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Colour Photography and Film:

Sharing knowledge of analysis, preservation, and conservation of analogue and digital materials

2022

Edited by Barbara Cattaneo, Filippo Cherubini and Marcello Picollo

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2nd Edition of the Conference "Colour Photography and Film: Sharing knowledge of analysis, preservation, and conservation of analogue and digital materials"

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Foreword

After the first successful 2021 online edition of the international conference "**Colour Photography and Film: Sharing knowledge of analysis, preservation, and conservation of analogue and digital materials**", its second edition took place in hybrid, mixed mode, with in-person participation at the venue in Florence (Italy) and with remote online access. The convening was scheduled for two days, the 15th - 16th September 2022. It was organized by The Gruppo del Colore – Associazione Italiana del Colore, in collaboration with the Istituto di Fisica Applicata "Nello Carrara" of the Consiglio Nazionale delle Ricerche (IFAC-CNR), the Opificio delle Pietre Dure (OPD), and the Fondazione Alinari per la Fotografia.

The organizers firmly believe that uniting the worlds of the conservation of photographic materials with that of film, and at the same time placing the analogue and digital worlds in conversation with each other will lead to an informative and highly productive dialogue between various fields of inquiry. For this reason, three groundbreaking keynote speakers were involved: Henry Wilhelm, Joel Meyerowitz, and Nicola Mazzanti. With their extraordinary expertise as researchers in the field of color photography and photographic film technology, Henry Wilhelm and his wife Carol Brower have been pioneers in the preservation of photographic and film material since the 1970s, while Joel Meyerowitz was indisputably a trailblazer in color photography. Nicola Mazzanti has dedicated his entire life to the preservation of film and media art. The individual professional experiences of all three have been valued over decades, they have witnessed the digital turn, and they have been inspirational professionals and teachers. The organizers were fortunate and truly honored to have Henry Wilhelm, Joel Meyerowitz, and Nicola Mazzanti agree to be the keynote speakers at the 2022 convening.

Approximately 130 participants from several countries and four continents had the chance to follow the 35 presentations that formed the program. Among them were the three keynote lectures, 20 full talks, six technical talks, and six shorter presentations.

As envisaged by the scientific committee, contributions discussing the history, practices, archiving and use of analogue and digital photography proved to be central issues in defining new strategies for the conservation and restoration of photographic and film materials. The topics covered during the conference ranged from the history of early color systems, such as interferential photography and additive screen processes, to issues dealing with identification and conservation of contemporary prints and film, and included technical descriptions of actualized historical color processes as well as the ways in which they can add value to contemporary photography as Art. Oral presentations also addressed the ways in which recent digital technology is contributing to the research and development of cultural aspects of Photography and Film.

Altogether 85 authors shared their experiences and recent research on analogue and digital color materials, highlighting the history, preservation, conservation, and digitizing issues of color photographs and film, giving the audience an insight into how color photography and film technologies have influenced society and culture.

The organizers wish to express their pleasure in witnessing the interest the participants demonstrated toward multidisciplinary exploration of color photography and film during the conferences. The inspiring presentations and exchange of ideas initiated in 2021 and continued in 2022 will surely lead to further stimulating discussions over the years to come. The organizers wish to thank everyone who participated in the events and contributed to the advancement of the fields of color photography and film. The proceedings serve as a reminder of the highlights of the 2022 conference.

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The Interferential Colour Plate aka Lippmann Plate: Materiality, Identification, and Conservation challenges of Lippmann Plates

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Keywords: Lippmann plate, Richard Neuhauss, Hans Lehmann, Herman Krone, museum collection, conservation, interferential colour photography, photographic technique,

Extended Abstract

The Lippmann Colour Photography is one of the most unique and interesting examples of early colour photograph technology. Unlike most other, but no less complex, colour techniques around 1900, it does not use dyes or pigments but still delivers real, very permanent, and even true colour. This is very interesting, not only for the expert in the field of early colour photography but also for the general lover of early photography and photo history. In fact, it represents a landmark on the way to correct colour in the history of photography.

Today only a few institutions and collectors worldwide have original examples of these rare colour images in their possession. This fact has not so much to do with the fragility of the object as with its practical use and application at the time of its origin. However, because of the very special properties in terms of the technique itself, its presentation form, and its requirements for viewing, there is a need for additional awareness about this medium in the field of both photo history and photograph conservation, with special attention to the conservation and long-term preservation of this photographic material.

Preus Museum, the National Museum of Photography in Norway, has a significant collection of twelve Lippmann colour plates together with historic objects, books and papers related to these photographs. Like many early photographic and colour photographic materials, the presentation and preservation advice seem similar. Nevertheless, the conservation challenges among these are often very different and extremely complex. While conservators have found different solutions for image preservation and recovery for the most common materials of our photographic heritage, useful solutions for many of the early colour photographic materials and especially the Lippmann interferential photography, are almost not presented. The research project, launched by the Preus Museum Conservation Department in 2021, addresses this gap in numerous ways, by investigating this photographic technology, the consequences of using and handling these types of objects, and what this means for handling, presentation, and future preservation challenges.

Conclusion and tentative outlook for permanence

The long-term stability of Lippmann plates seems good. They are comparable to dry plate and wet collodion negative and positive material. Plates with a cemented glass prism, varnish, or cover glass are expected to keep in good condition since the fine-grained silver image for the most part is sealed from aggressive air pollution or moisture. Experiences with even older image materials sealed in similar ways have shown that this has been very beneficial for the long-term stability. Of course, long-term stability can be improved by following the above-mentioned preservation recommendations (Gold 2018, 33–35, 83–86). Conservation work should be limited to a minimum, such as cleaning the surface of the glass materials, restoring papers seals and labels, and building

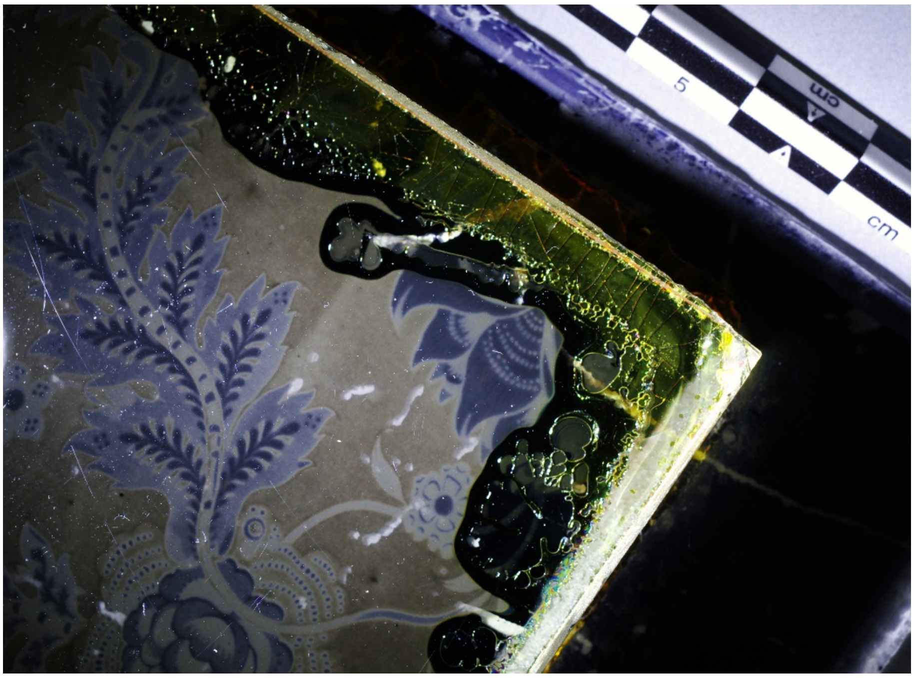

Fig.1 – prism delamination

suitable conservation housings and display materials. The major threat to Lippmann plates is any form of delamination (Fig.1) and image silver deterioration. Such issues may largely be controlled by good environmental conditions. In the collection of Preus Museum, some plates have challenges with delamination of the optical prism. These are stable for now but also being closely monitored in the future. Consolidating the delaminated areas could be considered in order to secure the optical properties of the colour image. After 130 years, Lippmann technology still reveals many interesting issues relating to these fascinating colour photographs. Of course, there are challenges regarding the preservation of this part of photographic culture heritage. But thanks also to its good permanence compared to many other early colour photographic materials, we will still have them with us for a long time (Gold 2018, 245- 247). More information including the detailed analytical data contacted by the author and the University of Oslo is planned to be ready for publication within the publication of the PhD work by author in 2025 (Research project duration: 2021 - 2025).

References:

Gold, Jens. 2018. “The Ambrotype / Wet Collodion Positives on Glass: Treatment Challenges on Complex Nineteenth-Century Photographic Objects”. Master’s thesis, University of Oslo. pp. 16–18, 33–35, 74–86 Available at URN: NBN:no-67385.

Gold, Jens. 2022. In Gabriel Lippmann’s Colour Photography - Science, Media Museums (Hanin Hannouch Ed.), Materiality, Identification, and Conservation of Lippmann Plates, chapter 9. / pp. 245 – 247. DOI: 10.5117/9789463728553/ch09

Photography:

Jens Gold, detail: Richard Gustav Neuhauss (1855-1915). Textile close-up II [no original title]. Lippmann process aka interferential colour photography. 8,4 cm x 6,8 cm. Glass plate with wedge prism at 10° angle. Undated. Albert Narath Collection, Preus Museum.

Finlay, Thames, Dufay, and Paget color screen process collections: Using digital registration of viewing screens to reveal original color

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Abstract

We discuss digitization, subsequent digital analysis and processing of negatives (and diapositives) made by Finlay, Thames, Dufay, Paget, and similar additive color screen processes. These early color processes (introduced in the 1890s and popular until the 1950s) used a special color screen filter and a monochromatic negative. Due to poor stability of dyes used to produce color screens many of the photographs appear faded; others exist only in the form of (monochromatic) negatives. We discuss the possibility of digitally reconstructing the original color from scans of original negatives or by virtue of infrared imaging of original transparencies (which eliminates the physically coupled color filters) and digitally recreating the original color filter pattern using a new open-source software tool.

Photographs taken using additive color screen processes are some of the very earliest color images of our shared cultural heritage. They depict people, places, and events for which there are no other surviving color images. We hope that our new software tool can bring these images back to life.

Keywords: Paget plate, Finlay colour plate, Dufaycolor, additive color photography, early color photography, digitization.

Introduction

Although the first attempts to produce color photography date back to the late 1840s (Edmond Becquerel), the principle of color photography as we know it today was introduced/demonstrated by James Clerk Maxwell during a lecture before the Royal Institution in London on May 17, 1861. Maxwell asked the photographer and inventor Thomas Sutton to take three separate black and white negatives through three colored liquid filters (red, green, and blue) which resulted in three *separation negatives*. These negatives were copied to positive transparencies (*separation transparencies*) and projected through filters of the same color to demonstrate practicality of the additive color synthesis principle. Due to lack of sensitivity of photographic emulsions to red light this experiment was only partly successful. However, this principle was later developed into a practical method of *three-color photography*. One of the main drawbacks was the difficulty involved in viewing photographs: it was either possible to use expensive projectors or chromoscopes to combine 3 separation transparencies into a full color image or print the photographs using very laborious method of color dye-transfer processes. Consequently, color photographs were not widely available and known. See also (Lavédrine and Gandolfo, 2013) and (Pénichon, 2013).

To simplify the process Louis Ducos du Hauron, in 1869, proposed an idea of color photography process which used only one (monochromatic) negative. Following his idea John Joly, in 1884, and James William McDonough, in 1896 with first patent in 1892, introduced the first commercially available implementations of this method: While taking a photograph, a special *taking screen* consisting of regular red, green and blue lines (each about 0.1mm wide) was placed directly on the top of orthochromatic negative inside of camera. Later the negative was copied to a positive monochromatic transparency. Finally, the original color was reproduced by registering the transparency with a *viewing screen* consisting of the same color pattern.

Joly Colour screens were produced from 1896–1900, **McDonough plates** 1896–1900, but their practical use was limited by long exposure times and lack of panchromatic negatives. The idea was developed further with improvements in exposure time, color quality and applied by several commercial color processes (Casella and Cole, 2022): **Thames Colour Screen** (1908–1910), **Dufay Dioptichrome** (1909–1910), **Paget Color screen** (1913 – ca. 1922), **Duplex Screen Plate** (1926 – ca. 1928), **Finlay Colour Plate** (1929–1941, Fig. 1), **Johnsons Colour Screens** (1953 – ca. 1954).

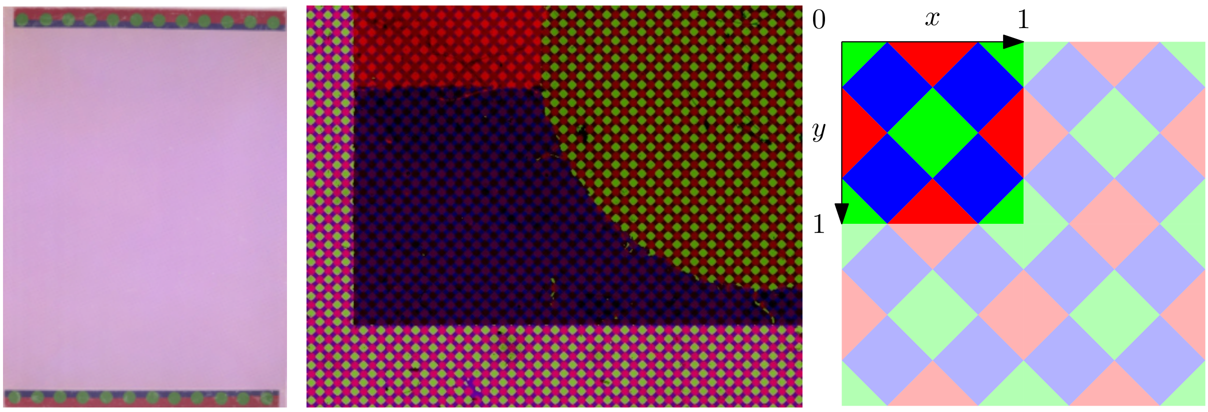

Fig. 1 - Finlay taking screen 13x18cm (left), a detail of a 5400PPI scan using Eversmart Supreme (middle) and a digital model (right). These screens are characteristic by registration marks (a strip with green disks) along top and bottom edges of the plate simplifying the viewing screen registration.

While these processes differed in many details, they all share the key feature of using taking screen in combination with an (orthochromatic, later panchromatic) black and white negative. In all cases the transparency is later registered with a viewing screen to produce a color image. Several other processes employ the same basic principle, however making the color screen (or *réseau*) integral part of the glass plate or film containing the emulsion. Known examples include (Casella and Cole, 2022): **Thames Colour Plate** (1909–1934), **Omnicolore** (1909–1911), **Dufay Dioptichrome-B Plate** (1910–1912), **Dufay Improved Dioptichrome-B Plate** (1912–1914), **Finlaychrome** (ca. 1933–1940), **Krayn Line Screen** (1909–1911), **Krayn Color Film** (1910–1911), **Dufaycolor Film** (1935–1958), and **PolaChrome** (1983–2002).

All those processes are examples of *additive color screen processes* (with regular screens as opposed to autochrome and Agfa color screen plates which uses *random* or *stochastic screen*) on which techniques discussed in this paper apply. In most cases the color filter physically attached to the negative has faded or physically warped in a way that totally obfuscates the color originally recorded of the scene. However, the unique geometrically regular pattern of these processes allows us to digitally reconstruct the original scene color. This is not attempting to shift or adjust the image based on the color as seen today, but a mathematical reconstruction of that color based on a first principles understanding of what each color in these processes was at the time of capture.

Producing an additive color screen photograph

To take a color photograph using an additive color screen filter one proceeds in following basic steps: **1.** Fix taking screen filter to the emulsion side of an ordinary (ideally panchromatic) black and white negative. (It is important that the color screen is in direct contact with the emulsion and thu binding tape was used to fix glass plates together.) **2.** Expose the photograph the same way as when taking black and white photographs (with a longer exposure time accounting for the filter.) **3.** Develop the black and white image. **4.** Use contact copying to produce a black and white transparency. **5.** Register the viewing screen filter to the transparency to reconstruct colors.

Steps 2–4 are quite standard, and every photographer of that era could do them. The last step, *registration of the viewing screen*, involves determining rotation and translation of the viewing screen to match the original position of the taking screen and binding it to the transparency using binding tape for magic lantern slides. This needs a great degree of precision, since color patches are small ($1/10^{th}$ of millimeter in the case of Paget and Finlay screen processes). Today it is common that the transparencies completely or partly lost registration resulting in a color quality loss (Fig. 2).

Fig. 2 - Paget color transparency 8×8cm (left), ca. 1921, author unknown, Šechtl and Voseček Museum of Photography. Probably due to aging of the binding tape, the viewing screen is rotated by approximately 0.04° resulting in loss of color in the upper left and lower right part of the image.
Digital color reconstruction based on an infrared scan of the transparency (right) eliminates the problem. Note that by studying the dot pattern of the transparency one can verify that the image originally indeed had a strong green-yellow cast.

Identification of negatives taken using additive processes with non-integrated screens

Negatives taken using regular additive color processes can be easily mistaken for normal black and white photographs, since the pattern originating from the color screen is visible only at magnification (or in high PPI scan). It is also quite easy to mistake the regular pattern (recording the color information) for a reproduction of a halftone print (Meyer, 2020). See Fig 3.

Fig. 3 - Matson Photo Service: Sudan. Khartoum. Hallway of the Palace, cannon facing entrance, 1836.
Library of Congress, Prints and Photographs Division LC-DIG-matpc-00295.
A negative taken using Finlay Color screen digitally inverted to positive (left) and detail of scan at 1000PPI showing regular pattern well visible in bright colors. One can also notice barely visible registration marks (compare with Fig. 1) along the edges of the negative.

Presently we know of the following collections which contains substantial number (over 10) of photographs taken using regular color screen processes:

1. ***Matson (G. Eric and Edith) Photograph Collection (the American Colony collection)*** at the Library of Congress. This collection contains 179 Finlay color negatives and 3 color transparencies. Most photographs were taken in Africa in 1936. Earliest (taken in Betlehem) are dated 1934 and latest (taken in the archaeological site of Petra) are dated 1946.
2. ***130 Paget plate negatives by Yvette Borup Andrews*** taken during the first Asiatic Zoological Expedition 1916–1917 in collection the American Museum of Natural History.
3. ***Paget plates (positives with viewing screens attached) by Frank Hurley*** from the British Imperial Trans-Antarctic Expedition, 1914–1917, 32 photographs and ca. 30 Paget plates (also positives) by Frank Hurley taken during WW1 in the collection of the State Library of New South Wales.
4. ***Paget plate transparencies with viewing screens attached and negatives by Frank Hurley*** taken during WW1 in the collection of the Australian War memorial. Ca. 300 photographs.
5. ***Finlay color negatives and transparencies by Oscar Jordan*** at the Franklin D. Roosevelt Presidential Library and the Herbert Hoover Presidential Library.
6. ***The National Geographic collection*** contains several Paget, Finlay and Dufaycolor transparencies. This collection is slated for mass digitization at FADGI 4 standards by Digital Transitions / Pixel Acuity in late 2022.
7. ***Collection of approximately 320 lantern slides made by the Paget Colour process by Henden Hardwick***, depicting views in London, Hampstead and the Wye Valley listed at Science Museum Group catalogue. The collection contains also lecture notes and negatives.
8. ***Private collection of Mark Jacobs***, while focused on Autochrome, contains examples of transparencies by Joly, Paget, Finlay, Dioptichrome and Dufay color screens.
9. ***Collection of color photographs taken by Oscar Jordan at the Franklin D. Roosevelt Presidential Library and Museum***. This collection contains probably hundreds of large format (8x10in) negatives and transparencies taken using Finlay color screens.

Collections of negatives are hard to find. We believe that many additional examples remain hidden and have yet to be identified as color photographs. We hope that our work will help this process.

Digital processing of additive color screen photographs (with regular screens)

We started by implementing simple GUI to aid digital registration of the viewing screen to the scan of the negative which developed to a specialized open-source tool (ColorScreen). Presently the tool consists of a queue of image transformations which resembles ones performed by tools for processing raw image data from digital cameras (since modern digital cameras use a Bayer filter which is an additive color screen process):

> scan linearization & channel mixing → sharpening → simulation of negative-to-positive process → viewing screen registration → simulation of viewing screen → demosaicing → recovery of fine details → simulation of color dyes in the viewing screen → brightness, white balance and saturation adjustments

We briefly outline the four steps most specific to processing early color photography.

Viewing screen registration: This step establishes a map between scan-coordinates and screen-coordinates. Scan-coordinates address pixels in the input image. Screen-coordinates are defined in a way so the whole screen can be produced by repeating a tile of size 1×1 (see Fig. 1, right). We found this step to be difficult (impossible to do in general purpose image manipulation programs) since scans are not produced by contact copying and it is often necessary to compensate for several geometric errors. In addition to rotation and translation we also compensate for scaling (caused by slight deviation of the photographic emulsion from scanning plane), skewing (caused by sensor rotation in scanner with linear sensors), scanner lens distortion and perspective correction (since the original may be slightly tilted from the scanning plane). All these corrections were motivated by real problems in the scans. Many scans contain additional errors, most notably caused by imprecisions of the stepping motor moving the sensor for which we have not yet compensated.

Simulation of Viewing screen: Now it is possible to simulate the viewing screen filter placed on the top of the transparency; for every pixel of the input image the RGB color of the viewing screen is determined and these RGB values are multiplied by the luminosity of the pixel.

Fig. 5 - Original scan (left), result of viewing screen simulation (middle) and demosaiced image using bicubic interpolation (right).

***Demosaicing (optional step)**:* While we now can closely approximate the actual additive color transparency, it is difficult to display or print the results since color screen processes relies on high resolution, high dynamic range, and saturated colors (see Fig. 5, left). Because colors in screens are organized in an analogous way as colors in the Bayer filter used in modern camera, it is possible to compute luminosity of each patch (by collecting weighted average of scan pixels mapped to it) and apply standard demosaicing algorithms (such as bicubic interpolation) to obtain a smooth picture with full RGB information for each pixel (see Fig. 5, right). This picture is however not very sharp: 8×8cm Paget plate yields to digital equivalent of 0.6-megapixel photograph which we compensate for later by another optional step with a specialized algorithm.

***Simulation of viewing screen dye color**:* In this step we turn RGB values in the "color profile of the original process" computed earlier into RGB or XYZ values of the output color space.

Towards this we collected published measurements of the spectra of dyes used by some of the additive color processes (Trumpy *et al.*, 2021) and simulate their color when viewed by the CIE 1931 Standard Observer under simulated daylight. Where available we can also simulate the color based on a spectral measurement of reconstructed filters (Lavédrine, 1992), (Wagner, 2006), (Casella and Tsukada, 2012). However, dyes used by individual color screens yet need to be understood.

Digitization guidelines

Precise analysis of the original transparency or negative is possible only when the digital scan meets certain minimum criteria. It is necessary to ensure the following:

Resolution: Since the color screen processes are based on contact copying of the taking screen to the photographic negative their resolution exceeds the resolution of ordinary black and white images. Minimal acceptable resolution depends on the size of color patches in the color screen. It is necessary to set resolution, so that each color patch is at least 2 pixels in diameter (this is approximately 500PPI for Paget and Finlay screens). This is by Nyquist theorem also the minimal resolution. The resulting color quality of our reconstructions noticeably increases until 8 pixels in diameter is met (approximately 2000PPI for Paget and Finlay screens). Where possible, even higher resolution can provide greater confidence in the result.

Sharpness: The optical sharpness of the scans (spatial frequency response, or SFR) should be good enough to render clearly the viewing screen. This is a problem especially for finer color screens (such as Dufaycolors) where at least 3000PPI scans are necessary. We recommend following FADGI 4-star guidelines for SFR 10, SFR50. However, we suggest keeping original files before any digital sharpening is applied. While not implemented yet, sharpening patterns created by color screen differs from usual sharpening and we expect specialized algorithms to lead to better results.

Geometric precision: Since taking screens are quite fine, significantly higher geometric precision is required than for digitization of standard photographic material. It is necessary to test individual scanners and understand their errors and see if they can be compensated for. We recommend producing a detailed documentation of the digitizing setup which included details such as type of device used (single-shot digital camera, digital camera with moving sensor or scanner with moving lenses), lenses used, focus distance, and other details which may affect the geometry of the scans.

