains, cooking, pinot noir and crime series. He is looking forward to using more of his free time to return to painting.

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