Preserving relative densities: To obtain realistic results it is necessary to keep a connection between the densities of the transparency (or negative) scanned and the digital data stored in the scan. This is possible with raw scans but any digital image enhancement (such as dynamic range compression, sharpening, noise removal) is harmful. Where available we recommend saving linear TIFF files in the original profile of the device used to capture the image. A reference scan of an imaging target with known density such as the DT Trans OLT Target in the same capture frame or made in a separate capture with the same settings, can provide further documentation of the density at the time of capture. A proper even-fielding of the capture is also necessary.

Dynamic range: We found that negatives for additive color screen processes are quite contrasty. If the scanner is not able to digitize the full dynamic range of the original, the color information will be damaged or fully lost in highlights, shadows, or very saturated parts of the image.

Infrared scanning: Dyes used to manufacture color screens are transparent in infrared spectra. This makes it possible to use infrared scanning to obtain scan of the original monochromatic transparency which is sandwiched with the color screen and reconstruct original colors of transparencies which faded or got misregistered. Some scanners provide infrared scanning to aid dust and scratches removal of subtractive color films.

***Light and heat considerations**:* While scanners are believed to be safe for digitizing standard color materials, extra consideration should be given when scanning color screens, especially in the infrared spectra. The process required development of very thin filters which easily peel when heated. In fact, while working on the project we damaged one Finlay taking screen which peeled during an experiment which involved about 1 hour of scanning at different settings and resolutions.
We tested scans made with the following devices:
Epson Perfection V850 scanner. This scanner features an infrared lamp, and it is possible to save linear TIFF files using the third-party VueScan software. The optical resolution about 2000PPI-3000PPI is good (but not ideal) for Paget and Finlay screens. It is not good for finer screens, such as Dufaycolors. To our surprise, we found that the dynamic range is not sufficient for significant percentage of Paget plate negatives from the Yevette Borup collection (while it works well for regular glass plate negatives). Finally, we fear that the scanner may be dangerous for scanning materials that involve color screens in infrared due to the heat it produces during slow high-resolution scans.
Nikon Coolscan 9000ED: This scanner has optical resolution close to 4000PPI which is enough to capture screens of Dufaycolor slides. It is limited to 6×9cm originals and shows noticeable stepping motor errors which produce a banding in scans. The depth of focus is small, and it is hard to get sharp scans even with glass holders. This device can produce perfectly aligned RGB and infrared scans, making it easy to analyze Dufaycolor color screens and produce quality renderings.
DT Atom Rainbow MSI Station (with Eureka narrowband multispectral lights and the broad-spectrum high-CRI DT Photon white light source, a Schneider 120mm ASPH lens and a DT Phase One iXH 150mp camera)**:** This setup can achieve enough of optical resolution and dynamic range to obtain very good captures of Paget and Finlay color screen negatives. In addition, the provided software supports export in "linear scientific" files which precisely preserve relative color densities needed to get the colors right. DT Photon light source is 37º C and roughly room temperature at the point the film is held which, together with very short scanning times, eliminates the fear of light and temperature damage. Because infrared imaging is possible, it is also ideal for photographing transparencies. While not tested, we believe it to be an excellent solution for other additive screen processes as well, including Dufaycolor.

Examples

Fig. 6 - Yvete Borup Andrews: Two Japanese Children, Kyoto, First Asiatic Expedition. April 1916. Paget plate negative 4×5in, AMNH Special Collection, 228811 (left) and digital color reconstruction based on the negative. Scanned at 2400PPI using Epson Perfection V850.

Fig. 7 - Probably J.B.S. Thubron and/or his wife Diana, Dufay color transparency, ca. 1930s, 6×9cm. Color calibrated scan (left) and digital color reconstruction based on infrared scan (right). Scanned at 4000PPI using Nikon Coolscan 9000ED.

Fig. 8 - Unknown photographer, Paget lantern slide 8×8cm, ca 1921. Color calibrated scan (left), infrared scan (middle) and digital color reconstruction (right). Scanned at 4000PPI using DT Atom Rainbow MSI.

Conclusion

Additive color screen processes combine a viewing screen (which is not very physically stable) with a black and white transparency (that is very stable). Even if the pictures appear faded, with special image processing it is possible to digitally reconstruct the original colors with a high degree of precision. This processing stresses some qualities of the digital scan (resolution, sharpness, geometric precision, and dynamic range which exceed the needs for digitizing regular black and white photographs). These requirements, however, can be practically achieved with existing scanners.

It is our hope and expectation that this paper, along with the software we will be publishing alongside it, will help unlock the beauty and value of the original color of these collections by lifting the veil imposed on them by time.

We would like to thank to Bertrand Lavédrine for remaks which significantly improved this paper.

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Autochromes from the Bombelli Collection: History and Conservation Survey on an Early Colour Photographic Process

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Abstract

The Istituto Centrale per il Catalogo e la Documentazione (ICCD) is the Italian leading institution dedicated to photography. In 1895 Giovanni Gargiolli founded Gabinetto Fotografico Nazionale (GFN) to document the Italian cultural heritage for the purposes of cataloguing and protection. The Archive counts more than 380.000 black and white negatives in different formats, historical and modern positives, corresponding to most of the negatives, 35.000 colour photographs and 25.000 digital prints. The entire body of records has been originated and increased by photographic campaigns dedicated to the Italian cultural heritage, it is the result of its own production and the acquisition of archives and collections that belonged to photographers and collectors.

Within the colour photographic materials at the ICCD the presence of autochromes is remarkable. The present work shows the result of a recent project that has been carried out at ICCD and has been focused on the preservation and restoration of Autochromes belonging to the Bombelli Collection.

The Bombelli Collection was acquired to GFN in 1971 by the director Carlo Bertelli. The collection of about 20.000 photographs, dating from 1915 to 1950, offers a glimpse into the rarely seen public and private art collections, a fascinating picture of the art market in the North of Italy between the two wars. Photographic subjects are mainly historical, artistic, pictorial from the 1800s and early 1900s.

Among other photographic processes the Bombelli Collection is composed of 2030 autochromes in different formats, mainly on glass plate and rarely on film, protected and sealed with black paper tape. Overall, the plates are in good condition. However, oxidation and silver mirror have been detected, as well as widespread presence of mould. Small point-like spots appear often in correspondence with deposits of dirt; yellowing and sulfuration, up to colour shift sometimes occur on the image layer. Glass plates show signs of degradation, such as abrasions, scratches and in some cases cracks and breaks; films are often affected by curves.

The conservation project has achieved the stabilisation of the materials through cleaning and consolidation treatments, as well as the re-housing of the entire section, currently located in the climate-controlled storage of the ICCD. Moreover, a conservation survey has been carried out shading light on several degradation patterns.

This work will explain the study and analysis of the state of conservation and will give a description of different effects visible on the photographic objects with the attribution to possible causes of deterioration. Preservation methods and housing solutions will be also illustrated along with choices and decisions made during the intervention of restoration and the obtained results.

Keywords: autochrome, deterioration, conservation, photography.

Introduction

The Istituto centrale per il catalogo e la documentazione (ICCD, to make it simpler) was established in 1975 with the foundation of the Italian Ministry of Culture.

ICCD includes the Office of Catalogue, born in 1969 with the duty of managing the general catalogue for the national cultural heritage and defining methods and standards, and the

National Photographic Cabinet, founded in 1895 to produce and collect photographic documentation, constantly increasing and making them accessible to the public. In 1959 it also incorporated the National Aerophotographic Archive.
Today the institute conserves historical photographic collections, and hosts a permanent exhibition of cameras and photographic instruments dated from the half of the XIX century to the 1950's and a library specialised on the history of photography.
The Photographic Cabinet was founded in 1895 on the initiative of engineer Giovanni Gargiolli and became National in 1923 under the direction of his student Carlo Carboni. The goal was to document the Italian cultural heritage for the purpose of cataloguing and safeguarding it.
The archive is composed of:

- 380.000 negatives, black and white (plates and films of different formats) positives, historical and modern, which represent a good portion of the negatives;
- 35.000 photocolors, starting from 1954, composed of slides and colour negatives of different formats;
- 25.000 digital photographs, starting from 2005.

The group of phototypes represents the result of photographic campaigns dedicated to Italian cultural heritage. The documentation therefore regards the entire national territory in all its regions. The negatives, placed in a special deposit, are ordered by format and in chronological sequence. The positives are fixed on cardboards, placed in drawers, and are arranged topographically by alphabetical order.

The Bombelli Collection

Girolamo Bombelli's photographic archive entered the National Photographic Cabinet through various acquisitions. In 1971 on the suggestion of Federico Zeri, who collaborated with GFN at the time, the director Carlo Bertelli purchased the first group of ten thousand plates. Also, the opinion of the Central Inspector prof. Giorgio Vigni was categorical: writing to the Superior Council for Antiquities and Fine Arts, he required to make any effort to acquire that material because it documents a remarkable quantity of Italian works of art. In fact, it appeared in the antique market and soon generated the interest of an American institute with the risk of being sold and exported abroad. Then, another part of the collection was added in 1989 from Luigi Cattaneo, Bombelli's collaborator. The last acquisition dates back to 1992 when new materials were acquired through a deal with Cattaneo's widow.
Girolamo Bombelli was a photographer in Milan between 1920 and 1970. He worked mainly for Alfieri and Lacroix publishers, but also for private customers. His archive at ICCD counts about 20.000 items of various formats and processes, such as black and white negatives and colour screen plates. The photographs document works of art belonging to auction houses, art galleries, publishers and collectors in Milan whose works went lost before, during and after the II World War, works of minor portrait artists active in Milan between 1930 and 1940. Industrial photography, documentation on the artistic production of the Academy of Fine Arts of Brera, landscape photographic campaigns and studio photographic portraits constitute another important set of plates added to the major group (De Marchi, 1991).
Bombelli produced his autochromes during his professional activity when he collaborated with the publishers Alfieri & Lacroix and with numerous collectors, auction houses and art galleries in the region of Milan. Subjects are mainly historical, artistic and pictorial, from the XIX and XX centuries, but also landscapes that offer particularly evocative glimpses through the autochrome process.
The collection counts 2030 items, of which 774 have been treated during a recent project that completed the conservation work on all items. Most of them are autochromes 13x18 and 10x15 cm, on glass plate protected and sealed with a black paper tape. Within this group we rarely

found autochromes and chromogenic positives on film, also mounted between two glass supports or sealed on a protective glass or loose with no protection.

The Conservation Project

Prior to treatments the conservation project started with the assessment of the state of conservation of the plates. Then we proceeded with dry cleaning using an air pump and microfibre cloths. Wet cleaning has been carried out with cotton swabs and hydroalcoholic solution or demineralised water or pure ethanol. Paper labels have been gently cleaned by rubbing the surface with gum, carefully avoiding to apply it over graphite inscriptions.

In case of lifting or detachment of the black paper sealing tape, we applied by brush Klucel G in ethanol at 6%. Where some parts of the tape were missing, we mended it with Filmoplast P toned in black with acrylic. At last, we rehoused each plate in a glassine paper envelope with the indication of the inventory number and we placed them vertically, in groups of about 25, in a conservation cardboard box.

The result of the condition assessment on this portion of the collection gave us the idea of this research. The amount of material and the wide variety of cases encountered during our assessment, some of which we had never detected nor observed before, fed our curiosity and raised new doubts about the causes responsible for the damages or flaws.

So, we started from the comparison between various effects on a large number of plates, then we moved on to the evaluation of the frequency of those phenomena and at last we analysed other data collected and published in the available literature in search of similarities.

Autochrome is the first successful photographic colour process based on the theory of additive colour synthesis. The technique was patented in 1904 by Lumière brothers and the plates were produced and sold starting from 1907. In 1931 the glass support was replaced by cellulose nitrate film and Filmcolor were produced until the 1950's.

Autochromes are positives visible in transparency, constituted by a glass plate covered with different layers: a varnish with adhesive features to hold a thin and regular layer of potato starch grains coloured in green, violet-blue and red-orange. Lampblack was employed to fill spaces between the grains and to avoid possible white light infiltration. These first two layers were then pressed to increase the quantity of transmitted light. Afterwards, a waterproof varnish of cellulose nitrate, dammar resin and castor oil was applied with the aim of protecting the grains from humidity. At last, a fine panchromatic silver gelatine emulsion was added to the surface. After developing, inverting, rinsing and drying, the plate might be coated with a finishing layer of varnish to improve transparency and brightness of the image, and to build another protective layer. Protection was also guaranteed by another glass and a seal with tape.

Autochromes can be observed and identified by examination under magnification using a loupe or a microscope, in transmitted or reflected light coming from different angles. It is recommended to avoid excessive light exposures and to limit heat sources. For our purpose we used a digital microscope with white and UV lights and a light table or a small dimmable light box for the observation in transmitted light. The observation has been carried out on both sides of the plate, through the supporting glass where the colour grain layer is first, or through the protective glass where the varnish or gelatine layer are more evident.

As a result of our observation, we detected different signs of deterioration: physical damages, such as scratches, breaks, cracks, losses and folds of the emulsion; chemical deterioration is the most frequent, particularly silver mirror and oxidation, but also stains and spots. Some plates show mould growth, others are affected by discoloration and fading.

Supporting and protective glass present signs of degradation, surface dirt, fingerprints, abrasions, scratches and in some cases cracks and breaks that may have contributed to further alterations of other layers, such as cracks and deformations of the emulsion layer, and facilitated chemical or biological degradation phenomena of the constituent materials. The protective glass of some autochromes were missing, and the thin gelatine layer often shows curves and folds, up to the complete detachment of some fragments or the loss of significant portions of the image in the most severe cases (Fig. 1).


Fig. 1 - An example of physical alteration


Fig. 2 - Small circular stains.

We often detected wrinkles and folds in the gelatine layer, that we observed at various magnification and under different lights. This kind of damage is provoked by external agents such as temperature and relative humidity.
The small circular stains with wrinkles that we observed in the autochrome in Fig. 2 are probably due to swelling of the gelatine layer. While drying gelatine shrinks, deforms and folds. In the related literature (Lavedrine, Gandolfo, 2013) a similar type of defect is associated with high temperature of the processing baths. So, the alteration would be caused by the manufacturing process.
The most frequently detected chemical alterations concern different types of silver mirroring on the plates, that probably have not received the final protective layer of varnish: the most common oxidation extends regularly from the margins to the centre; in other cases, it is limited to the centre of the plate, may present a regular or irregular pattern; often the alteration is visible along the margins of masks or retouching areas (Di Pietro, 2002). In most cases the colour of silver mirroring is blue in reflected light. However, on the most degraded plates and especially when the phenomenon occurs along the edges of the plate, the colour may vary in shades of green, violet, or bronze (Fig. 3).


Fig. 3 - Effects of silver-mirroring.

It is possible to encounter often small dark and circular stains randomly distributed over the image surface. In the autochrome in Fig. 4 in reflected light the alteration of the emulsion layer is evident: silver mirroring surrounds a small fibre inclusion. Under transmitted light the extremities reveal dark stains. These black spots can be due to imperfections in the application of the emulsion, where dust or particles make difficult a precise and homogenous distribution of the gelatine (Lavedrine, 2009).
Rarely we found white spots (Fig. 5). Under magnification they look transparent, like a loss in the layer of gelatine, while they become yellow (the colour of varnish) when observed in transmitted light. As in the previous example, this is another imperfection related to the distribution of the gelatine. The white stains have a filamentous core while in other cases the core is punctiform.
Sometimes we noticed small white-yellowish spots that show an inclusion in the centre. In the images at high magnification a dark core is visible, as well as the absence of violet, probably faded because of an excess of exposure of the autochrome to light. The violet-blue dye is indeed the most sensitive to light, followed by red-orange and then by green (Penichon, 2013).

Fig. 4 - Dark spots.

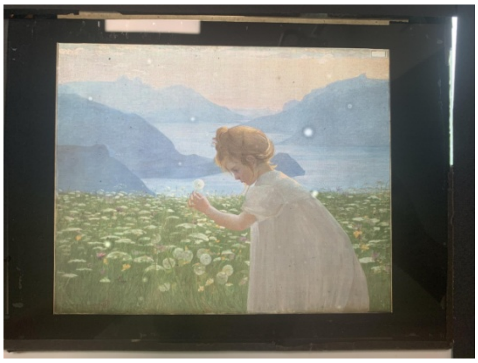

Fig. 5 - White spots.

Orange spots are quite recurring in the autochromes (The Graphic Atlas). The case in Fig. 6 seems particularly interesting because the phenomenon of silver oxidation of the emulsion engages also the adjacent layers. At low magnification we detected cracks in the emulsion and darker edges of the spots. Under UV light they become yellow-green. Orange spots may be caused by silver oxidative agents and are quite common (Lavedrine, 2009). Silver oxidates generating colourless silver ions which migrate to the surface and transform into yellow/orange colloidal silver or silver sulphide.
Green spots can be also generated by the alteration of the emulsion layer, when it gets perforated or abraded during manufacturing (Namias, 1921), or later on because of handling. In correspondence of the damaged area, humidity can reach the coloured grain layer and dissolve the green dye, with the consequent effect of halos and darker edges due to the interaction with red and blue grains (Penichon, 2013). In the autochrome in Fig. 7 a green spot is clearly visible to the naked eye on the right eye of the woman. The stain is formed by concentric circles that surround a small puncture, varying in colour and thickness from yellow-orange to light green, from dark green to blue.

Fig. 6 - Orange spots.

Fig. 7 - Green spots.

Attributable to the oxidative phenomena affecting silver is also a particular type of mirroring characterised by a strong iridescence and amber tones (Fig. 8), always concentrated on the margins, which affects not only the silver component but also the coloured starch layer, which results to be altered when observed under an optical microscope: it is possible to note the absence of the violet dye in the margins of the areas affected by oxidation and the dominant of the red dye in the form of circular spots with a darker core.
Some of the plates affected by strong humidity or water damage show bleeding and discolouration effects. The same areas of colour bleeding were often damaged also by the presence of fungi, visible both on supporting and protective glass, that appeared inactive. Indeed, no fluorescence has been revealed by UV light (Fig. 9).

Fig. 8 - Example of strong iridescence and amber tone.

Fig. 9 - Colour bleeding and mould.

Finally, the results of our observations have been registered in a database (Fig. 10), where each photographic object is described by the related data for their identification (inventory number, format, etc.) and through images taken under different magnification, with white or UV light, transmitted or reflected. We also added a short note on the analysis of the detected phenomena of deterioration.

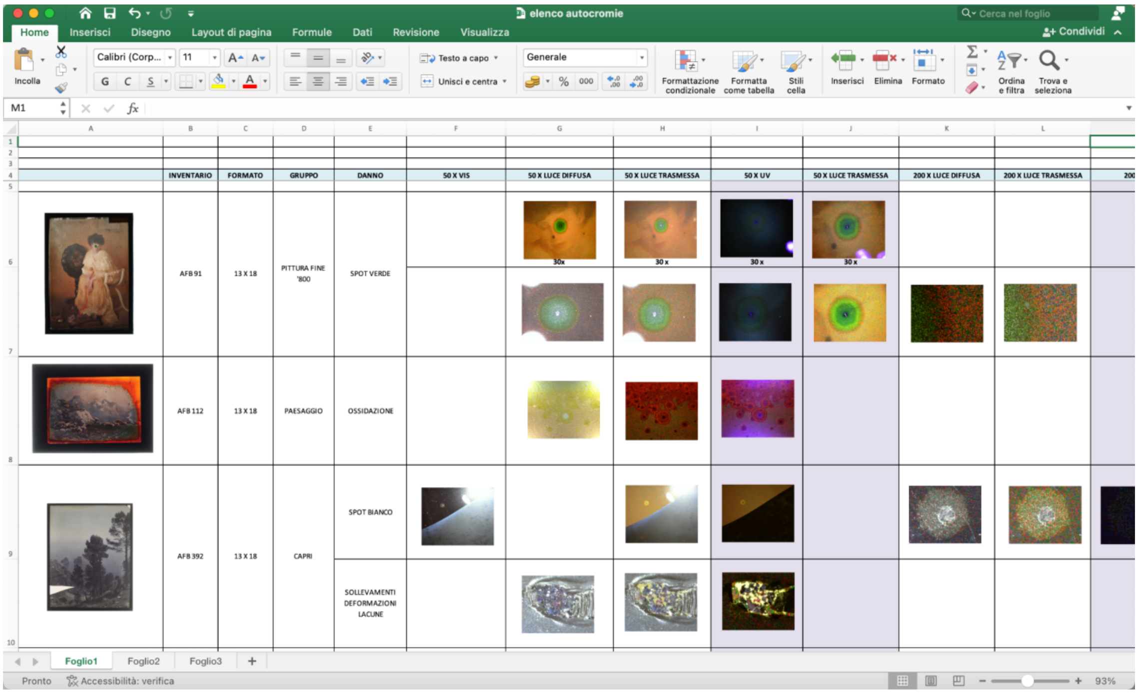

Fig. 10 - The database with a detailed description and images of the alterations under different lights.

Conclusions

In conclusion, our research - which is far from being exhaustive - has the goal to better understand the degradation process of this complex photographic object. With this aim, we would like to build an open access database to be implemented in the future with the contribution of anyone interested in sharing new examples of deterioration.
Indeed, descriptions are not provided for all phenomena in the available literature (Conservation Wiki), which means we need to investigate them more in depth. Also, we will include diagnostic analysis for the identification of dyes and layers composition and we will try to discriminate damages due to bad conservation from defects related to production. Moreover, the entire collection of Bombelli's autochromes has been digitised and it is accessible online on the ICCD website (https://fotografia.cultura.gov.it/iccd).

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Autarchic Colors:
Preserving Gustavo Petronio's "Autarcolor" and the Chromatic Self-Government of the Italian Animated Cinema of the late 1930s

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Abstract

Our presentation is part of a research and preservation project focused on the nitrate film collection of the Italian illustrator and animator Gustavo Petronio, dating back to the 1930s and held by the University of Udine.
In addition to his work as an illustrator and cartoonist, Petronio played a pioneering role in the Italian animation cinema along the 1930s. During the second half of the decade, he designed and produced several animated drawings films, including a series of short advertising and feature films. On 17 February 1939, he patented the *Autarcolor*, a coloring device and system based on the bi-chromatic imbibition technique, already used in photography since 1901, which he applied to a series of commercials (1938-1941). *Autarcolor* (patent number 370.680) should be considered as a pioneering event for the national context, despite having little diffusion due to the introduction of the Agfacolor chromogenic film in 1942 on the Italian market, which made such process obsolete.
Starting from the original film materials (negative and colored positive prints) and several not yet considered primary sources (patents, subjects, scripts, storyboards, and correspondence), we will seek to investigate and reconstruct the historical and cultural framework of the experimental chromatic practices of the *Autarcolor*.

Keywords: Italian animated cinema, Gustavo Petronio, film philology and preservation, advertising film, film color system.

Introduction

The project stems from the discovery of the nitrate films collection of the Italian illustrator and animator Gustavo Petronio, dating back to the 1930s and early 1940s. The film collection was formally donated to the Department of Humanities and Cultural Heritage of the University of Udine on July 14, 2021, by the heirs of Gustavo Petronio[1]. It preserves part of Petronio's filmography and consists of 45 elements on 35mm nitrate films: positive and negative, color and black-and-white, silent, and sound (Table 1).
We focus on two aspects, starting from the original film materials and other primary sources collected and bearing in mind Italy's cultural and political background in the late 1930s. On the one hand, specifically on the advertising-colored films made at the end of the 1930s; on the other hand, on a group of black and white camera negatives found inside a metal film can, dating back to the mid-1930s, and part of an unpublished animated cartoon.

[1] First, we would like to thank Giorgio Oreste Arena, Maria Clotilde Beatrice Arena, Laura Pivetti and Paolo Pivetti.

Gustavo Petronio

Gustavo Petronio was born in Trieste in 1889 and attended the Industrial Schools of Trieste, thus acquiring an artistic-entrepreneurial profile[2]. From 1911 Gustavo Petronio would combine his prolific production of advertising posters with working as a graphic-humor illustrator and cartoonist for the Trieste's best-known satirical magazines.

In 1924, Petronio introduced the Arrigoni Food Company of Trieste to film advertising experience with the short film cartoon series Sor Arrigo, which was a surprising promotional success (Zanotto e Zangrando 1973; Antonini and Tognolotti, 2008). He produced four silent, black-and-white animated episodes to be screened in cinemas throughout Italy.

The success of Sor Arrigo's series of animated shorts persuaded "Corriere dei Piccoli" to extend the character into print media. In October 1929, Sor Arrigo first appeared in the "Corriere dei Piccoli" and would remain an advertising milestone for at least 20 years.

At the beginning of the 1930s, with publicist Brunetto del Vita and well-known illustrator and animator Nino Pagot, he founded the Rex Film (Antonini and Tognolotti, 2008; Montanaro, 2014). He co-produced several advertising films for almost a decade during the 1930s, including a few animated ones[3].

In 1931 Petronio moved his whole family to Milan, where he worked as an author and cartoonist of short humorous comic stories, inventing and publishing new comic characters. From 1934 to 1937, the "Corriere dei Piccoli" published Zimbo's adventures, the successful humorous cycle with propaganda intent featuring his friend Bomba.

In 1941, Anton Gino Domenighini, the owner of IMA (Idea Metodo Arte), appointed Petronio as Technical Director of Production to produce the first Italian full-length animated feature film, *La rosa di Bagdad* (1949), for his artistic talent and long career in animated films, even if he was later ousted from the production. He returned to the production of animation and cartoon films only after the war.

Primary sources – The Gustavo Petronio Film Collection

Gustavo Petronio's heirs donated to the Department of Humanities and Cultural Heritage Studies (DIUM, La Camera Ottica Laboratory) of the University of Udine, the film materials described in Table 1.

They consist of forty-five 35mm nitrate materials traceable to Petronio's filmography, including animated shorts for local companies or vendors dating back to the mid-and late 1930s. Such as the black and white *Una partita ai birilli* (that promotes a local ceramist; Figure 1a), or *Avventura poliziesca* (that sponsors the auto parts business of a certain Annibale Monteverdi; Figure 1b); other are color advertising films for nationally marketed products, such as *Notturno*, an advertisement for the floor wax "Cera Rob" (Figure 1d), or *S.O.S*, that promoted the "Persil" laundry detergent (Figure 1e). Among the collection, there is a fragment of a Donald Duck film from the Second World War series (*The Vanishing Private*, 1942; Figure 1c), other animated fragments not yet identified; and amateur materials that have yet to be identified, in which figures Petronio with his family (0105-FO-0009). The rest of the collection (from 0105-FO-

[2] Gualtiero Scalvini conducted ground-breaking thesis research (*Gustavo Petronio. Grafica Pubblicitaria, Fumetto, Disegno Animato,* 2015) to shed light on the work and figure of Gustavo Petronio, a little-known Italian animator and cartoonist. He tracked down preliminary biographical notes that allow us to contextualize the surviving documents and archival materials retrieved historically. Many of those notes came from other interviews between Scalvini and Gustavo's son, Glauco Petronio. Also, the leading texts on the Animation Cinema history (Rondolino, 1974) or film advertising report only a few biographical notes, the same redundant and sometimes even unreliable news and considerations about him and events related to him. So, we must thank Scalvini for much of the biographic and professional information retrieved about Petronio's life and work.

[3] In an interview with Toni Pagot collected by Camilla Ghirardato on February 17, 1988, Pagot talks about the foundation of Rex film and its closure in the early 1940s. Thanks to Roberto Della Torre for the information provided.

0012 to 0105-FO-0045) consists of silent, camera negative materials, traceable to an unpublished animated cartoon, as we will better understand later.

All the material film artifacts have been monitored, repaired where needed, cleaned, and placed in long-term preservation film cans and storage vaults. We preserved all materials, digitizing them at 4K, including the camera negative ones that had been previously assembled in one single reel.

DAGMA ID	ORIGINAL ID	TITLE	ELEMENT	COLOR	SOUND	LENGHT
0105-FO-0001	1	«Una partita ai birilli» – Pubblicità Ceramiche (a) / [not identified] (b)	Positive	B/W	Mute	40m
0105-FO-0002	2a	«Le trovate di Meneghino» (1954) – Pubblicità di Pierre Faquin&C. 1 di 2	Positive	Color	Sound	60m
0105-FO-0003	2b	«Le trovate di Meneghino» (1954) – Pubbiicità di Pierre Faquin&C. 2 di 2	Positive	Color	Sound	60m
0105-FO-0004	3	«The Vanishing Private» (1942)	Positive	Color	Sound	100m
0105-FO-0005	4	«Notturno» Pubblicità Cera Rob (a) / [not identified] (b)	Positive	Color	Sound	80m
0105-FO-0006	5	«S.O.S.» Pubblicità Detersivo Persil	Positive	Color	Sound	80 m
0105-FO-0007	6	«Avventura Poliziesca» – Pubblicità Annibale Monteverdi ricambi per auto	Positive	B/W	Sound	45m
0105-FO-0008	8	[not identified]	Positive	Color	Sound	20m
0105-FO-0009	7	[not identified]	Positive	B/W	Mute	40m
0105-FO-0010	/	[not identified]	Positive	B/W	Mute	30m
0105-FO-0011	/	[not identified]	Positive	B/W	Mute	30m
0105-FO-0012/0045	/	«Zimbo, Zimba e Bomba nel castello incantato»	Negative	B/W	Mute	ca. 20m each

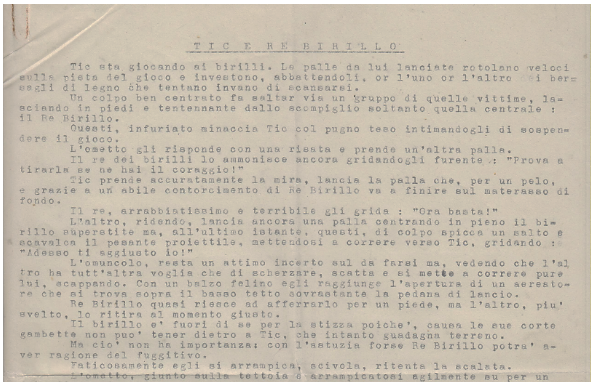
Table. The Gustavo Petronio Film Collection at La Camera Ottica (University of Udine) preserves animated shorts and advertising films, unedited negative materials, a fragment of a Donald Duck film from the Second World War series (The Vanishing Private, 1942)

Figure 1. Frames from five films found in Petronio's Fund, deposited at the laboratory La Camera Ottica. From the top left corner: a) Una partita ai birilli [0105-FO-0001] is a black and white, mute advertise film for "La ceramica". b): Avventura Poliziesca [0105-FO-0007] is an advertisement film for auto spare parts, black and with and sound. c): The Vanishing Private (1954) [0105-FO-0004] is a Donald Duck film from the Second World War series found in the Petronio's film fund; colored and sound. d) Notturno [0105-FO-0005] is the title of Petronio's advertising film for the floor wax "Cera Rob", produced between 1938 and 1941; it is colored with the Autarcolor system and sound. e) S.O.S. [0105-FO-0006] IS Petronio's advertising film for laundry detergent Persil, produced between 1938 and 1941, colored and sound.

Primary sources – A "Rogue" Digital Archive: the Gustavo Petronio Private Fonds

In addition to the film collection, another set of primary sources related to the film production is Gustavo Petronio's private funds, preserving valuable documents such as letters, contracts, and notes.

Unfortunately, the original material belonging to Petronio's fonds and traceable has been dismembered and purchased by various collectors in Italy (particularly between Milan and



T I C E R E B I R I L L O

Tic sta giocando ai birilli. Le palle da lui lanciate rotolano veloci sulla pista del gioco e investono, abbattendoli, or l'uno or l'altro dei bersagli di legno che tentano invano di scansarsi.

Un colpo ben centrato fa saltar via un gruppo di quelle vittime, lasciando in piedi e tentennante dallo scompiglio soltanto quella centrale : il Re Birillo.

Questi, infuriato minaccia Tic col pugno teso intimandogli di sospendere il gioco.

L'ometto gli risponde con una risata e prende un'altra palla.

Il re dei birilli lo ammonisce ancora gridandogli furente : "Prova a tirarla se ne hai il coraggio!"

Tic prende accuratamente la mira, lancia la palla che, per un pelo, e grazie a un abile contorcimento di Re Birillo va a finire sul materasso di fondo.

Il re, arrabbiatissimo e terribile gli grida : "Ora basta!"

L'altro, ridendo, lancia ancora una palla centrando in pieno il birillo superstite ma, all'ultimo istante, questi, di colpo spicca un salto e scavalca il pesante proiettile, mettendosi a correre verso Tic, gridando : "Adesso ti aggiusto io!"

L'omuncolo, resta un attimo incerto sul da farsi ma, vedendo che l'altro ha tutt'altra voglia che di scherzare, scatta e si mette a correre pure lui, scappando. Con un balzo felino egli raggiunge l'apertura di un aereatore che si trova sopra il basso tetto sovrastante la pedana di lancio.

Re Birillo quasi riesce ad afferrarlo per un piede, ma l'altro, piu' svelto, lo ritira al momento giusto.

Il birillo e' fuori di se per la stizza poiche', causa le sue corte gambette non puo' tener dietro a Tic, che intanto guadagna terreno.

Ma cio' non ha importanza: con l'astuzia forse Re Birillo potra' aver ragione del fuggitivo.

Faticosamente egli si arrampica, scivola, ritenta la scalata.

L'ometto, giunto sulla tettoia e arrampicatosi agilmente su per un

Figure 2. An example from the "rouge" digital archive of Petronio's documents. Here is the script and the storyboard of a cartoon non found in the cinematographic collection "Tic e Re Birillo".

Trieste) and other European countries. Especially in Belgium, where the main storyboard of an animated medium-length film was purchased, which was resold on the collector's market after being disassembled into individual pages (Figure 2).

Fortunately, thanks to an Italian collector and historian from Saronno, Samuel Rimoldi, who purchased part of the collection from the Petronio family, it was preserved in digital form. In fact, before dismemberment, the collector took digital photos of it, "building" what De Kosnik (2016) called an unprofessional and "rogue" digital archive. This work lies at the intersection of digital cultural memory, media fandom, and DIY collecting practices. However, it was fundamental because it allowed several primary sources dating back to the 1930s and early 1940s to be "preserved" in this way.

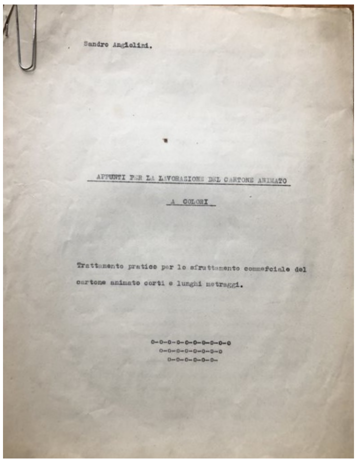
Within this so-called Petronio fund, there are essential documents, such as storyboards and film scripts, as well as some exciting letters (such as the correspondence between Petronio and Domenighini, a letter from ENIC - Ente Nazionale Industrie Cinematografiche), to understanding Gustavo Petronio's pioneering technical-artistic work in the animation film production and coloring systems related to the Milanese and Italian context between the 1930s and 1940s.

Thanks to these materials, we could trace how Petronio had begun work on an important film project a few years before IMA's project for an animated, full-color feature film. Among them, we found a typescript drafted by Sandro Angiolini, titled "Notes for the processing of the color cartoon"[4]; this draft describes and reports practical considerations and operational guidelines for making animated films, with specific reference to color film and in the direction of medium and feature films. Moreover, a correspondence between Petronio and Franco Bianchi, editor of the "Corriere dei Piccoli", who published from 1934 to 1937 Petronio's Zimbo, Zimba and Bomba character adventures (Figure 3).

Despite the permission obtained on December 13, 1935, by Bianchi to use those characters in an animated film, the project, started in collaboration with the young draughtsman Dino Attanasio (Morane, 2006), remained unfinished. However, Petronio's dimension was essentially artisanal. Indeed, his project was missing the coeval grandeur of the Disney factory,

[4] Sandro Angiolini, Appunti per la lavorazione del cartone animato a colori. Trattamento pratico per lo sfruttamento commerciale del cartone animato corti e lunghi metraggi, s.l., s.d.

as well as support from an institution such as Istituto LUCE and the proto-industrial intuition and strength of IMA Film to gather the best Italian animators and drafters of the period for a feature film production.

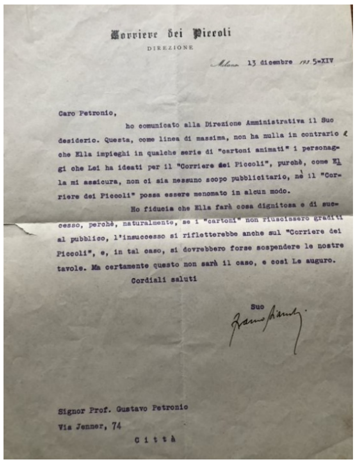


Sandro Angiolini.

APPUNTI PER LA LAVORAZIONE DEL CARTONE ANIMATO

A COLORI

Trattamento pratico per lo sfruttamento commefciale del cartone animato corti e lunghi metraggi.



Corriere dei Piccoli

DIREZIONE

Milano 13 dicembre 1935-XIV

Caro Petronio,

ho comunicato alla Direzione Amministrativa il Suo desiderio. Questa, come linea di massima, non ha nulla in contrario che Ella impieghi in qualche serie di "cartoni animati" i personaggi che Lei ha ideati per il "Corriere dei Piccoli", purchè, come Ella mi assicura, non ci sia nessuno scopo pubblicitario, nè il "Corriere dei Piccoli" possa essere menomato in alcun modo.

Ho fiducia che Ella farà cosa dignitosa e di successo, perchè, naturalmente, se i "cartoni" non riuscissero graditi al pubblico, l'insuccesso si rifletterebbe anche sul "Corriere dei Piccoli", e, in tal caso, si dovrebbero forse sospendere le nostre tavole. Ma certamente questo non sarà il caso, e così Le auguro.

Cordiali saluti

Suo

Signor Prof. Gustavo Petronio

Via Jenner, 74

Città

Figure 3. On the left, typescript draft, entitled "Notes on making color cartoons" edited by Sandro Angiolini. The guidelines suggest a continuous interest in Petronio's professional career to join the production of color films with the production of medium-length or feature films, a common dream of many Italian animators at that time. On the right, correspondence between Petronio and Franco Bianchi, editor of the "Corriere dei Piccoli" who published the adventures of Petronio's Zimbo, Zimba and Bomba characters from 1934 and 1937. On December 13, 1935, Bianchi authorized Petronio to use those characters in an animated film.

Primary sources – The Color Film Process Patent

Last but not least, a third primary source of central importance is the patent for a color film process, currently preserved at the Central State Archive in Rome and later marketed as "Autarcolor"[5].

The patent was registered with the Prefecture of Milan on February 17, 1939, under code 370680 and the name "process for coloring color film and device implementing this process."

A copy of it was found in the Ministry of Corporation, Intellectual Property Fonds at the Central State Archive in Rome after its successful deposit at the appointed ministry office on April 26, 1939[6]. It describes in detail all the elements required to operate the device, with the help of three explanatory drawings, and explains the process in 5 points.

Very briefly: the system was devised to color both-sided sensitized dyed films (most likely Agfa bipack films[7]) that were passed into two separate dye solutions, one blue and one red, respectively.

To obtain the result, the passage of the dye solution to the other side must be totally prevented, spirally wounding the film on a cylindrical holder (The numbers in brackets refer to the numbers in Figure 4; 1) so the edges do not overlap. The cylindrical surface is covered with foam rubber (5) to increase the adhesion between the film and the cylinder. Furthermore, an inner tube (3) under the cylindrical surface gets inflated to expand the area and prevent the adhering surface

[5] Marlazzi, P. (2021) *Hitherto intangible features. Questioni di materialità nella documentazione del restauro del film tra archeologia del reperto, pratiche materiali e ri-mediazione tecnologica.* PhD dissertation, University of Udine.

[6] Archivio Centrale dello Stato, Ministero delle Corporazioni – Ufficio della Proprietà Intellettuale, "Procedimento per la colorazione delle pellicole cinematografiche a colori e dispositivo attuante tale procedimento", Brevetto 370680, domanda n. 1507, 1939 (Gustavo Petronio, Milano verb. 439/508 17 febbraio 1939 ore 10.30, protocollato al Ministero in data 26 aprile 1939). Già datato 31gennaio 1939, con riferimento bibliografico Bollettino della proprietà intellettuale, 1939, nn. 7-8, p. 387, da Friedemann, Alberto, Caranti, Chiara (a cura di), *Dizionario dei brevetti di cinema e fotografia rilasciati in Italia, 1894-1945* (Torino: Fert Rights, 2006).

[7] *Agfa bipack films | Timeline of Historical Film Colors* (no date). Available at: https://filmcolors.org/timeline-entry/1293/ (Accessed: September 21, 2022).

from contacting the dye. Then, the cylindrical support is immersed and dragged, by hand or motor, in slow rotation on its longitudinal axis in a basin containing the (blue) dye solution until the dye bath takes effect. After that, the film gets washed and is let to dry.

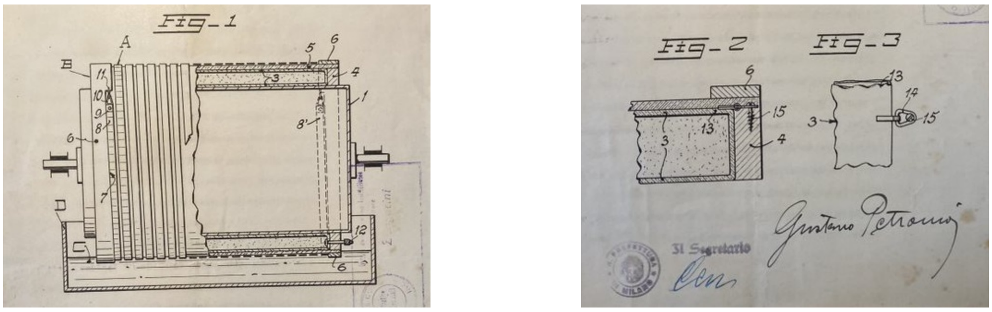


Figure 4. Three explanatory drawings through which the Autarcolor patent details all the elements required for the device to work. Translated from the patent: "Fig .1 shows the film support device, partially in section completed by the basin with the dye solution….A indicates the film, B the supporting organ, and C the dye bath contained by a basin D. [...] Figs. 2 and 3 show, on a larger scale, a corner of the carrier body in a longitudinal section and plan from above, respectively "

Then, the film is wounded on the other side and immersed in the red dye solution.
The device allowed for an effect comparable to trichrome, which he applied to animated short and advertising films between 1938 and 1941 (Figure 5) (Zanotto and Zangrando, 1973). With Autarcolor Patent and Brand, we face the convergence of cultural industry, consumer society, experimentation in color film technology, and aesthetic and ideological self-government.
Thus, with regard to framing Petronio's advertising and short color films of the late 1930s, we should highlight their intrinsic and exceptional novelty, especially if we consider that they came after Royal Decree-Law No. 1389 of September 4, 1938, called the "Alfieri Law" (from the name of the Minister of Popular Culture), one of whose measures was to introduce distribution autarchy.

Figure 5. On the left, a frame example from a positive print of the film «Notturno», preserved in the film collection, produced for the advertisement of "Cera Rob" between 1938 and 1941 and on which Petronio applied the patented method and technique. Element 0105-FO-0005, La Camera Ottica. On the right), an advertise made by Petronio to publicize the 'Autarcolor' brand for his 'color advertising cartoons' and for other animated films.

Petronio's patent recounts an ingenious attempt to further accredit Petronio in the Milanese cultural and industrial scene, particularly at Domenighini's IMA Film. Even if we can appreciate the excellent result that can be achieved with Autarcolor, the dissemination of this technique and, thus, its patent can be classified as a dead end in the history of coloring systems (Parikka, Huhtamo and Los, 2011). In fact, in 1942, Agfacolor arrived in Italy. The German film stock was used for two animated shorts presented at the Venice Film Festival that same year: "Anacleto e la faina"[8] (directed by Roberto Sgrilli for Bassoli Film) and "Nel paese dei

[8] *Agfacolor Neu / Agfacolor | Timeline of Historical Film Colors* (no date). Available at: https://filmcolors.org/timeline-entry/1276/?_sf_s=anacleto+e+la+faina#/ (Accessed: September, 21 2022).

Figure 6. The screenplay (on the left) and the storyboard (in the center and on the right) of the animated feature film that Petronio never edited. The screenplay is titled "Tambo, Timbo e Timba" perhaps because he wrote it before Bianchi of Corriere dei Piccoli authorized its production.

ranocchi" (directed by Antonio Rubino for Incom) (Bendazzi 1988). Their great success, and the fact that the first version of monopack film made processing less complicated, marked a distinct setback for patent research and the production of color films such as Petronio's Autarcolor.

Rediscovering a Lost Italian Animated Film

Thosee mentioned medium-length animated films Petronio never edited turn out to be the point of union between the two primary sources traced. In fact, within what we have called a "rogue" digital archive, we have traced the three-page screenplay and storyboard of "Zimbo, Zimba and Bomba nel Castello Incantato" ["Zimbo, Zimba and Bomba in the Enchanted Castle"] (Figure 6)

The source text that moves Petronio in the direction of transmedia circulation and storytelling of his characters (from comics to cinema) is, in all probability, one of the most successful and celebrated episodes of the period's Disney and Mickey Mouse saga. While Petronio was working on the "Corriere dei Piccoli" with his characters Zimbo, Zimba and Bomba, in 1935, the Florentine publisher Nerbini published "Mickey and Horace in the enchanted castle", based on Walt Disney and Mickey's original "Blaggard Castle" (1932-1933)[9].

Meanwhile, inside the Petronio Film Collection, in a large tin box, we recognized 33 negatives that turned out to be the unreleased cartoon "Zimbo, Zimba and Bomba in the Enchanted Castle" produced by "Petronio-Film" starting in 1935. The negatives inside the box were well preserved, but there are not traces of an original soundtrack (Figure 7).

Figure 7. On the left and at center: Zimbo, Zimba e Bomba camere negatives were found in a large tin in the Petronio Film Collection, at La Camera Ottica; On the right, the frame with the title has been found in the element 0105-FO-0033.

We are currently beginning the reconstruction of the cartoon, starting from the storyboard and script mentioned above, which are crucial to reconstructing the alleged original montage. The first step is to compare the three sources we have traced – the digitized camera negatives, the

[9] Topolino e orazio nel castello incantato (1935), Firenze: Nerbini.

script, and the storyboard – to check for matches, differences, and editing order and then propose a hypothesis of a critical edition of Petronio's film (Figure 8).

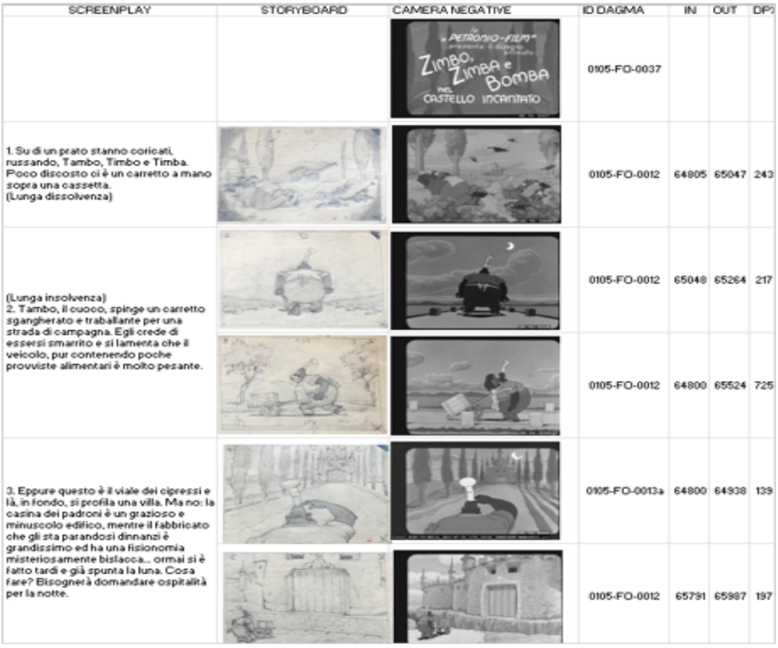


Figure 8. An extract of the first attempt at the film reconstruction. In the first column is the screenplay transcription; in the second one, the drawing in the storyboard and a frame from the camera negatives are in the third column. The other column is the metadata reference for the element and the frame number.

Conclusions

Regarding the unpublished work and the pioneering color experimentations, we are still comparing the three-main sources and searching for new archival materials to obtain more comprehensive documentation and knowledge of the production methods and color processes devised and applied by Gustavo Petronio. Since we still need more documents showing convergence between the animated film project and the development of the Autarcolor process, we are still determining whether the feature film would have on the big screen the same colors of Corriere dei Piccoli. However, finding an appropriate form to make the films, and especially the one featuring Zimbo, Zimba and Bomba characters, available to the public will undoubtedly enhance such valuable Italian cinema and intermedial heritage.

At the very end, to properly frame the artistic and cinematic project conceived by Petronio, it is necessary to refer to the cultural industry of the time, which will have a further impulse around 1935. That year Walt Disney arrived in Italy, invited by the heads of the newly created Fascist film institutions of the time (i.e., Luigi Freddi and the Direzione Generale della Cinematografia founded in the same year). Here, and more generally throughout the 1930s, "local" and "Italian" self-government and *ante-litteram* autarchy unfolded not in opposition to foreign production. Instead, it expanded their first influence and thus nurtured an Italian cultural industry in great ferment. Milan, regarding the animated cinema, was the epicenter of this fruitful contamination network that needs to be deeply explored.

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Chemistry and colorimetry: preliminary investigation on chromogenic motion picture film

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Abstract

Color fading due to the degradation of the dyes is the main concern regarding the conservation and restoration of photographic and cinematographic materials. The intervention on the physical support is most of the time unsatisfactory and insufficient for restoration, which makes the digital conversion and digital restoration the only means to recover the film content. However, missing the non-degraded version of the support, the restoration is still dependent on the subjectivity of the operators that perform the work, even being experts. In this context, colorimetric studies are necessary in order to formulate hypotheses on the real evolution of the degradation process of the dyes as a function of time, with the purpose of obtaining information about the original appearance in respect to the analog materials. Different materials mean indeed different gamuts that lead to different colorimetric coordinates.

The existence of a wide number of different films makes the conservation and restoration process very challenging. Indeed, in the photographic and cinematographic history, not only several supports (cellulose nitrate, cellulose triacetate and polyester) have been used, but also many techniques of coloration or color development (from early cinema to chromogenic motion films) have been employed, as well as many emulsions, dyes and couplers. In this scenario, knowing the material that composes the physical part of the film object could help the experts in all their work, from conservation to restoration.

Unfortunately, the leading production companies have always been reluctant to divulge the compositions of the used compound due to the competitive logic that has always governed the film industry. Moreover, with the decline of the film market, the technical datasheets of films are harder and harder to find. This scenario is even worsened by the fact that a very limited number of studies have been reported on the identification of coloring substances of film materials.

In this work, we want first to make the reader aware of the difficulties and problems we have encountered on this topic, highlighting the importance of scientific research on this cultural object that would otherwise be lost. Finally, we want to show the preliminary results that make Raman spectroscopy, and especially SERS (Surface-Enhanced Raman Spectroscopy), a promising method to individuate the dyes of motion picture films, revealing a new potential application of this technique in the field of conservation science.

Keywords: SERS, Raman, Chromogenic films, Color films, Film dyes.

Introduction

Photographic and cinematographic materials have enriched our cultural heritage over the past century. Unfortunately, with the advent of digital technologies and streaming platforms, analog film support is no longer a technology used today. However, there still exists a wide cultural heritage printed on these supports. Despite being quite recent, film materials rapidly deteriorate in function on the environmental condition when not monitored, depending on humidity, temperature and exposure to light. Besides the degradation of the supports (being them nitrates, acetates, or polyesters), in color motion picture film the color fading due to the degradation of the dyes is the main issue since it can also occur in the dark without the presence of light, making the films stored in our archives and film libraries difficult to preserve.

In this work we consider only chromogenic films which are the most common in the color motion picture field. Before continuing, it is important to recall first the mechanism under the formation of dyes in chromogenic films. In this type of films, there are three separate layers of emulsion, respectively responsible for the development of magenta, cyan and yellow. Each of these layers contains the same developing agent (p-phenylenediamine derivatives) that oxidizes in the presence of light and then reacts with three different color couplers (one for each emulsion layer) to form the dyes as shown in Figure 9. The color coupler can be connected to several functional groups that enhance the features of the dye: *ballasting groups* stop dyes from moving across layers; *leaving groups*, often referred to as coupling-off groups, both optimize the coupling rate and encourage the direct synthesis of the chromophore.

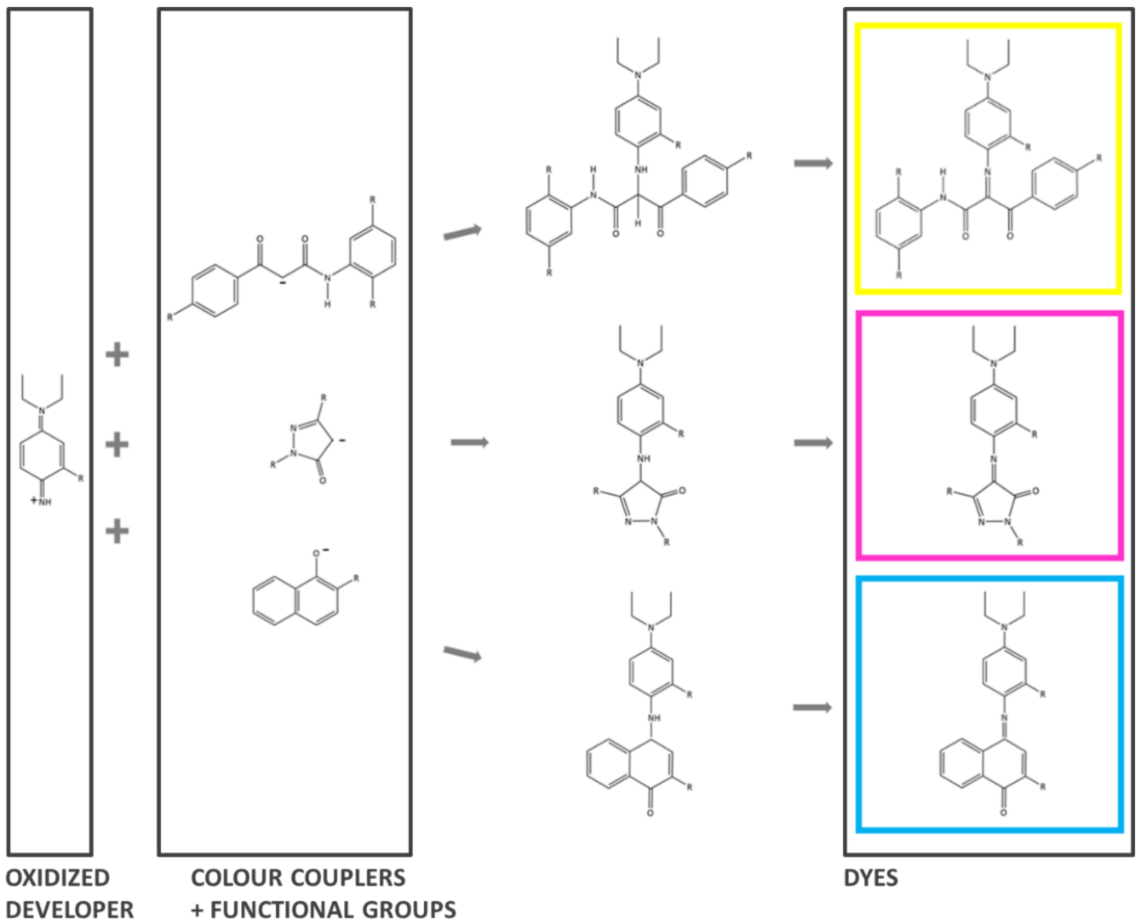

Figure 9 - Schematic representation of yellow, magenta and cyan dyes, resulting from the coupling reaction with benzoylacetanilide, pyrazolone and substituted naphthol type of color coupler, respectively (Silva, 2019)

The type of coupler, ballasting groups, and the developing agent will determine the precise nature of the final dye. The knowledge of this nature is important because the degradation processes that must be taken into account when conserving and restoring the films are connected to the molecular classes to which the dyes belong (Di Pietro, 2007). However, throughout the history of photography and filmmaking, a variety of supports, including cellulose nitrate, cellulose triacetate, and polyester, as well as a wide range of emulsions, dyes, and couplers were indeed utilized. Different materials are used depending on the film type and stock (negative, print, reversal film, and intermediate). However, even within the same category, the chemical nature of color couplers and dyes has changed significantly throughout time for finding dyes with more saturated colors, greater stability, increased grain size and sharpness, and lower costs. It is clear that, in this context, conservation and restoration are made difficult and challenging by the availability of such a wide variety of materials, and scientific support and diagnosis are paramount for the correct treatment and process of this type of cultural heritage.

PhotoFire2 and Colorimetric analysis

The first step we did in this direction is the creation of *PhotoFire²*, an online and open-source database both for cinematographic and photographic films. For a more in-depth presentation of the database and the relative webpage (https://mips.di.unimi.it/photofire/), the readers can refer to (Sarti *et al.*, 2022). The database collects physical data of the film stocks and the technical datasheets released by the producing companies at the time.

This type of information can support the work of the experts both for conservation for choosing the best-storing condition and restoration for obtaining a faithful retrieval of the cultural object to the original materials and period of time. Unfortunately, in the case of digital restoration (that most of the time is the only option left since the original colors cannot be chemically restored), the analog supports are often not even considered by the operator that performs the restoration since the main focus is given to the movie or the photography contents. Nevertheless, every image is the direct outcome of the radiation-matter interaction between the light and the film substance and this means that the fundamental qualities of each image are determined by the physical and chemical characteristics of the material making up the analog stock. Among other features, this can lead for example to a different set of colors that a particular film can or cannot reproduce (i.e. the color gamut).
Figure 10 shows a comparison between two reversal films to give an example: Fujichrome Provia 400X Professional [RXP] by Fujifilm and Kodachrome 64 by Kodak. From the spectral dye density found in technical datasheets of the film stocks (Figure 10a), we were able to extract the color gamut following the Neugebauer and Demichel equations (Oleari, 2015), whose representations in the CIE xyY Chromaticity plot and in the CIE L*a*b* space are reported in Figure 10b. Then, applying the ICC profiles to the same image with an absolute colorimetric intent leads us to the color reproductions in Figure 10c, supported by the ΔE200 map that indicates the pixel-wise color difference between the two reconstructions. With this study, we had proven that the differences in the material composing the films reflect the difference in the color gamut and, consequently, the variation in the appearance of the content printed on the supports.
It is clear that the availability of film technical and sensitometric data will make the preservation and restoration process easier and, above all, more objective. Tone and color rendition errors can be avoided and some film properties and features may be supported by mathematical and physical models. From the film's spectral sensitivity and spectral dye density curves, specific algorithms can be developed not only to reconstruct the color gamut but also to obtain other colorimetric data, such as the creation of a dye degradation model starting from the original data sheets of the film materials. Although some attempts have already been made to achieve this aim (see for example (Gschwind and Frey, 1997; Rizzi *et al.*, 2008)), much improvement is still needed to faithfully reproduce the perception of color film.

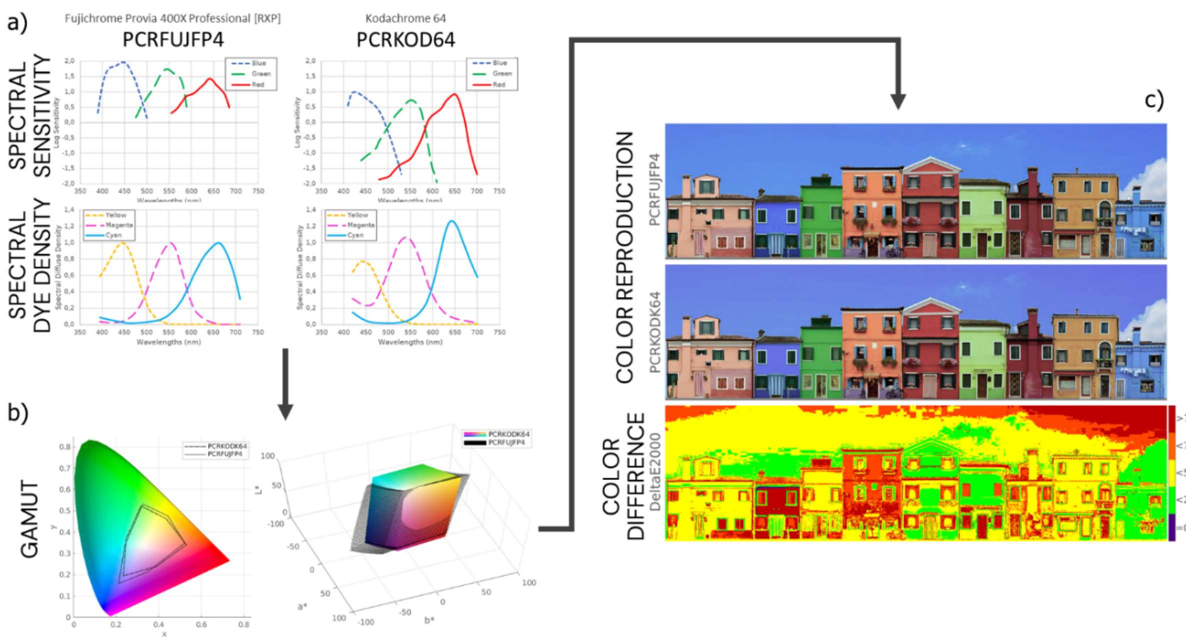

Figure 10 – Comparison of the two reversal film stocks: Fujichrome Provia 400X Professional [RXP] (PCRFUJFP4) by Fujifilm and Kodachrome 64 (PCRKODK64) by Kodak: (a) Spectral sensitivity and dye density, (b) 2d and 3d representation of the gamut of the two films and (c) color reproduction (Sarti et al.*, 2022)*

Up to this publication, we have collected 601 photographic and cinematographic films (233 with technical datasheets) produced by 22 production companies and datable from 1935 to 2018. However, this is an ongoing project and the database is designed to grow.

Chemical analysis

The second step we made in this direction is the chemical analysis. Although there are several books and manuals about the nature of the couplers and developers (see for example (Bergthaller, 2002a, 2002b, 2002c; Rogers, 2007)), the literature search about the analytical technique that can be used to gather information about the molecular structure of chromogenic dyes leads us to only two works: (Di Pietro, 2007) and (Silva, 2019). According to these contributions, there are three different possible ways to examine the chromogenic dyes.

The first one is using an analytical method that allows for non-destructive layer selection, such as confocal Raman spectroscopy. This technique allows indeed to select the depth from which the signal is taken, however the film materials have a high fluorescence response (probably deriving from the gelatin binder and/or impurities within the emulsion layers), which hides the characteristic signals of the dyes and makes ineffective the application of this technique in this field.

The second strategy consists in cutting the film with a microtome for a thin section and then examining the layers separately. Since each layer has a thickness between 5 and 10 µm, the analytical method must have a measurement area with a diameter of 5 µm or less, such as micro-Raman or micro-FT-Raman spectroscopy. This approach is interesting but is limited by the technical difficulty of preparing thin sections in which the layers are clearly distinguishable.

Finally, the last method involves chromatographic separation. This involves a first step in which the dyes are extracted from the emulsion, after which the separation can be done in two ways: in the case of High-Performance Liquid Chromatography (HPLC) coupled with Mass Spectrometry (MS), the samples separated in the liquid chromatography column end directly to the mass spectrometer; in the case of Thin-layer Chromatography (TLC), the isolated compounds can be then analyzed with further and suitable diagnostic techniques such as Fourier-transform infrared spectroscopy (FTIR) or Raman spectroscopy.

Both (Di Pietro, 2007) and (Silva, 2019) conclude that although some of the tested analytical techniques have shown promising results, the identification and assignment of the dyes to a specific family of chromogenic compounds was not possible due to the lack of reference databases, both for Raman and IR spectroscopies and MS.

Based on these considerations, we studied and proposed the application of Sequentially Shifted Excitation (SSE™) and Surface-Enhanced Raman spectroscopy (SERS), whose methodology and results are deeply described in (Longoni *et al.*, 2022). In this work, we inspected a 35mm Fujicolor Positive Film Eterna-CP 3513DI with PET support, printed with the trailer of the animated movie *Happy Feet* (Warner Bros, Burbank, CA, USA, 2006).

The fluorescence emission associated with organic compounds makes standard Raman spectroscopy unsuitable for detecting such molecules. However, the recent introduction of the SSE™ technique has improved the ability to overcome this problem (or at least minimize it) in various analytical fields (Conti *et al.*, 2016). We applied this technique to the three emulsion layers preventively carefully isolated with a scalpel (Figure 11a). Since this technique does not use a conventional Raman spectrometer but relies on a technology that reduces the fluorescence, the results in Figure 11b show flat background spectra with intense and well-defined signals of the dyes, very different from the gelatin spectrum.

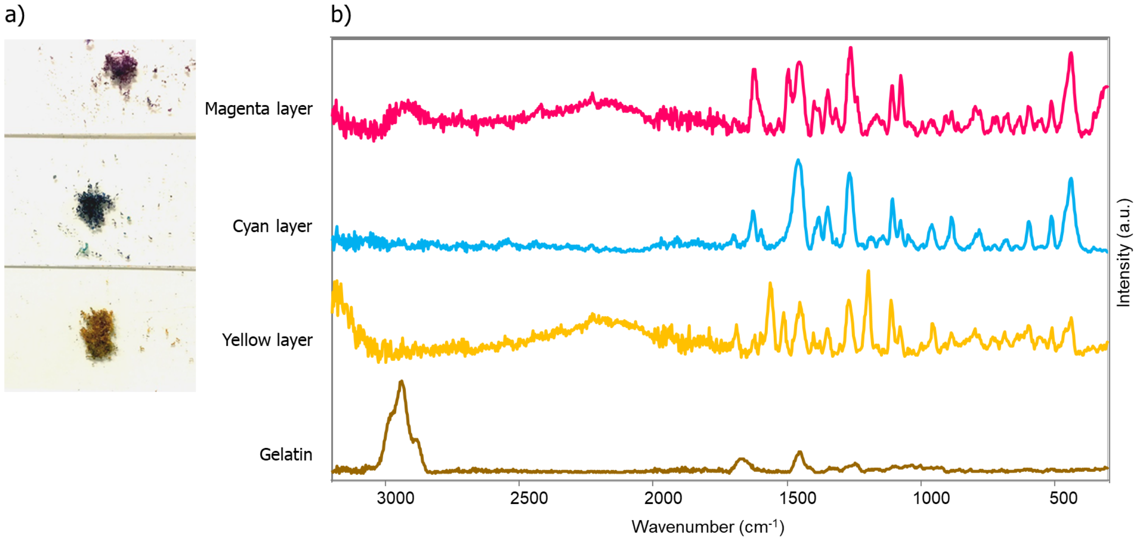

Figure 11 - (a) Powdered cyan, yellow and magenta emulsions of the Fujicolour Positive Film Eterna-CP 3513DI and (b) their SSE™ Raman spectra compared with the gelatin spectrum.

Furthermore, we wanted to investigate the SERS response of the dyes. Although, as far as we know, nobody ever applied it to film materials, we believe that this technique could have enormous potential in this field. The great enhancement of the Raman signal (up to a factor of 10^8) when the analyte is absorbed or is in the proximity of a rough metal surface (Fleischmann, Hendra and McQuillan, 1974) allows the detection of analytes even at very low concentrations, meaning that a small quantity of dye is required. Moreover, the quenching of the fluorescence photons emitted by organic molecules determines its wide application in the analysis of natural dyes in cultural heritage in the past 20 years (Pozzi and Leona, 2016). First, we used TLC to isolate the dyes (Figure 12a), which were then scratched away from the plate and prepared for the SERS analysis by extracting the analytes by sonication in ethanol. The spectral responses were compared with those of three reference compounds, previously reported by some of us (Longoni *et al.*, 2022). These compounds, whose structures are shown in Figure 12b, derived from the most common families of couplers used in films: a *substituted phenol* for cyan; a *benzoylacetanilide* for yellow; and a *pyrazolone* for magenta. Figure 12c shows the SERS spectra of the three dyes and the three respective reference compounds. Due to the aforementioned functional groups, the film dyes are significantly more complicated molecules than the synthesized ones, as demonstrated by MS analyses (data not shown). Nevertheless, the similarity of the spectral patterns in terms of signals due to the molecular core indicates that the film dyes are members of the same chemical families as the reference ones.

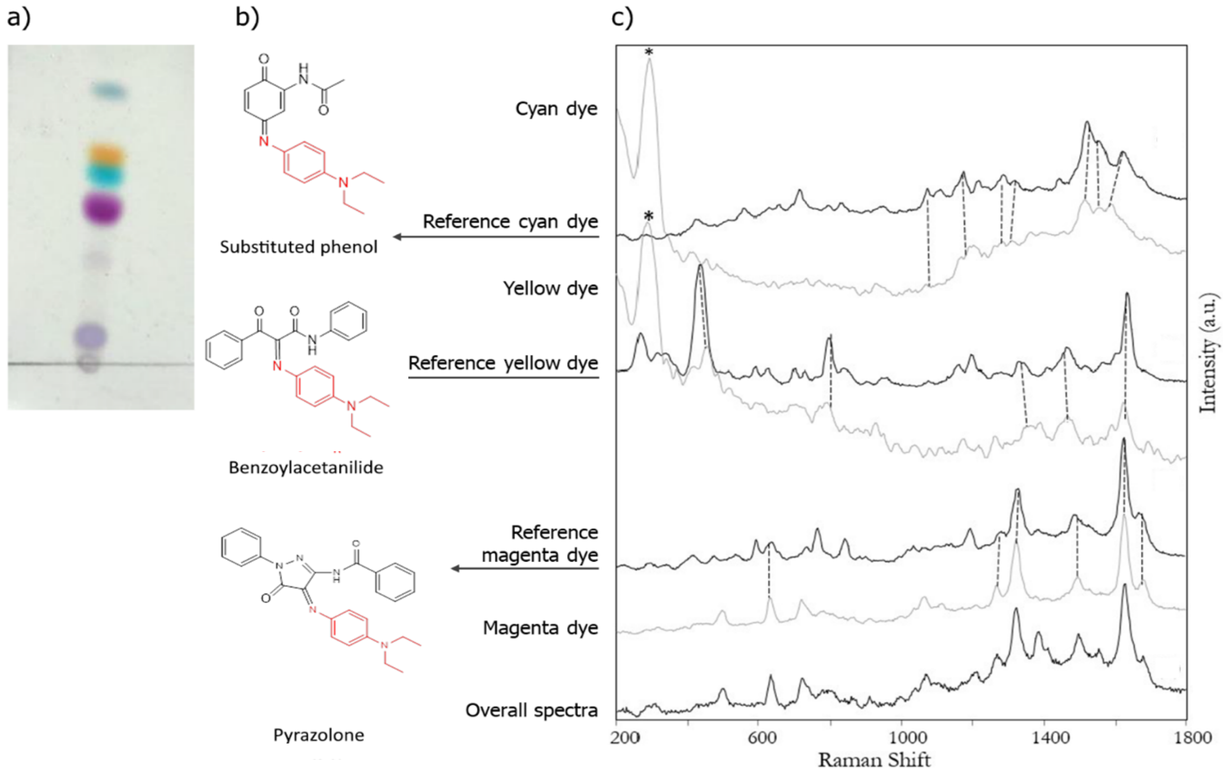

Figure 12 - (a) TLC of the Fujicolour Positive Film Eterna-CP 3513DI; (b) synthesized molecules for dye references; (c) SERS spectra of the isolated cyan, yellow and magenta dyes and the respective reference molecules (Longoni et al.*, 2022).* The asterisk marks a band involving the Ag nanoparticles.

Conclusion

The purpose of this contribution is to increase awareness of the value of scientific data among film experts and restorers since it is essential for proper conservation and faithful restoration of the film content to the time it was printed. To overcome the need for technical information, we introduced PhotoFire2, our scientific, open-access and growing database.

From the colorimetric point of view, we have demonstrated how variations in the dye density of the films affect the color gamut and the appearance of the final image.

From the chemical point of view, Raman spectroscopy and especially SERS, as opposed to other molecular analysis methods like infrared spectroscopy, in the preliminary investigations had revealed itself as a promising method to individuate and classify the dyes of motion picture films. In future developments, we want to deepen these investigations, including a wider range of reference compounds, representative of additional coupler types and dyes extracted from films of various brands and dates.

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Non-invasive microanalytical studies of hand coloring materials in 19th-century daguerreotypes

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Abstract

The color was a characteristic expected from the early photographic images; however, daguerreotypes failed to register them. After 1840 several coloring methods were developed to complement the realistic effect of the Daguerreian images. Historical records are rich in information regarding the methods to add color to daguerreotypes, yet, the scientific studies of hand-colored daguerreotypes are limited in the literature. This work aims to contribute to the knowledge of those techniques by studying nine colored daguerreotypes with a non-invasive methodology based on XRF, micro-Raman spectroscopy, and micro-FTIR in reflection mode. The results revealed the different colorants and some of their mixtures employed by the colorist.

Keywords: daguerreotypes, pigments, Raman spectroscopy, XRF, FTIR.

Introduction

In the 19th century, the daguerreotypes were compared by François Arago to butterfly wings because of their fragility, iridescence, and precision; the only thing missing was color. Since the early years of the daguerreotype era, there was a particular interest in colored images, a characteristic that the contemporaries expected from the newly available photographic images. To solve this inconvenience, painters and photographers took advantage of the experience of miniaturists and hand-colored the Daguerreian images. As early as 1840, painted layers application to daguerreotypes became common, several manuals were published (Fisher, 1994), and a new market of ready-to-use materials was developed (Lehmann, 2015). Historical records – rich in technical information – offer an insight into the painting materials and their diverse methods of application exploited by daguerreotypists and colorists. The most common way was to apply pigments bound with gum arabic, using stencils to delimitate the area to hand color.
Despite the consistent amount of published literature regarding the history, the physical and chemical properties of the daguerreotype plates, and their conservation, little is known about the practice of hand-coloring, particularly from the analytical point of view (Ferguson, 2008; Kozachuk *et al.*, 2018). Identifying pigments and dyes plays an important role in the conservation of daguerreotypes, since some, mainly lake pigments, are prone to photodegradation, and their presence may have an impact on the outcome of the cleaning procedures, for example, when laser cleaning is involved(Turovets, Maggen and Lewis, 1998). Very few studies report on daguerreotype painting materials characterization with a multi-analytical approach. Golovlev et al. (Golovlev *et al.*, 2003) deduced the presence of Prussian blue ($Fe_4[Fe(CN)_6]_3$), iron oxide (Fe_2O_3), and barium white ($BaSO_4$), based only on the elemental LIBS results. Kozachuk et al. (Kozachuk *et al.*, 2018) found Cochineal lake in the flesh tones using SEM-EDS, FTIR, and SERS spectroscopies, the latter enabled by the intrinsic nanostructure of the daguerreotype plate.
In this work, we report on the results obtained with non-invasive techniques, such as X-ray Fluorescence (XRF), micro FTIR in reflection mode, and micro Raman spectroscopies, on nine 19th-century hand-colored daguerreotypes from the Fondazione Alinari per la Fotografia (FAF) and the Chiesa-Gosio collection. Our goal was to identify the painting materials and compare our findings with the available literature.

Results

In the majority of the daguerreotypes analyzed, single red pigments were applied to the flesh tones, which was a common practice recommended by the manuals available at the time, the higher amount of pigment was generally applied to the lips and cheeks of the portrayed person. Two colorants were primarily used for this purpose, cochineal lake, and iron oxide. Only in one daguerreotype a less common pigment, vermillion, was identified. In very few cases, a mixture of these red colorants with Prussian blue was used to obtain a natural hue of the flesh tones. Moreover, in the hair of one of the portrayed women, indigo and an organic yellow colorant not fully identified was applied.

Regarding the garments of the portrayed person and the objects present in the background (e.g., cushion, tends), Prussian blue, bismuth white, cochineal, red oxide, and shell gold were identified. In some cases, a mixture of more than one colorant were applied.

The identification of the coloring materials impacts the research regarding the technology employed in hand-coloring daguerreotypes. So far, the data available is limited. In this work, we have found pigments reported previously in the literature, for example, cochineal lake or bismuth white (Swan, 1989; Kozachuk *et al.*, 2018); however, some of the colorants, such as indigo or vermillion, and the mixtures identified were not confirmed analytically before.

Conclusions

The results allow us to identify nine different colorants: Prussian blue, cochineal lake, barite, bismuth white, indigo, vermillion, iron oxide, yellow organic pigment and shell gold, and their mixtures. These materials were employed to color both flesh tones and the garments of the portrayed individuals. Besides, in one of the daguerreotypes studied we found a synthetic organic pigment probably applied to recover the coloration of the image. These results complement the knowledge of colored daguerreotypes available in the literature and increase the number of colorants, mentioned in the historical records, identified in daguerreotypes. More detailed information can be found in the Special Issue "Colour Photography and Film: Analysis, Preservation, and Conservation of Analogue and Digital Materials (Quintero Balbas *et al.*, 2022)."

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Authenticity.Art– a new way of preserving and protecting art

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Abstract

The platform Authenticity.Art collects certificates, technical details, condition reports, assembly instructions and other information that is useful for the provenance, preservation and protection of artworks. This data is stored with the highest standard of security using near field communication and blockchain technology, thus protecting it from data loss, forgery or any kind of alteration. This is a new and innovative way of preserving and protecting tart and could set a new standard for art documentation for generations to come.

Keywords: art reproduction, art preservation, restoration, provenance, NFC, IPFS, CID, hashing, blockchain, smart contract, data security.

Introduction

To precisely understand how an artwork was created, can be restored or even reproduced, there is a profound need for a clear, safe and dynamic documentation of any information serving the preservation of the artworks authenticity. What is the title? When did production take place? How was it assembled or is it to be displayed?
Today's art forms and materials show a higher sensitivity to external influences than artworks from past decades. In the last fifty years contemporary artists have shown a much bolder use of materials than ever before. Modern art such as Dieter Roth's *Chocolate Gnome* or Marc Quinn's *Self,* which consists of a bust made from his own frozen blood, pose new challenges concerning preservation, due to the perishable nature of its matters (Waters, 2015). Photographic materials also show changes in appearance as soon as 20 years after manufacturing, due to light exposure and different environmental influences.

Reproduction and Authenticity

In her report of the symposium "Reproduktion in der Fotokunst" (2014) Rita Hofmann discusses the challenges of preserving and restoring contemporary artworks and its meaning regarding the definition of an original. A photographic work might change in colour and contrast over the years, at a certain point making reproduction the only means to restore it to its "original" form. Considering that the materials used are part of the historical reference of an artwork, changing materials and technologies can force a decision between keeping the materiality of the artwork or the aesthetic (Hofmann 2014; Matyssek 2010).
Rightfully so, Hofman (2014) poses the question whether a reproduction replaces the original, should be considered a reprint, or a new work of art. A question that emerges in the wake of art history's reverence for the European canon and its masters, where a reproduction is often dismissed as a mere copy. However, in Chinese culture an original is defined by endless process and change, as opposed to a singular act of creation. In a complete inversion of the relationship between copy and original, the copy becomes an original itself, as Philosopher Byung-Chul Han explains in his book "Shanzhai: Dekonstruktion auf Chinesisch" (2011).
A new definition of originality might not be a single print of a photograph or the finished painting, but the sum of all material forms of the artwork the artist has authorised. For a photograph that includes the negative, original data, test prints, notes, editions, and furthermore the artistic intention, production and all compromises made to realise the artwork (Müller, 2020).

This view is supported by lawyer Winfried Bullinger (2018) who, in an article published in Rundbrief Fotografie, explains that originality is not synonymous to singularity but refers to the direct relationship between artist and artwork. This leads to a need for a clear artist agreement concerning changes or occurred damages to help guide restorers, conservators and collectors, especially after the artist's passing.
Hofman (2014) also describes the precise documentation of any reproduction, replacement and change as imperative for any museum institution, restorer, art historian as well as art dealer, and argues it should be communicated as part of the artwork. Subsequently, to maintain art in its originality means to document as meticulously as possible.
The problem is: digital forms of data change, and physical data carriers are not built to last forever. Up till today, there is no international standard for art documentation and ensuring the authenticity of provided information. Documentation itself is only a solution as long as preservation, legitimacy and access to it is ensured.
Authenticity. Art is a project by **Youngji Bae, TapIt Inc. and Markus Paul Müller** that aims to solve that problem and change the way we preserve and protect art in the future.

The future of art preservation and protection through blockchain technology
Authenticity.Art is a web based platform that helps collect and safely store information that is imperative for the provenance, preservation and protection of the work of art.
As we explain in the introduction, the problem of preserving contemporary art for future generations to come has many aspects. It is as much a matter of precise documentation as of data sustainability, safety and proof of authenticity, while taking into account the different needs of its stakeholders. Authenticity.Art approaches these problems in different ways.

How to access Authenticity.Art
First it provides access to important information, using a near field communication technology (**NFC**) Sticker attached directly to the art piece (Fig.1).

Fig. 1 – Authenticity.Art's NFC Sticker

NFC is a safe and convenient technology for bidirectional transfer of encrypted data by short proximity using a messenger/reply concept. Data attributed to the Sticker can be retrieved by an NFC compatible device sending a message to the Sticker, and the Sticker sending a reply back to the device (Goje et al., 2007). In this case, one can retrieve information about the artwork by holding a smartphone to the Sticker and the Sticker sending back the Authenticity weblink attributed to the artpiece (Fig. 2).

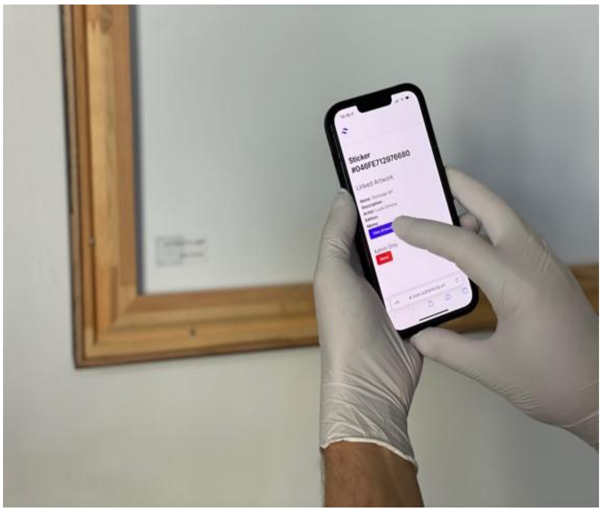

Fig. 2 – Accessing Authenticity.Art's website

This weblink gives access to certificates, technical details, condition reports, assembly instructions, artist agreements, artist estate and any relevant data that stakeholders of the artwork have secured via Authenticity.Art's website.

Data safety and durability

Authenticity.Art's interface is designed to enter different kinds of data in a convenient and sustainable way. It provides templates for important art related data, as well as the possibility to create customized templates to fit the user's needs. The text information provided by the user is automatically transformed into a **JSON** file format (Fig.3). JSON is not dependent on a specific programming language and has hardly changed in the 21 years it has been used. Due to its simplicity, it can be understood by computers and humans alike, leading to a rise in popularity among web developers making it the "main format for exchanging information over the web," (Pezoa et al., 2016). JSONs simple structure assures its longevity and readability for the future.

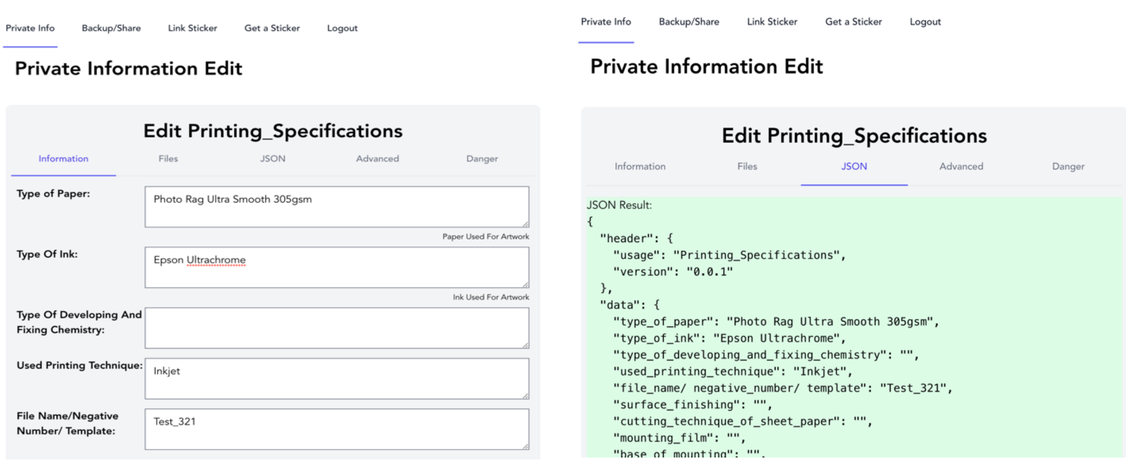

Fig. 3 – Entered information is transformed into a JSON file that can be read by humans and computers alike.

Another measure to assure the safety of data entered into Authenticity.Art is adding image files such as documentation of damage or printing files to the JSON file by referencing an **IPFS**

Content Identifier (**CID**)**. IPFS** is the short form of interplanetary file system and is a peer-to-peer decentralized storing system for digital data**.**
When data is entered into the IPFS, a resulting CID is returned by which said data can be identified by. The CID is composed of a code indicating a hashing algorithm, and the corresponding hash of the data.
The CID can be compared to a digital fingerprint that is determined by the numerical information of the picture file (Fig. 4). Because of their hash-based structure, content cannot be altered without also modifying its CID, making it immutable and self-certifying (Trautwein et al., 2022).

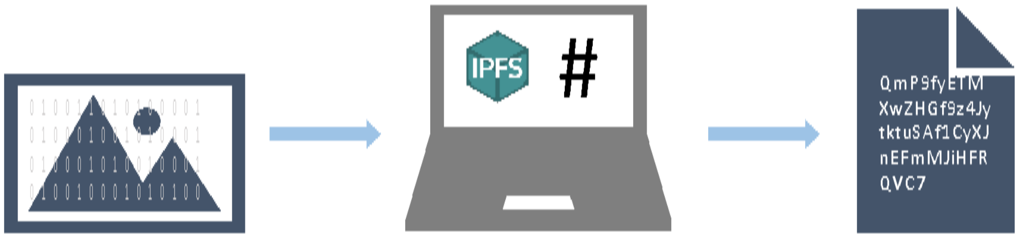

Fig. 4 – Numerical information of an image uploaded to IPFS is returned as a CID

Typically, files added to IPFS are identified by the hash or CID and then immediately made public. In the case of Authenticity Art, a CID is created without sharing the file itself on the IPFS, and instead the CID is published in the JSON file with the written information. This gives the user full control over the access of the file, because the file itself stays with the user by default but its authenticity can be understood through the assigned CID if necessary.
As mentioned, if a single pixel of a picture is changed, it will have a completely different CID, which in combination makes sure a final printing file can never be tampered with or a fake file be presented as an original (Fig. 5).

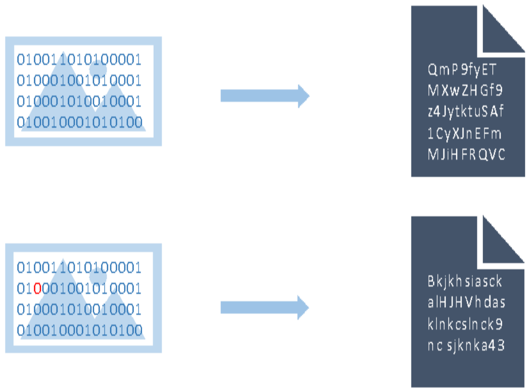

Fig. 5 – Changing a single pixel of an image will result in a completely different CID

Saving data to a blockchain

To add another layer of security, the CID corresponding to the published JSON file containing the image can be saved on a **blockchain smart contract**, ensuring the authenticity and preservation of the entered information concerning the artwork.
A smart contract is computer code which executes the agreement made by two parties and is stored on a blockchain-based platform (Levi, S. and Lipton, A., 2018). It is a digital way of legitimising information, as a common written contract would. At Authenticity.Art it can be understood as a program that has the ability to store files and define how those files are saved, how they can be retrieved and keep them safe forever.

Conclusion

We have entered an age in which data is referred to as the new gold. When confronting fleeting and fragmented data, the question of how to store and manage data streams appears of immense importance.

Authenticity.Art's level of data security and flexibility in adding different types of data to the platform provides new ways of preserving art, not only in its materiality but as well the artist's intention and legacy. By bundling all relevant data on an artwork in one place, the artist gains full control of the way the artwork can be reproduced or restored and offers a solution to securing the artist's intent and estate.

The web based platform makes it easy to publish any information the artist deems important in a durable fashion through its high level of cyber and data security. By publishing entered information on a blockchain smart contract, the artist can claim authorship and endorse the authenticity of said information.

This means the artist can protect a work of art by legitimising exact instructions for reproduction, damages, display, intent, estate handling and whatever other information needs to be preserved for different stakeholders beyond the artist's lifespan.

For restorers, conservators and art researchers it means exact and authentic information of materials used, exposure to light and humidity, documented in chronological order. Storing all this data in one place can be of great help to further understand art decays biggest influences and how to improve preservation in the future.

For collectors, institutions, art handlers and insurance companies it resolves the problem of preserving an art piece within the rights granted by its creator and how to handle the artwork after the artist's passing. It gives insight into how to assemble the artwork, its history of damages, restoration and instructions for safe transportation in case it needs to travel for an exhibition or other purpose.

Overall, but especially for smaller galleries, estates or studios, Authenticity.Art solves the problem of creating, maintaining and securing a personal database by offering a platform, storage and the technical know-how for preserving art related data for generations to come.

The technique behind Authenticity.Art has the potential to change not only how we secure art data but how we protect art from fraught, theft and unrightful duplication.

It could be used by police forces to identify stolen artwork and its rightful owners by simply scanning the Authenticity.Art Sticker. Appraisers would be enabled to secure their assessment of the artwork on a blockchain, making forgery of their work impossible.

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Oil photography: A color-photographic technique, with no discoloration, unique to Japan in the nineteenth century

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Abstract

In Japan, in the second half of the nineteenth century, combining the techniques of photography and oil painting introduced from the West and the art of mounting for the appreciation and conservation of oriental paintings and calligraphic works, a technique commonly known as "oil photography" was developed. The technique, patented by Azukizawa Ryoichi in 1885 (18th year of Meiji), contained two types of "oil photography": one on a glass plate, and the other on paper. In this study, we try to reconstruct the technique of oil photography mainly on paper, based on the description of the patent written in an archaic Japanese language.

Keywords: oil photography, forgotten photographic techniques, Azukizawa Ryoichi, Yokoyama Matsusaburo, Japanese paper, East Asian binding, conservation.

Introduction

In the second half of the nineteenth century in Japan, oil photography, which is a unique color-photographic technique, was invented by combining oil painting and photography techniques. The purpose of this technique was to enable the coexistence of preservation and colorization by coloring a photograph. This was detailed by the photographer Azukizawa Ryoichi (1848–1890) who applied for a patent in 1885. Two types of oil photography techniques are noted in the patent for which Azukizawa applied. The first involves creating the work on a glass plate, while the second creates it on paper. Both are photographic techniques that express a high level of preservation with no discoloration in that the underside of the image is colored with oil paints in comparison to the previous method in which photographs were colored with watercolor paints applied on the top of the photograph. However, Azukizawa died only five years after obtaining the patent, and oil photography became a forgotten technique.

Unfortunately, after approximately 120 years of production, the physical deterioration of oil photography works is becoming more and increasingly noticeable. Accordingly, we have clarified information related to materials and structure, which is essential to explain the conservation and preservation of the valuable oil photography pieces to be found in various regions of Japan.

Oil photography technique—Glass plate

In February 1882, photographer Yokoyama Matsusaburo, Azukizawa's teacher, was the first to enjoy success in creating work on a glass plate. In March 1882, the Hakodate Newspaper noted that Yokoyama saw a color photograph on a glass plate that Suzuki Shinnichi, a photographer acquaintance of Yokoyama, who had traveled to the United States in 1879, had purchased in the United States. Subsequently, Yokoyama completed oil photography creations after studying the technique for 11 months.

The detailed statement of techniques of the patent by Azukisawa related to glass plate oil photography methods may be explained as follows:

1. Polish the glass plate with alcohol and stick an albumen print or a lithograph on it using glue. The glass surface and the image layer surface are applied facing each other.
2. After it has dried, remove the reverse paper surface of the image layer by rubbing it with your finger, leaving only the thin membrane of the image.

3. Paint over with a solution that consists of turpentine oil with a little castor oil and leave it for 24 hours.
4. After removing the oil with a cloth, use oil paints to color the underside of the image layer.
5. After drying it thoroughly, apply the varnish. Finally, the colored photographic image can be viewed from the glass side.

The glass plate oil photography involves scraping away the supporting paper from the back of the albumen print stuck on the glass plate, leaving only a thin image layer. Subsequently, the image layer is colored with oil paints from the underside. Therefore, it imitates the crystoleum technique used in the West. However, Yokoyama Matsusaburo's private collection (Takada Nana Collection) of glass plate photographs (Fig. 1), includes several unfinished pieces at stage 2, in which only the thin albumen print image layer is left (Fig. 2). Moreover, there are partially completed photographs at stage 4 which have been partly colored with oil paints from the underside of the albumen print stuck on the glass plate (Fig. 3). Their existence has been our inspiration for the following explanation of oil photography techniques using Japanese paper.

Fig. 1 - glass plate oil photography (Takada Nana Collection)

Fig. 2 - peeled albumen print image layer (Takada Nana Collection)

Fig. 3 - colored albumen print image layer (Takada Nana Collection)

Oil photography technique—Paper

Oil photography created on paper applied traditional Japanese binding techniques that were skillfully employed in different ways to suit several kinds of Japanese paper with differing characteristics. A detailed statement of the techniques of the patent related to paper oil photography methods is as follows:

Preparation

After Polishing the glass plate with alcohol, water-spread the paper. The paper is thin and transparent like ganpi paper, which is a Japanese paper made from Diplomorpha sikokiana of Thymelaeaceae. It is a luster paper and half-transparent due to its thin and short fibers. The paper is water-spread onto the glass with a solution of distilled water mixed with a small amount of ginger juice.

1. Clean the glass plate with alcohol.
2. Prepare ginger juice. Put a small amount of ginger juice in distilled water.
3. Scrape with fingertips a handmade ganpi paper (Japanese paper) and thin it down, until it becomes transparent.
4. Stick the transparent ganpi paper onto the glass plate using the aqueous solution of ginger.

Make a water–wax paste by taking the wax secreted by the larvae of the Chinese wax scale insect (Ericerus pela) that live as parasites on privet, applying heat to melt it, and solidifying it in cold water. Then, wrap the wax in a silk cloth and rub the paper stuck on the glass

In addition, rub the surface of the photograph or lithograph with the water–wax paste. Thereafter, water-spread the surface of the photograph or lithograph onto the thin, transparent separating paper, which is a piece of ganpi paper inserted in between to prevent the pieces from rubbing against each other, that was stuck onto the glass previously.

5. Spread the wax on both the ganpi paper and on the image surface of the photograph (Fig. 4).

[Fill the unevenness of surface with the wax pulverized into fine powder through a silk cloth.]

Fig. 4 - wax on ganpi paper

Fig. 5 - Photo pasting with water

6. Match the image surface of the photograph and the ganpi paper, then paste them together by wetting them with water (Fig. 5).
7. Fix the four sides of the photograph with slips of paper glued with starch paste.

Elaboration

After it has dried, rub off the paper of the underside with your fingertips, exposing just the thin membrane of the image. Then, apply over the latter with a solution of turpentine oil and a little castor oil. Leave it for five days.

8. Scrape away with fingertips the back paper of the photograph (Fig. 6), leaving only the image layer (Fig. 7).

[Limit the extent to which the light and shade of the photograph can be recognized.]

Fig. 6 - scrape away with fingertips the back paper

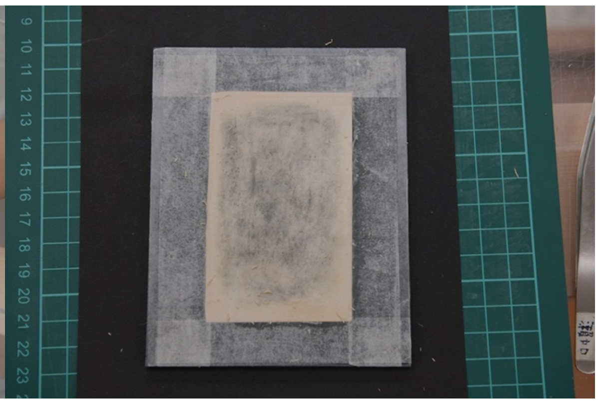

Fig. 7 – back paper in the process of being peeled off

9. Spread the oily liquid based on turpentine essence with a little castor oil (Fig. 8).
10. After about five days of natural drying, wipe off the excess oil.

Coloring
After wiping away the oil with a cloth, use oil paints to color the thin membrane of the image from the underside. After coloring the image, stick it onto tengujo paper, which is a durable and extremely thin Japanese paper made from paper mulberry [scientific name is Broussonetia kazinoki × papyrifera] that has long, thick fibers). Once the paint has dried, apply the varnish.

11. Color from the back of the image layer (Fig. 9).
12. Start coloring from the finishing part, contrary to the normal procedure of coloring (Fig. 10).

[The technique of coloring is like that of animation cel production (Fig. 11). For example, usually the entire face is primed first, and then the eyebrows, eyes, and mouth are painted on top of that. However, in the oil photography process, the eyebrows, black eyeballs, and red lips must be painted first, then the entire face.]


Fig. 8 - spread the oily liquid


Fig. 9 - the reverse of the image layer


Fig. 10 -viewed from the glass side

13. Retouch the parts that you want to stand out, such as outlines and highlights (Fig. 12).


Fig. 11 - retouch


Fig. 12 - shows stand out outlines and highlights

14. Stick onto a tengujo paper (Fig. 13) while the oil-painted layer is still wet.


Fig. 13 - tengujo paper


Fig. 14–press the paper

15. Press the paper, adapting it to the unevenness of the surface of the oil-painted side (Fig. 14).
16. Apply varnish when the paint has almost dried.

Finishing
Using torinoko, which is a type of Japanese paper similar to a thick ganpi paper, or another type of paper, or a cotton cloth to perform the backing process. After it has dried, peel it off the glass to complete the work.

17. Reinforce with a torinoko paper blackened with Japanese ink, gluing it with starch paste (Fig. 15).
18. After drying, cut off the four sides and turn it over, making the image layer face up (Fig. 16).
[Remove the ganpi paper remaining on the surface.]


Fig. 15 - reinforce with a torinoko paper


Fig. 16 - cut off four sides and turn it over

19. After being removed from the glass and the ganpi paper (Fig. 17), the image is further affixed to a backing paper and can be appreciated as a colored photograph (Fig. 18).

Fig. 17–paper oil photography

Fig. 18–paper oil photography

Conclusion

In this study, we tried to reconstruct the technique of oil photography, based on the description of the patent, and we succeeded in reconstructing some parts of the production process of this technique. We believe that the results of our study would, henceforth, help in the conservation and restoration of oil photographs. We also hope that our achievements will contribute to the study of art expression, the history of photography, the history of art, and the historiography of the mid-nineteenth century.

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Painting or Photograph? - Study of Avant-Garde photographer Noboru Ueki (1905-1992)

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Abstract
Japanese photographers, since the Meiji period have explored different processes which involved applying inks or colours on photographic prints. Before the appearance of colour photography, there were a handful of Japanese photographers experimenting with colours. Among them, we focused on Noboru Ueki (1905-1992), who was active during the divergent era of Japanese photography. During 1950s, he started to produce a group of hand coloured gelatin silver prints. Here we will report our research on his painted photographic works in historical and technical aspect. This study can lead to understanding more deeply about his works and an interaction between Art and Photography which made a significant turning point in the history of Japanese photography.
Keywords: hand coloured photographs, painting materials, technical analysis, Noboru Ueki, Japanese photography.

About the photographer: Noboru Ueki

Noboru Ueki was born in Fukuyama-city, Hiroshima Prefecture to a father who ran a photographic studio. He soon aspired to work in a larger city and left for Kyoto in 1927 when he was 22 years old. There, he found Ryutaro Kohno Photography studio and started to work as an intern retoucher. At Kohno's studio, he learned retouching and bromoil process, which was popular in Japan at that time. After he got his first Vestan camera (which is a small version of Vest Pocket Camera by Kodak), he started to take photographs outdoors, capturing local people working in the fields.

In 1934, he opened Noboru Hiroi Photo Studio (taking his wife's family name) in Kyoto, subsequently changed the studio name to Noboru Ueki Photo Studio in 1946. 1930s was a very rich era of Modern Photography in Japan, with several groups and communities of photographers flourished across the country. He was a member of two important associations; Nihon Kōga Kyōkai (Art Photography Association) and Bijutsu Bunka Kyōkai (Fine Art and Culture Association). He started to publish his works in the periodicals after the war and became an active member of the group, Kyoto Photo Society (K.P.S.). Although Ueki had always been a commercial photographer, he became more and more interested in making Avant-Garde works using techniques such as photomontage, multiple exposure, deformation (making deformed image manipulating lens and mirrors during shooting or by bending the paper during exposure), soft focus, eventually leading to hand coloured works in 1950s. He was one of the first photographers in Japan after the war to pursue colour as an important factor for creating Art photography and produced a substantial number of hand coloured works.

Ueki's works

His earlier works from the 1930s represent Pictorialism style and some are called Zokingake. Zokingake is a Japanese word meaning dusting off or wiping with a cloth (Teraoka, 1933). Few Japanese photographers practiced this technique, which is said to be derived from oil and bromoil print. Zokingake is based on gelatin silver print. You first apply oil paint to the entire surface (sometimes thin oil is applied before the paint) then wipe off the highlights and mid tones with a cloth. It is not building up images by application, but removing the paint to get the desired finish. Zokingake's softly focused, airy images were popular, especially still life and landscape which had similarities to Japanese traditional paintings. Unlike bromoil process

Zokingake does not have a bleaching step and usually black or dark brown colours were used, which sometimes makes process identification difficult.
After the war, Ueki became interested in hand colouring the print. His background as a retoucher made him confident to retouch or finish the prints, adding his hand works to produce unique images. Ueki, according to a published review, exhibited 20 hand coloured prints in the 1948-49 exhibition; Jiyu Shashin Bijutsuten (Free Photographic Exhibition) in Kyoto and Osaka (*Shashin to Gijyutsu*, 1950). They were vividly coloured photographs depicting abstract and constructive forms. Over 40 of Ueki's hand coloured gelatin silver prints exist, mostly in the collection of Tokyo Photographic Art Museum (Fig.1). These works are crossing borders of photography and painting, evidence of him exploring and creating surreal, abstract images, using monochrome photographs as a base. He was playing with light and shadows, forms and colours.

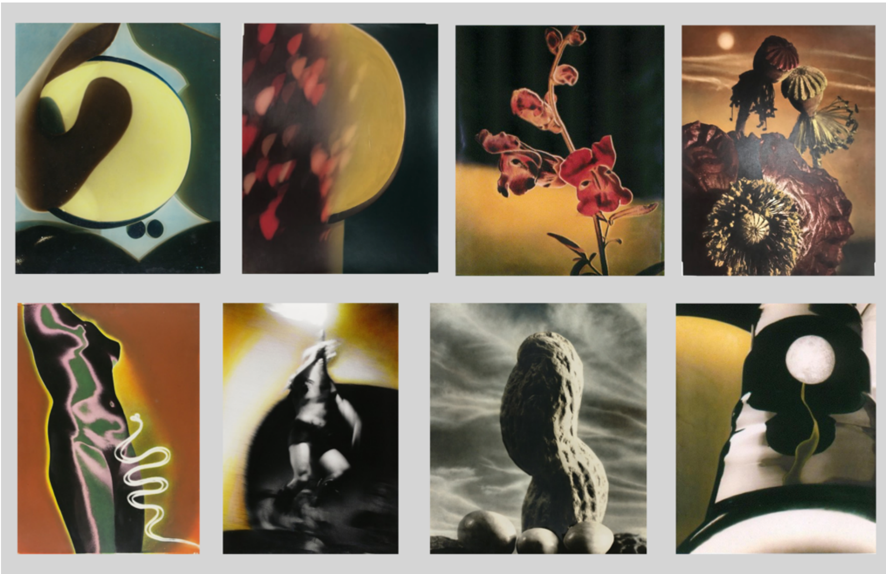

Fig. 1 - Ueki's hand coloured photographs from late 1940s - 1955
Collection of Tokyo Photographic Art Museum

Colouring materials for photographs

Painting on photographs in Japan goes back to hand coloured albumen prints from the Meiji Period. It may be, that from this tradition, Japanese photographers had been proactive towards coloring or retouching prints often combining different techniques from different fields of Art. There were citations of Japanese photographers using Eastman Kodak's Velox Transparent watercolor stamps and Oriental Transparent Oil Colours in late 1920s (*Fototimes*, 1929). These were used over oil based medium such as turpentine oil or linseed oil. It is important to mention that bromoil was extremely popular in Japan during 1920s and 30s and bromoil inks and medium by Sinclair and Roberson from U.K. were available at that time (Ishida, 1930). Faber's Polychromos colour pencils were imported by Konishiroku (Konica Corporation) in 1931. Eastman Kodak's Transparent oil color was probably imported as well around the time when it was on the market.

Investigating Ueki's technique

His choice of photographic paper

By going through the collection of Ueki's hand coloured works at Tokyo Photographic Art Museum, we have noticed he used several different photographic papers for his hand coloured works. As he published his works in the periodicals in 1950s, we were able to gather some information. We confirmed from the periodicals that some of the chlorobromide paper Ueki

used were: Yae G, Somei FS, Somei GS (all three by Rokuosha / Konica Minolta, a manufacturing division of Konica, producing dry plates and papers); Bellona F2 and Bellona F3 (both by Fujifilm); Gekko V2 (Mitsubishi), (*ARS Camera Annual*, 1950. *Photography Shinsei Shashin Zasshi*, 1950).
On verso of some of the prints, in addition to his signature, he has handwritten information about the camera he used, aperture, and the type of paper. The papers he used could be loosely grouped into two types; smooth, slightly glossy, light weight paper and grained, luster, medium weight paper (Fig. 2). The size of the hand coloured works are varied but most of them are approximately 56 x 46 cm.

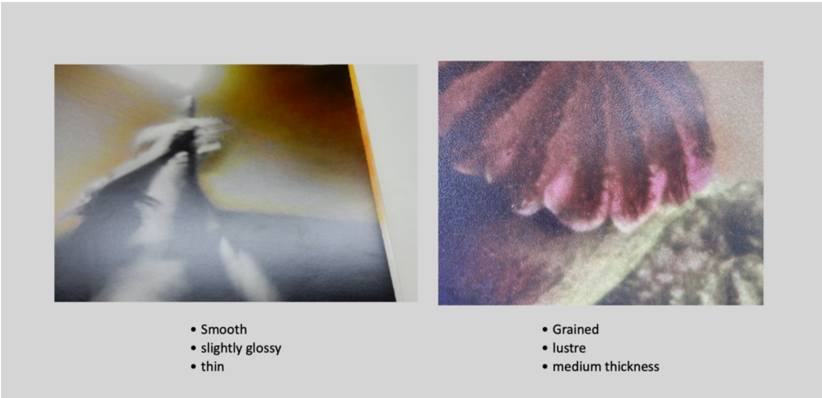

Fig. 2 - Types of photographic paper Ueki' used

Painting medium and application
At a first sight, it is difficult to see brush strokes or signs of painted surface on the works. Vibrant colours are blended into the surface of the print. He layered and mixed the paint, sometimes outlining the forms in the image and emphasizing highlights. There are some works which have unpainted sections, however, they appear natural with no awkwardness. Under the microscope, the surface appears different according to the types of the paper and how the colouring was done. The grained paper has the paint in the texture of the rough surface. The smooth paper has the colours staining the surface. It is probable that he selected specific painting medium for different papers to achieve the effect he desired. Some works he used coloured pencils and a blending stump scratching the painted surface to create a special effect. For large sections, he probably used cotton or soft cloth to apply paint with adding touches using fine brushes, just as he would do Zokingake or retouching. Although he often coloured the entire print, occasionally photographic image appears through thinly and subtly painted surface.

Scientific analysis of paints
We investigated the paints of selected works of Ueki in the collection of Tokyo Photographic Art Museum by non-invasive methods. We used a handheld XRF spectrometer (Thermo Niton XL3t) and a portable FTIR spectrometer (Bruker Alpha) in external reflection mode.
XRF showed similar results at all colors in different prints. As shown in the figure (Fig.3), the detected elements were almost the same in different colors although the ratios of peak height varied (the figure shows only the low energy area where peaks with significant intensity were obtained). These detected elements, such as barium (Ba), calcium (Ca) and silver (Ag), might be present in the original print, but not in the paint. The peak height of iron (Fe) at green color was higher than other colors. It implies the presence of Prussian blue and was confirmed by FTIR showing a characteristic sharp peak of cyanide stretching around 2090 cm^{-1}.

FTIR was used to obtain information about organic materials present in the paints; their colorants and binding media. Obtained reflection spectra were interpreted by comparing with databases, such

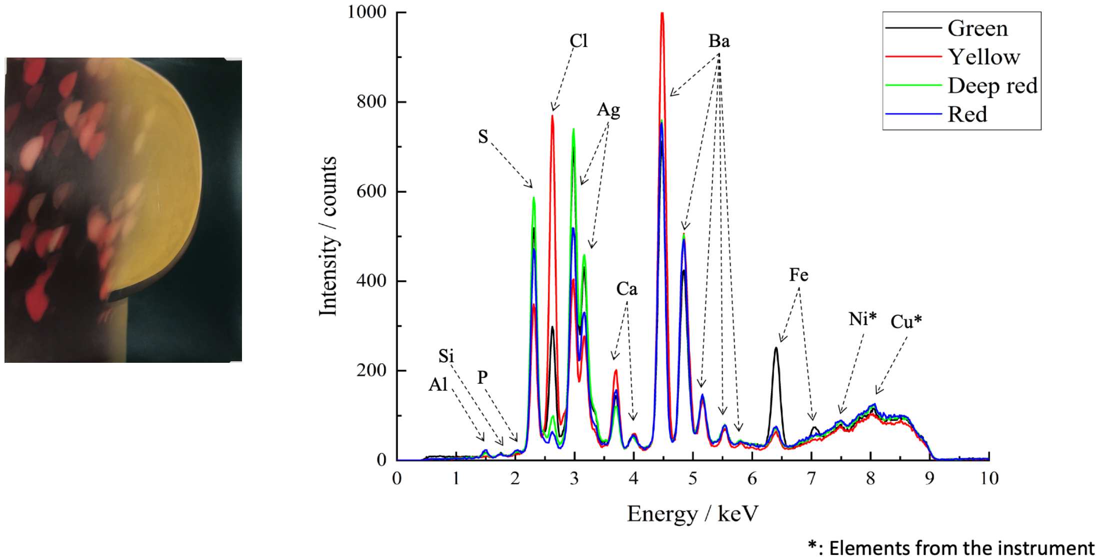

Fig. 3 -XRF Spectrum of a work: Reference no. 10007668

as IRUG Spectral Database, applying Kramers-Kronig transformation as needed. At most of the colors, we obtained spectra with the peaks (2920, 2850, 1740, 1460 and 1170 cm^{-1}) which could be attributed to fatty oil, but this interpretation is not definitive as the overlapping peaks from other materials prevent the comparison of other spectral features. In some parts, the presence of protein was also suggested, but it was not clear if it is present in the paint or if it comes from the gelatin layer of the original photograph. As for the colorants, in addition to the confirmation of Prussian blue, by FTIR we could find the use of alizarin crimson in red paints, which is a lake pigment produced with synthetic alizarin (color index number PR83).
After the above-mentioned non-invasive analysis, we could obtain a minute fragment of green paint from the back of one print. We are planning to perform GCMS analysis to investigate further its binding media.

Conclusion

Ueki's hand coloured photographs were made during a short period of time just before colour photography became common. He chose specific images for this group and he took advantage of combining of several techniques he acquired throughout his career in order to make a group of highly artistic works. We will continue our research and hope to explore his painted photographs as well as unravel the diversity and richness of photography in Japan during this period.

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Photographic Films on Chemically Unstable Plastic Supports: Identification, Care & Optimal Practices for Lebanon & The Middle East

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Abstract
Films on chemically unstable plastic supports are a common problem within the field of photograph conservation worldwide. Practitioners working in Lebanon have specific circumstances to consider and obstacles to overcome. This paper provides an actionable plan for deteriorating photographic films that is specifically relevant to the needs, obstacles, and limitations within the Middle East region. Existing literature was applied and evaluated by conducting a survey to investigate photographic film collections housed within the Arab Image Foundation in Beirut. Through quantitative methodologies, and using scientific tools, data was gathered to determine the types of film bases available, and the overall condition of the collections. Actively deteriorating samples were used to devise a plan for cold storage using locally sourced materials and equipment wherever possible. The results showed that the majority of the films are deteriorating, putting into question the damaging effect of current storage conditions and the critical need to implement cold storage on a large scale. A plan was devised but so far has proven extremely difficult to implement due to the ongoing crisis in Lebanon.

Keywords: cellulose nitrate, cellulose acetate, films on chemically unstable plastic supports, film preservation, preventive conservation.

Introduction

Photographic films on chemically unstable plastic supports are very common within collections worldwide and their deterioration is one of the most difficult and challenging problems in the field of photograph conservation (Lavédrine, 2009, p. 256). The case is no different at the Arab Image Foundation (AIF), where over 100,000 photographs in storage are photographic films on plastic supports, with hundreds of thousands more still awaiting proper preservation work. These supports include cellulose nitrate and cellulose acetate, which due to the inherent instability of their plastic film base undergo an irreversible deterioration (Valverde, 2005, p. 4). This inherent instability affects black and white and colour films alike.

Cold storage is the only way to slow down deterioration of photographic films, and conservation literature recommends using photo-safe materials that will not interact with the films and cause further damage over time. These materials, however, are not produced in Lebanon and are very difficult and expensive to purchase. This has always been the case but more so since 2019 as Lebanon entered one of the most severe economic collapses in the world since the 1850s (World Bank, 2022). This paper aims to bridge the gap between the optimal standards found in literature and the lack of resources professionals in Lebanon face by providing a sustainable and accessible plan for deteriorating photographic films on plastic supports that is specifically relevant to the needs, obstacles, and limitations within the Arab region. This research was conducted as part of my dissertation when I was a Preventive Conservation MA student by distance learning at Northumbria University from 2017 to 2019. At the time I was also working in the preservation department at the Arab Image Foundation. Since then, the AIF has been trying to implement cold storage for its collections but this has proven difficult given the ongoing economic crisis in Lebanon since October 2019.

2019 Survey at the Arab Image Foundation

In 1997, The Arab Image Foundation was established as a non-profit organization in Beirut as a response to the lack of efforts in preserving the region's photographic heritage. For over 25 years, the AIF has been collecting and caring for photographic collections from the Middle East and the North Africa region, as well as the Arab diaspora. The overall number of photographs acquired through the years is estimated at 600,000. Around half of which still await proper cleaning and rehousing. At the time of this research in 2019, 170,000 items had been cleaned, rehoused, and moved to storage where they are kept at a temperature ranging between 18-22°C and a relative humidity (RH) between 35-45%. The survey conducted included all the collections in storage containing photographic films.

Fig. 1 The cool storage room at the Arab Image Foundation in Beirut.

The cool storage room has very limited space *(Fig. 1)*. The AIF is situated in an apartment building, and the storage area consists of a 11m^2 room which, according to the original floor plans, used to be the bathroom. Because of the space limitation, once a collection is properly rehoused and ready to be moved to storage, it would not be assigned a single box. Instead, the photographs are assigned boxes depending on their support and their format. Thus, each collection is stored in several boxes and each box will likely contain several collections. The first step was identifying the types of supports available in storage. Looking at the AIF database, I found that photographic films make 86% of items in storage and amount to 146,000 items out of 170,000. Around 600 samples were surveyed, and the following data was gathered for each:

1. Physical features: this included the film format, the image type, and tone
2. technical information: markings on films such as nitrate or safety film, notch codes, and the date.
3. Support assessment: which included the identity of the film base judging from the physical features and technical information, the level of deterioration based on visual examination, and the level of acidic emissions using A-D strips.

Fig. 2 Conducting the acidity test with the A-D strips.

A-D strips, or acid detector strips were developed by the Image Permanence Institute to assess the condition of cellulose acetate films. They are small strips of blue papers, which when in contact with a film base will turn to shades of green or yellow in the presence of increasing amounts of acetic acid (Image Permanence Institute (IPI), 2022). Each sample was left at room temperature for at least 24 hours to

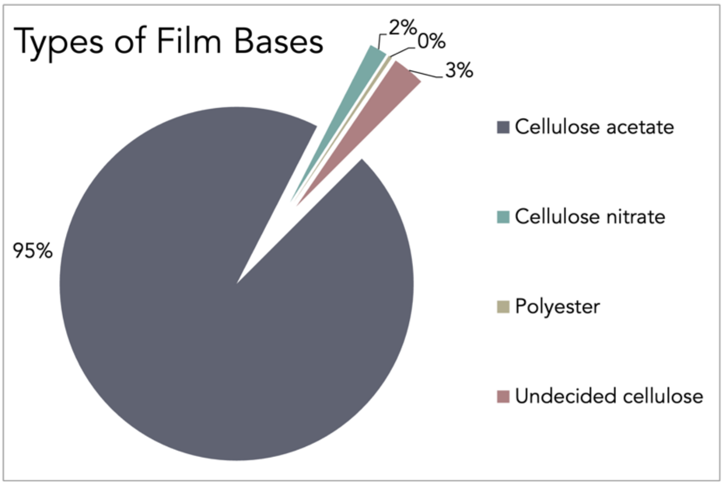
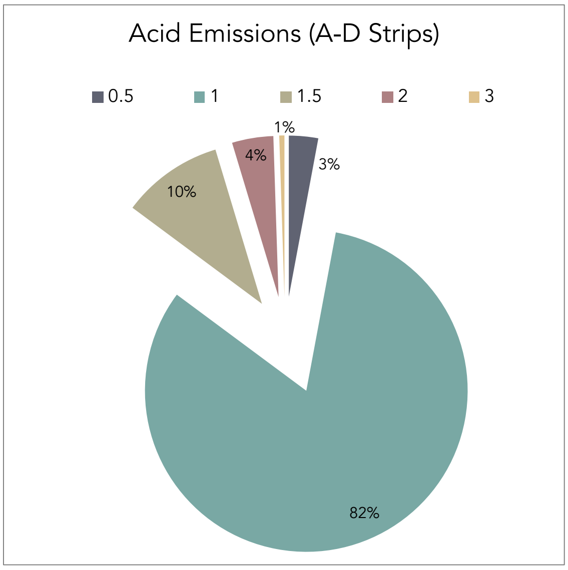


Fig. 3 Overview on the types of film bases identified among the samples observed during the survey.

ensure a proper reading *(Fig. 2)*. Samples that were suspected to be cellulose nitrate were left for a week as the user guide mentions that the strips will take longer to react with cellulose nitrate bases. Each sample was tested using a polarizing filter test, which shows green and red interference patterns on a polyester base.

Based on the survey questionnaire, 95% of the samples were identified as cellulose acetate, with a minor percentage, about 2%, of cellulose nitrate, 3% of undecided cellulose bases, and a very marginal percentage of polyester as only two negatives showed interference patterns on the polarization test *(Fig. 3)*.



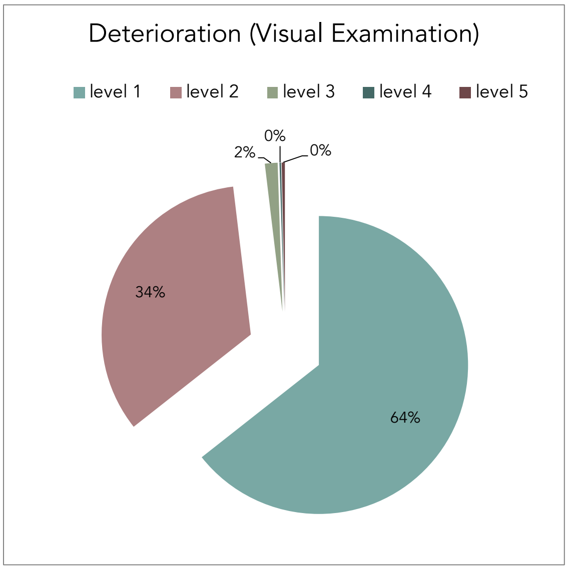


Fig. 4 Left: Survey data interpreted based on the A-D strips acidity level chart. Right: Survey data interpreted based on the deterioration level chart provided by the NorthEast Document Conservation Center (NEDCC) (see bibliography).

The Image Permanence Institute recommends prioritizing any film beyond a 0.5 acidity for digitization and cold storage (Reilly, 1993; Image Permanence Institute (IPI), 2022). Based on the acidity tests conducted with A-D strips in the charts above *(Fig. 4, see chart on the left*), 97% of the photographic films needed to be prioritized for cold storage (>0.5), and only 3% recorded an acceptable acidity of 0.5. Based on visual examination following the level of deterioration chart from the NorthEast Document Conservation Center (NEDCC) film base guide (Fischer, 2020), 64% of the photographic films collections in storage are in a good condition and show no deterioration (level 1) while the remaining 36% (≥level 2) are actively deteriorating and should be prioritized for cold storage *(Fig. 4, see chart on the right)*. This discrepancy highlights the importance of relying on a scientific tool such as acid detectors when assessing the condition. The level of deterioration chart yielded unreliable results as many negatives that seemed to be in a good condition, with no visible signs of deterioration, showed acidic emissions of 1 and above.

Action Plan

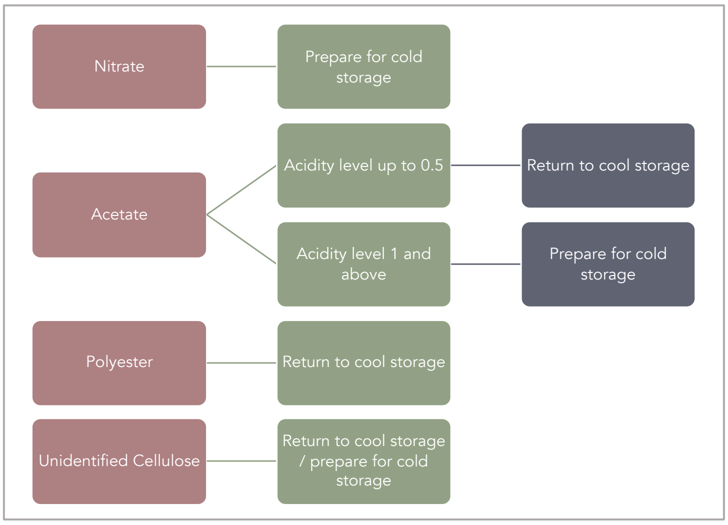


Fig. 5 Devised action plan based on the survey results.

The action plan *(Fig. 5)* was developed based on the survey results. The first step was to separate all films on cellulose nitrate supports from the films on cellulose acetate and polyester, and prepare them for cold storage, regardless of their deterioration symptoms and acidic emissions. For acetate films, it was decided that films with acidic emissions of 0.5 would be returned to storage but closely monitored, and films with acidic emissions of 1 and above would be prepared for cold storage. Polyester films should be returned to cool storage and placed separately from cellulose films. And finally, unidentified cellulose bases should be returned to cool storage or prepared for cold storage based on the acidic emissions results.

Packaging Materials

To prepare films for cold storage, a list of materials and equipment needed was compiled. The aim was to identify materials that can be easily purchased from supermarkets and stationery shops, even if they are not of conservation quality. To make sure the action plan is sustainable, each material needed to pass one of the following criteria:

- Already available within the preservation department.
- Locally sourced and can be bought continuously at an affordable cost.
- If not available in the country, the materials used should be easy to ship, with no high shipping costs or customs clearance required.

Available at AIF	Locally sourced	From abroad
Data logger	Ziplock bags	Humidity cards
Frost-free freezer	4 ply mountboards	
Vacuum cleaner	Renaissance paper	
Label maker	Clear adhesive tape	
Scissors		
Nitrile gloves (powder free)		

Fig. 6 List of materials and equipment used for preparing photographs for cold storage based on the selected criteria.

In addition, the final package needed to be proportional to the size of the freezer, lightweight and compact, and most importantly, able to acclimate to room temperature without the need of a vestibule chamber, which meant that a microclimate had to be created within each package. These **parameters** were particularly relevant in the case of emergencies such as prolonged power cuts or sudden evacuation. In the case of a prolonged power cut, the packages could stay unattended in the freezer without any risk of condensation reaching the films. In the case of a sudden evacuation, the packages can be moved with the staff and placed in another freezer until it is safe to return to the office.

Packaging Method

The packaging method was developed based on several papers and publications: from the National Parks Service online *Cold Storage guide (National Park Service (NPS), n.d.)*, *On the*

Cold Storage of Photographic Materials in a Conventional Freezer Using the Critical Moisture Indicator (CMI) Packaging Method (McCormick-Goodhart, 2003), and *The Permanence and Care of Color Photographs* (Wilhelm and Bower, 1993). When preparing packages for cold storage, it is recommended to use full vapour barrier films like MarvelSeal 360 or static shielding bags (National Park Service (NPS), *n.d.*). I opted for low density polyethylene or Ziplock bags which are widely available in supermarkets and are made in Lebanon. To keep the final package simple and affordable, 4 ply mount boards were used for housing and support instead of a traditional box. Renaissance paper was used for buffering as needed. It should be noted that good quality materials were used because they were available at the time but using conservation quality materials has a minimal role with cold storage. The subfreezing temperature will slow down the deterioration process that develops in acidic materials over time (NPS Cold Storage, *n.d.*).

To ensure the photographs are conditioned to a low relative humidity (RH), the RH levels in the preservation department needed to be reduced. The climate in preservation is controlled with two AC units that run interchangeably, and a dehumidifier that is turned on or off as needed. The climate changes throughout the year and is generally kept between 18-24°C with 40-55% RH. A low relative humidity environment between 30-40% was easily achieved by turning on both AC units and the dehumidifier overnight.

The final packaging method consisted of the following steps:

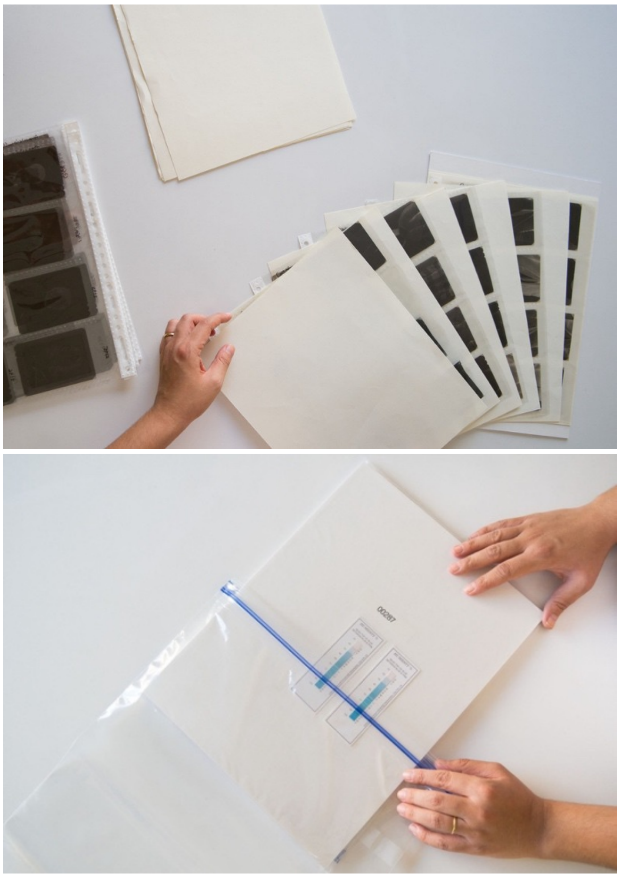


Fig. 7 Preparing films for cold storage by creating packages made from 4-ply mat boards, paper for buffering, humidity cards, and low-density polyethylene re-sealable bags.

- Films were organized by collection and format in chronological order and left to acclimate to 30- 40% RH in the preservation department overnight.
- Instead of a cardboard box, two pieces of cardboard were placed on the top and bottom of the stack. *(Fig. 7, top)*
- A label with a package number was printed and mounted on the top piece of cardboard with double-sided adhesive tape.
- A self-adhesive humidity card was added on the cardboard.
- The entire stack was placed in the first polyethylene bag, and excess air was removed using a suction pump connected to a vacuum cleaner.
- The bag was then sealed with clear adhesive tape, and another humidity card added on the bag.
- The bag was inserted into another layer of polyethylene, with excess air removed once again with a vacuum cleaner. *(Fig. 7, bottom)*
- Clear adhesive tape was applied on the second bag to make sure no air re-enters.
- In the case of roll films in plastic sleeves, acid-free paper interleaves were added between the sleeves.
- The packages were then moved to cold storage.

- The data logger was also conditioned to the same RH, and then packed in the same manner to ensure an accurate reading when monitoring the environment within the freezer in the future.

Testing the Freezer

Fig. 8 The final packages containing film collections from the survey, along with the data logger, in the freezer.

A household frost-free freezer was available at the AIF, and was used to test the cold storage packages. A data logger was left in the freezer and the climate was monitored over 2 months. The readings retrieved showed that during the defrost cycles, the temperature fluctuated between -25°C to -20°C and the relative humidity fluctuated between 55% and 80%. This humidity range was too high and needed to be brought down. The data logger was retrieved from the freezer and left to acclimate to a low humidity between 30-40%. It was then packed in a double layer of Ziplock bags and put back in the freezer. Readings were taken for another 2 months, and the relative humidity stabilized between 32-34%. Electrical blackout times were noted every day to see if the blackouts had any effects on the climate within the freezer. No fluctuations were recorded at the time of electrical cut-offs.

Report and Recommendations

Once the films were moved to cold storage, I wrote a report to the AIF administration and Board of Directors. The report detailed my methodology, condition assessments across the collections, and recommendations going forward. Below is a list of the main takeaways discussed:

1. Storing the films by format and support made sense because of the space restriction in storage, but it contributed to the spread of vinegar syndrome among collections. This should be reversed by re-organizing films by collection.
2. Relying on a scientific tool like the acid detectors was far more reliable than making an assessment based on visual examination
3. Although the films on cellulose nitrate support are mostly in a good condition, they are still a fire hazard and should be separated and placed in cold storage.
4. Films on cellulose acetate supports that are beginning to deteriorate or are actively deteriorating, should be digitized in high resolution, and prioritized for cold storage.
5. Based on data gathered using the Storage Calculator for Acetate, from FilmCare.org, it turned out that most of the films in storage, kept at an average of 19°C and 43% RH, will show further deterioration within the next 10 years. This damage can be eliminated by implementing cold storage and a microclimate environment. The AIF should consider implementing cold storage for all its collections containing film.

The AIF administration and Board of Directors were very attentive to this report, and we began discussing the possibility of moving to a larger office space so we can have two storage spaces with cool and cold temperatures. It was also decided that vulnerable film collections will be prioritized when applying for grants.

Ongoing Challenges in Implementation

Fig. 9 The cool storage room the day after the explosion at the Beirut Port in August 2020.

The films remained in the freezer at a stable climate for about 6 months. Unfortunately, in early 2020 we had to remove the films from the freezer and return them to cool storage. This was due to increasing power cuts, and the generator provider no longer being able to give us the amount of electricity we need. The freezer had to be turned off to minimize our electricity consumption and prioritize the cool storage room's HVAC system as well as the staff's working stations. 2020 brought a series of crises, including the COVID-19 pandemic, shortages in fuel which made transportation extremely difficult, the devaluation of the Lebanese currency and high inflation in the prices of the most basic needs. However, nothing prepared us for the explosion at the Beirut Port in August 2020 which decimated half the city and caused immeasurable losses. The AIF premises were situated only 800m from the blast site and suffered heavy damage. This forced us to stop all our operations until we recovered the collections and completed the repair works. After the explosion, there was no electricity or water for about a week in the neighbourhood. And due to the damage across the city, it was impossible to move the collection. Cars had very limited access to the blast area, so the collections had to stay in the damaged storage room in a 35°C weather and over 75% RH. It took us about 10 days to secure a room inside the office and turn it into a temporary storage. To secure the room, we removed all the debris. We sealed off the broken windows with plastic sheeting and tape and gathered all the tables and shelves we could use. Then we worked on assessing the damage and cleaning the boxes. Despite the apocalyptic view, no photographs were damaged thanks to well implemented and maintained preventive measures. It took four months to complete the repairs and stabilize the collections. The cool storage room is now running again and contains all the collections that have been cleaned and rehoused in conservation quality enclosures and boxes. The collections that are awaiting preservation work, however, are sitting on open cupboards secured with bungee cords. This situation is far from ideal which is why the plan is to move to new larger premises in the near future. Meanwhile, to address the fuel shortages and constant power blackouts, the AIF installed solar panels. The solar panels cover the electricity for the preservation department, the storage room, and the AIF server which contains all digital versions of the collections. But the aim is to have the entire premises running on solar panels.

Since 2019, we have implemented the decision to prioritize collections containing actively deteriorating films when applying for grants. Throughout 2020 and 2021, we worked on 10 collections, all containing cellulose nitrate and cellulose acetate films that were particularly vulnerable. This was done thanks to grants from the UCLA Modern Endangered Archives Program. These collections amount to over 47,000 photographic images on inherently unstable film supports.

Conclusion

Caring for photographic film collections in Lebanon poses multiple challenges. Even after carrying out the research, developing a plan and a safe packaging method, the factor of being in Lebanon makes it very difficult to implement long term changes. However, the AIF has been finding solutions to at least stabilize the collections for the time being, while working towards the long-term goal of moving to larger premises that would allow working on the hundreds of thousands of actively deteriorating film collections and placing them in a suitable storage to ensure their preservation.

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Hand-colouring Photographs: a Study on Reproductions of Islamic Art around 1910

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Abstract

The presentation featured the recently discovered photographs of a campaign on works of Islamic art that were reproduced in black and white and in color for the exihibtion catalogue of "*Meisterwerke muhammedanischer Kunst*" 1912, conducted by the Bruckmann publishing house.

Keywords: reproduction of art, publisher, collotype, coloured photographs, 19th century, Islamic Art

Extended Abstract

With the recently uncovered historical image archive of the Munich-based Bruckmann Verlag (est. 1858), the impressive photographic collection of one of the largest German publishing and printing companies in the field of art reproduction has been preserved (Lampe 2022a; Lampe 2022b). The archive was transferred to the Zentralinstitut für Kunstgeschichte (ZI) in Munich where this unique collection of approximately 150,000 photographs and photomechanical prints is now available for research for the first time. Bruckmann made a decisive contribution to the popularization of art and, in close cooperation with art historians and museum directors, also to the establishment of its canon. Bruckmann has long time been a leader in the field of collotype printing and at an early stage made enormous efforts to reproduce its products in colour too. The desire to reproduce the world in colour is omnipresent, but plays a special role in the context of art reproductions (Imorde and Zeising, 2016). With the help of the hitherto unexplored photographic material and it‘s historically survived archival structure, it is possible to investigate contexts and conditions surrounding the history of art, it's reproduction, reception and the related ideological instrumentalisation of artworks (in black and white or in colour).
One of the first major projects on non-European art at Bruckmann Verlag was an extensive photo and catalogue campaign for the "Exhibition of Muhammadan Masterpieces in Munich 1910" (Lermer and Shalem, 2010; Troelenberg, 2011). The exhibition, curated by Friedrich Sarre, director of the Collection of Islamic Art at the Berlin Kaiser-Friedrich-Museum, and Fredrik Martin, brought together around 3,600 Islamic art objects from international collections in this unique project, that were on display in 80 rooms at the Munich Theresienhöhe. Bruckmann was entrusted of taking some 400 photographs of selected art objects. These photographs were – in a first step – to be published as reproductions as individual sheets, that should exclusevly be sold during the exhibition and via art- and bookstores. The planned catalogue did not get ready in time, but 1912 finally a total of 257 images were published in the three volume opus as collotypes, 23 of them in high-grade colourprints. A richly decorated work, with embossed leather binding and a wooden slipcase support the character of a treasure, with a total print run of 400. For a long time, these images were the only photographs of the exhibited specific art works; they were groundbreaking as visual footage for Islamic art history. The original templates from 1910 have now appeared in the Bruckmann image archive.
Most of these artpieces show up in the catalogue as objects removed from 'time and space' (Fig. 1).

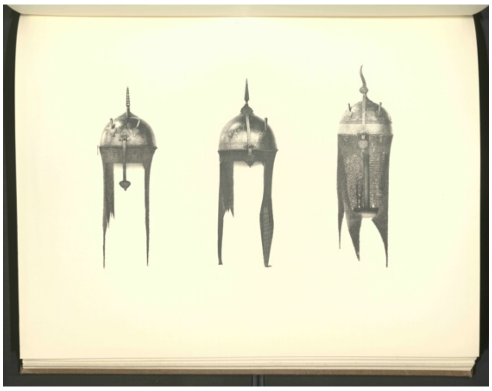

Fig. 1 - *Three steel helmets, Persia, sixteenth and eighteenth century*, in: Friedrich Sarre and Fredrik Martin, *Die Ausstellung von Meisterwerken muhammedanischer Kunst in München 1910*, Munich: Bruckmann, 1912, vol 3, plate 228. Photo: F. Lampe.

The unifying, supposedly objective moment of photography comes into play here: all objects in the exhibition have been photographed and printed in a standardized manner. No matter what category: wood, metal, glass or fabric, size, region or time period, they appear in the same way. Taking the photo templates from the archive for comparison, it reveals a lot about the photographic craftmanship around 1900: small wedges prevent tilting, also to ensure that the objects remain stable for a longer exposure time, shadows or backgrounds are removed with white retouching paint. The context of the shooting situation disappears in the printed version of the images. Collotype printing, as a photomechanical flat printing process, was particularly well suited for the reproduction of these art objects, because the net-like structure of the grains, the reticulation, could render the fine drawings on the objects quite precise. When it comes to the coloured works, the situation is different. They seem not only to try to capture a 'more' of reality through the colouring, but they are also located as objects in a real space, with defined shadows and backgrounds they seem to follow the concept of 'vivification' (Fig. 2).

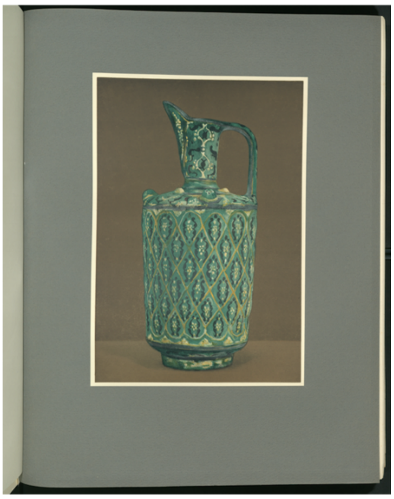

Fig. 2 - *Henkelkanne, Persia, thirteenth century, in:,*Friedrich Sarre and Fredrik Martin, eds, *Die Ausstellung von Meisterwerken muhammedanischer Kunst in München 1910*, Munich: Bruckmann, 1912, vol 2, plate 105. Photo: F. Lampe.

As colour plays an extraordinarily important role in Islamic art, photographers and colourists were allowed to work directly on the exhibition grounds to produce the templates for the colour prints directly from the originals. If one takes a closer look at the detailed work for the production of the proofs, this may explain why a total of only 23 coloured plates were printed. To make the coloured versions with the help of special filters and overexposure, a rather flat, softly contoured photograph was created, on paper with a matte surface, which was then mounted on cardboard. This photograph was painted over by hand with fine brushes and wet paint (Fig. 3a). In some overpainted photographs, one can also see a thin glaze that was used to fix the colour (Fig. 3b).

Fig. 3a - Verlag F. Bruckmann, *Henkelkanne, Persia, thirteenth century,* October 1910. Hand-coloured photograph on cardboard with annotations, 38,0 x 26,3 cm (sheet size), 34,0 x 21,0 cm (image size), produced for Friedrich Sarre and Fredrik Martin, *Die Ausstellung von Meisterwerken muhammedanischer Kunst in München 1910*, Munich: Bruckmann, 1912, vol 2, plate 105. Zentralinstitut für Kunstgeschichte, Photothek/Archiv, Bildarchiv Bruckmann, ZI-BAB-'Moham. K.'. Photo: F. Lampe.

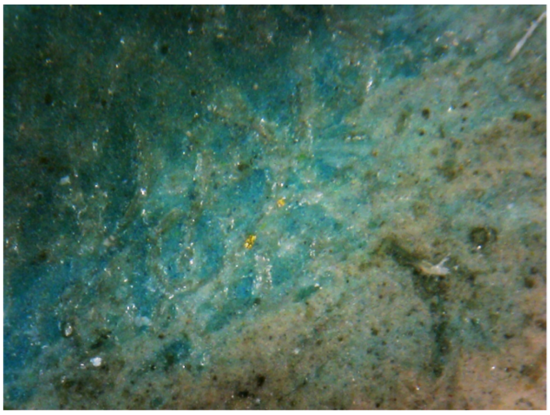

Fig. 3b - Microscopic enlargement, detail of coloured photograph from Fig. 3a. Photo: F. Lampe.

The preparation for colourprinting depended on an extremely complex procedure for which only a few selected works were chosen. There is a strong contrast in the catalogues from 1912 between the two types of images, those in black and white and the coloured plates. What does this say about the artworks and their reception? For whom was the visual material made – alternating between creation of a colourful 'Orient' or/and the recognition of the art objects? (Behdad and Gartlan, 2013). Who exactly should the audience be? The historical discourse on colour is a guiding basis for this, as it proves to be an extremely complex process, especially with regard to the reproduction of works of art, which not only touches on perceptibility, but is also closely connected with aesthetic, ethical and economic questions and problems (Gründler, Lampe and Stahlbuhk 2022). The photo-objects also bear witness to the controversy in art history as to whether works of art should be reproduced in colour at all. Where do these images

fit into this hierarchical discourse? The usual photographic colour processes were not well suited for the reproduction of works of art. So these somehow hybrid objects were created, testifying to the attempt to capture and reproduce colour. How can we make the 'knowledge of images' speak and how can we look behind their stories in order to deconstruct established narratives (on non-European art)? The Bruckmann image archive holds numerous discourses on the history of science and art when its photographs are placed in the center as actors.
In this context, it is important to methodically apply an expanded concept of photography that does not reduce photographic images to their visual properties, but recognizes them as three-dimensional objects, each with its own individual materiality, biography, and agency (Caraffa 2011, 2020; Edwards and Hart 2004). This approach lends itself particularly well to the study of historical photographs from a publishing house, since the photo-objects are marked to a very special degree with their modes of production, function and use in the form of retouchings and inscriptions.

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Jewish Blues and the Color Revolutions in John Akomfrah's Auto Da Fé (2016)

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Abstract

The Ghanaian-British media artist John Akomfrah performs in his muti-channel installations about forced migration the archival work of recording the calls of those drowning on the open sea: Photo- and phonographic memories captured at sea are dramatized as being washed ashore in installations such as Auto Da Fé (2016), which Akomfrah featured after he was awarded the Artes Mundi Prize in 2017. The sonic and photographic records of migrants, in Auto Da Fé the victims of religious persecution, are reanimated in allegorical performances of the alternative photographic process of cyanotypes, or blueprints, as Sir Herschel also called the reproduction of recordings in Prussian Blue. In Akomfrah's digital aesthetic, the blues of the sea are haunted by photographic records, which are washed ashore, immersed in the chants and songs of the persecuted on the soundtrack and the blues of the sea. In an allegorical recourse to the alternative photographic technology of blueprints, Akomfrah dramatizes a way of "seaing" the calls of the victims of forced migration as they are haunting the shorelines of Barbados – and the history of color and light in early photography.

Keywords: cyanotypes, blueprints, migration, color revolution, digital aesthetic, blue ecology, eco-archive.

Introduction

What the "color revolutions"—as they have unfolded in the new millennium in streets and squares and on the World Wide Web, from the Orange Revolution in the Ukraine to the Yellow Revolution in China—have in common is that they are bloodless revolutions and therefore decidedly not colored in the red that marked earlier left- or right-wing revolutionary politics. However, what is striking in the millennials' return to forms of civil resistance symbolized through colors of flowers, clothes, ribbons, and flags, is the organizational role that chromatic algorithms play in orchestrating the dissemination of a specific coloring (charged with songs, slogans) on the streets and on social media platforms, where "flower power" figuratively blossoms seemingly spontaneously and globally in cross-fertilizations, which I propose to explore in the photographic and filmic installations of the Ghanaian-British media artist John Akomfrah. For the urgency with which the color revolutions rise, often as acts of mourning the victims of political violence, is reflected in Akomfrah's multi-channel installations, in which photographic archives of recent and past memories of forced migration are haunting the archival footage of the "blue planet." While the BBC footage traces in pristine blues the (endangered) life of the sea, Akomfrah traces the calls of the dead for a revolution to come.

Fig. 1 - John Akomfrah: Auto Da Fé (2016). https://www.e-flux.com/criticism/239040/john-akomfrah

"Seaing" the Blues in the Diptych of Auto Da Fé

At the crossroad of forced migrations, from the transatlantic slave trade to the modern refugee crisis, Akomfrah performs in the diptych Auto Da Fé, exhibited in the Artis Mundi exhibition in 2017, contradictions instigated by modernity's liquidation of capitalistic flows of goods across the sea, welcomed in the harbors of the world, unlike the people who are forced to travel across the sea, escaping catastrophes and persecution in search for a safe haven (Alter, 2016). The diptych of Auto Da Fé presents a series of eight historical migrations over the last 400 years, starting with the 1654 fleeing of Sephardic Jews from Catholic Brazil to Barbados – after having been expelled from Spain at the end of the 15th century (Fig. 1). Akomfrah restages the arrival of a black Jew dressed in traditional blue costume on Barbados amidst the island's ruins and tombstones, reanimating, as I argue, photographic memories of (Jewish) blues. Akomfrah's performance of audio-visual memories of "Jewish blues" in Auto Da Fé emerges at the crossroad of the "black technology" of blues and the alternative photographic history of blueprints, to which Akomfrah returns throughout his work. Akomfrah's "blueprints" in installations from Transfigured Night to Vertigo Sea and Auto Da Fé are reminiscent of early cyanotypes, such as Anna Atkin's Photographs of British Algae: Cyanotype Impressions (1843), however, what emerges in Prussian Blue (Taussig, 2009) are the photographic reproductions of portraits of those who vanished on their journey across the sea.

The "Black Technology" of Blues

Akomfrah's digital reappropriation of the alternative photographic technology of cyanotypes presents itself as an allegory of a faithful reproduction, echoed the title's announcement of Auto Da Fés, which are literally translated "Acts of Faith." The sonic and photographic records of migrants, in Auto Da Fé the victims of religious persecution, are in Akomfrah's digital aesthetics allegories of "blueprints," which invite to look at an alternative way of "seaing" the calls of the dying and dead. Neither in black and white nor in color, Akomfrah's "blackblues" (Moten, 2017) are digital allegories of the photographic process of recording "last moments" in the blues of the sea and its blue mythologies (Mavor, 2013). Akomfrah's reanimation of the heritage of blueprint technology unfolds at the crossroads of what Akomfrah calls in his Afrofuturist manifesto, The Last Angel of History (1996), the "black technology" of the blues and references to African-Jewish diasporic culture (Fig. 2).

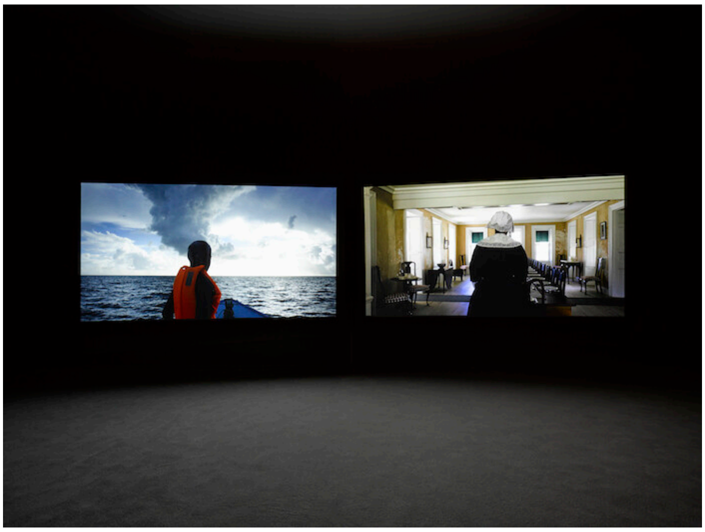

Fig. 2 - John Akomfrah: Auto Da Fé (2016). https://www.e-flux.com/criticism/239040/john-akomfrah

Conclusion

In Akomfrah's digital aesthetic, the blues of the sea are haunted by photographic memories of the drowned, exscribed and immersed in the chants and songs of the persecuted on the soundtrack (Weheliye, 2005). Akomfrah's allegorical recourse to the alternative photographic technology of blueprints (Sheehan, 2018) performs a way of "seaing" the calls of the victims of forced migration as they are haunting the shorelines of Barbados – and the history of color and UV light in early photography (Wilder, 2015).

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The conservation of "Icarus", 1984, Unique Cibachrome print, by Boyd Webb.

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Abstract
Boyd Webb's artwork "Icarus" is a direct positive, a unique Cibachrome print, also known as Ilfochrome. Cibachrome is a dye destruction positive-to-positive photographic process used for the reproduction of film transparencies on photographic paper. These prints are produced by the silver-dye bleach process, noted for their clarity, color purity, and being an archival process able to produce critical accuracy to the original transparency. "Icarus" took part in an exhibition at an Athenian gallery in 2021 and presented some peculiar conservation issues, caused by its way of mounting. The large photographic paper is nailed on a sheet of a white painted plywood through metallic hoops, which have been integrated into the paper. Due to the way the photograph is "hanged", the photographic paper is not flat, presenting tensions and curling. Tears have formed in the upper right and lower right perforated corners, which indicates that the frame was stored leaning on the left side for a long time. As the exhibition curators noticed that the artwork was in danger to fall inside the frame, they were led to seek for immediate conservation assistance. This case study will present the conservation strategy that was implemented for this unique print, in respect to the one-of-a-kind mounting and framing. Materials and techniques will be explained as well.

Keywords: Cibachrome, Ilfochrome, silver-dye bleach process, conservation of photographs, photograph mounting, Boyd Webb.

Introduction

Boyd Webb was born in New Zealand in 1947 and became a visual artist after completing his art studies in Christchurch and then in London, where he lives and works. He uses mainly the medium of photography although he has also produced sculpture and film. He was shortlisted for the Turner Prize in 1988 (Boyd Webb, Wikipedia, Accessed: 2022). His artistic language is minimal, humoristic, ironic, and surrealistic. He uses parallel universes, familiar objects that are not what they seem. His work addresses issues of reality and truth: Environmental pollution, nuclear waste and the impact of modern technology and science (Admin, 2021, *Boyd Webb*). Boyd Webb might be called a rational ecologist. His sarcastic-but-righteous photographs deliver eerie pro-planet sermons (*The Washington Post*, Accessed: 2022). The tale of Daedalus and Icarus in Greek mythology is the story of a father and a son, who used wings to escape from the island of Crete. Daedalus had constructed the wings using feathers and wax. Icarus, fascinated by flight, disobeyed his father's command not to fly too high so that the heat of the sun would not melt the wax of the wings. But Icarus flew up, causing the wax to melt and the wings to detach, so he fell into the sea and drowned. The didactic message of the myth is that the desire to transgress human boundaries, culminates in tragic consequences (Ancarola, G., Accessed: 2022). Boyd Webb uses the myth to make a sarcastic comment about levitation, staging an elephant, trying to elevate a short of carpet that looks like dried grass, that the enormous animal steps on. Perhaps Webb also has an ecologic message to convey, that it is futile to try to save nature, that weighs so much on it (Fig.1).

Fig. 1 – Boyd Webb's "Icarus", Cibachrome, before conservation

Photographic technique: Cibachrome

The photograph of Icarus is a unique Cibachrome print, as it was labeled on the backside of the frame (Fig.2). Cibachrome originates from the cinematographic technique Gasparcolor, which was introduced by the Hungarian chemist Bela Gaspar in the 1930's (Fisher, M., Accessed: 2022). It is a Silver Dye Bleach (SDB) process, based on the selective destruction of colorants. Agfa and Kodak had tried to exploit the possibilities offered by SDB technology, but their efforts were soon abandoned (Cartier-Bresson, A., 2008). In 1963, the group of Ilford and Ciba companies have launched the Cilchrome as it was first baptized, and later called Cibachrome. In 1991 the original trademark Cibachrome took the name Ilfochrome. It was used to make positive prints directly from color transparencies (Fisher, M., Accessed: 2022).

Cibachrome produces prints of high color saturation and excessive image contrast. Silver dye-bleach prints are noted for their clarity, color purity, and being an archival process able to produce critical accuracy to the original transparency. They are prone to fingerprints and to scratches, due to the lack of protective coating. Cibachrome has excellent dark keeping stability and good light fading stability, though it is not permanent on long-term display (Wilhem, H., 2010). In 2011, Cibachrome/Ilfochrome products were discontinued, due to waning popularity and to the ascendancy of digital photography.

Fig. 2 – The backside of the frame

Cibachrome fabrication steps

Cibachrome's support is made of Resin Coated Paper or opaque polyester, which is covered with three separate layers of silver bromide gelatin, each one sensitized in one determined spectral domain: blue, red, or green. Cibachrome print materials were manufactured with the dyes already incorporated into the printing paper. They are multi-layer products, each layer containing a dye of the opposite color to the layer's sensitivity. The layer sensitive at blue light contains a yellow dye, the layer sensitive at green light contains a magenta dye and the layer sensitive at red light contains a cyan dye. After the exposure, the photograph is developed, using black and white developer and a deposit of metallic silver is formed. This produces a negative silver image in each layer corresponding to a black and white negative of the red, green, and blue components of the transparency. For example, the image in the middle layer is a black and white negative of anything green in the transparency, or any color which is partially green. This image then undergoes a chemical treatment (bleaching) which will induce the selective destruction of the dyes in proportion to the quantity of metallic silver present. This removes the colored dye from the developed black and white negative image only, and leaves any dye not affected by the black and white developer. It works in the exposed parts of the red, green, and blue images only. A positive image is thus obtained directly from a slide, it is a so-called auto-positive process. The final chemical step is a fixing bath, which converts all the silver halides in the material, exposed and unexposed, to a soluble silver, which can then be washed out the print to leave only the dyes and to achieve the desired final colors (Fisher, M., Accessed: 2022).
A cross section of a Cibachrome can be summarized as follows:
-the support can either be polyester which shows a high gloss, either resin coated paper, with a pearl finish respectively,
-the binder used is gelatin and
-the final image materials are azo dyes.

"Icarus" condition assessment

The artwork took part in an exhibition at an Athenian gallery from February 4 to March 29, 2021, and presented some peculiar conservation issues, caused by the way of mounting. Before the exhibition closure, the curator from the gallery asked for conservation assistance, sending an e-mail with a picture indicating that something went wrong on the upper right corner of the photograph and expressing great concern that the photograph was in danger to fall inside the frame. When an art handler brought it to the Conservation Lab, the first impression was its large size and heavy weight. In fact, so heavy and large that the transporter rested it on the short side upright, which leads to the hypothesis that it rested that way for a long time when it was stored, thus burdening the right side of the work. The frame measures 112X152cm, so it is natural for one art-handler to hold the frame by its smaller side.
The mounting method was an unprecedent surprise. The photographic paper is nailed on a sheet of a white plywood. The plywood is placed in a black wooden frame with glass and wooden spacer respectively. At the verso of the frame, there is a wooden backboard, sealed with kraft paper tape perimetrically. After opening the frame, we could also notice that due to the way the photograph is "hanged", the photographic paper is not flat, presenting tensions and curling. The support is Resin Coated Paper and has a pearl finish, as observed with raking light. The photograph was also examined under high magnification (100x) with a dinolight digital microscope. Bleach halos were clearly visible and were compared with the Silver Dye Bleach technique in Graphic Atlas of the the Image Permanence Institute website (*Identification Graphics Atlas,* Accessed: 2022).
The photographic paper measures 76x102cm and is nailed onto the plywood. The nails penetrate the 4 corners of the photographic paper through metallic hoops, which have been

integrated into the paper. Tears have been formed in the upper right and lower right perforated corners, which indicates that the frame was stored leaning on the left side for a long time (Fig.3).

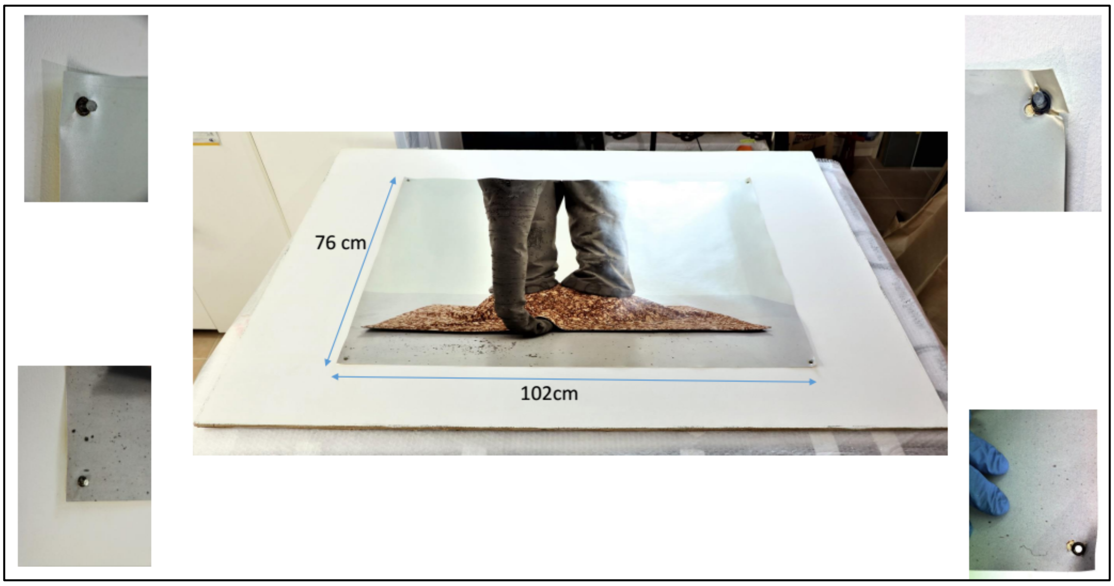

Fig. 3 – The photograph with the four corners enlarged, before conservation, recto

Close up and microscopic examination of the metallic hoops that come in contact with the photographic paper, reveals that the hoops are probably made of a ferrous alloy overpainted with bronze color. In the red circles we can inspect the damaging effect of the rusted hoops, transmitted onto the photographic paper (Fig 4).

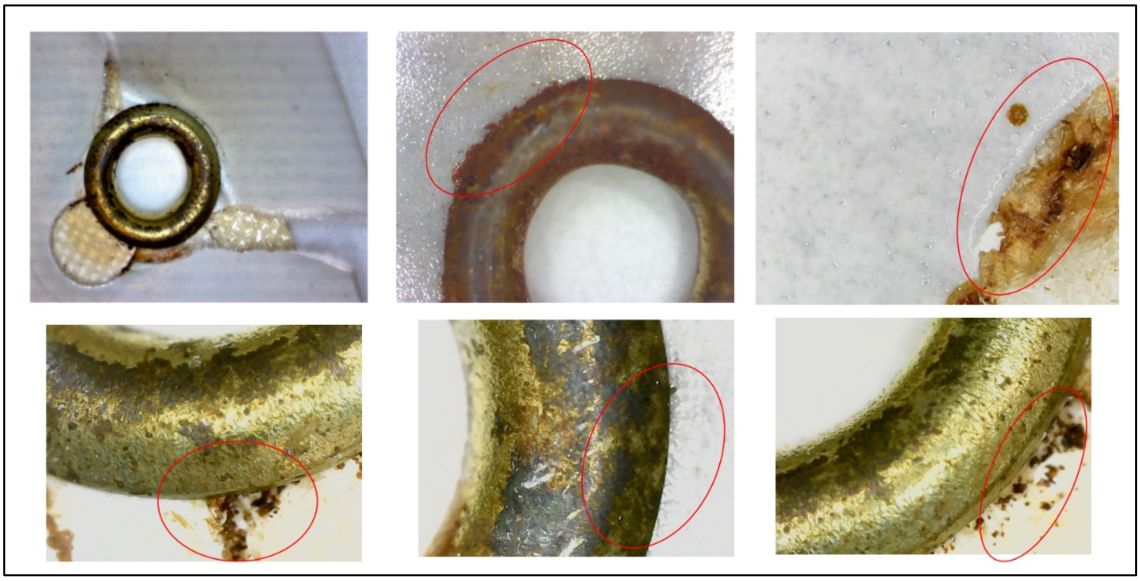

Fig. 4 – Damages caused by the metallic hoops

In all the four corners a piece of gaffer tape, has been placed, probably to protect the paper from tearing when the metallic hoops were being attached to the paper. The gaffer tape in all four corners has been partially detached and the adhesive has been oxidized (Fig.5). The two corners on the left recto, suffer from tears and adhesive residues, whereas the two corners on the right only from adhesive residues and slight detachment of gaffer tape. The most severe damage is the one located on the upper right corner of the photograph. The photographic paper is torn and creased and if it is left untreated, the photograph will eventually slip inside the frame. On the verso of the paper, we also notice the dripping stains, caused during the fabrication process of the Cibachrome print. Fortunately, they do not seem to affect the image stability. On the recto low right corner, less severe damages were noticed: small tears, wrinkles, rust from the hoops.

Fig. 5 – The photograph with the four corners enlarged, before conservation, verso

Conservation treatment

Once the frame was opened, the first step was to carefully remove the nails from the plywood. Underneath the photograph there were other holes present on the plywood, indicating that several efforts to nail the photograph in the desired place had been made. We must take under consideration that the original nails should be reinstalled in the same holes at the end of the conservation treatment. Having this in mind, both nails and plywood holes were chemically cleaned with toluene and coated with a protective layer of Paraloid B72 in toluene.

In order to protect the photograph from oxidation, all four hoops were chemically cleaned with toluene and coated with the same varnish. The hoops were opened carefully from their petal shaped back side. The petals flexibility played determinant role to their cautious release from the photographic support and to their thorough treatment (Fig.6-c).

The gaffer tape was lifted mechanically, and the adhesive residues were cleaned again with toluene. This solvent gave the most satisfactory result and was proved safe for the Cibachrome support. The tear located on the upper right corner was consolidated with Lascaux 496HV and Kozo Japanese paper (17gr) from the verso. Kozo was selected because of its long fibers, whereas acrylic adhesive, Lascaux because it contains minimum humidity, dries quickly, provides a strong bond and is reversible with toluene. An additional Linen Tape (Lineco®) with Lascaux adhesive was placed on top, for extra strength and durability. Following that, on the recto, there were aesthetically ugly gaps created. Those gaps were infilled using Baryta in Aquazol 50. Aquazol provided both extra strength and an insulating layer for the retouching at the same time. Retouching was done using gouache (Winsor and Newton) and pencil (Caran d' Arches) colors. Finally, the hoop was carefully reintegrated (Fig.6).

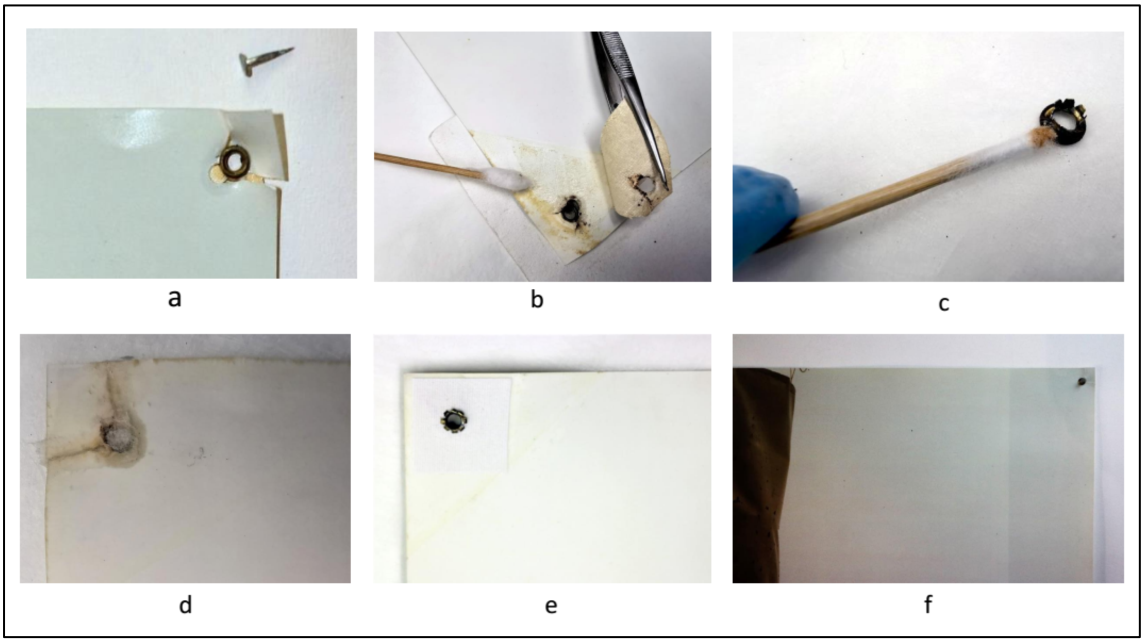

Fig. 6 – Details from the treatment of the torn upper right corner of the photograph

On the low right corner, the same treatment steps were carried out: cleaning of the rust residues, consolidation of small tears, loss compensation, retouching. Yet, after the removal of the hoop for cleaning, a small piece of detached photographic paper was being held underneath (Fig.7-d). This was reintegrated with Lascaux as well (Fig.7-e).

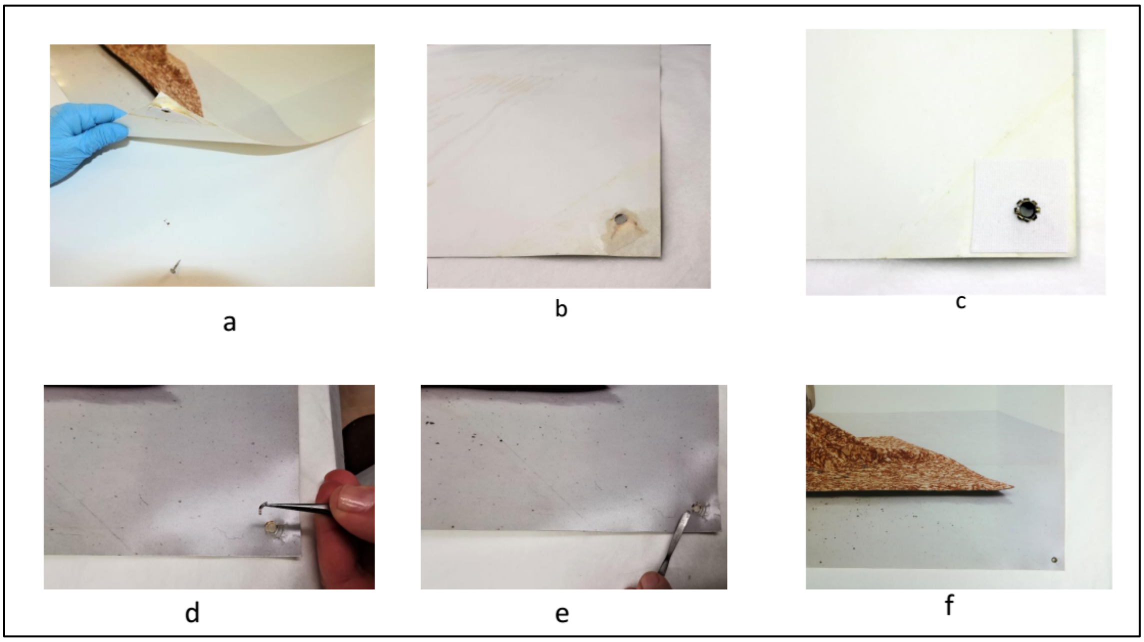

Fig. 7– Details from the treatment of the low right corner of the photograph

The other two corners of the recto left-side were in stable condition, so they were only chemically cleaned from adhesive residues and the old gaffer tapes were kept and reinforced where needed. The hoops also received preventive conservation treatment and were integrated in place (Fig.8).

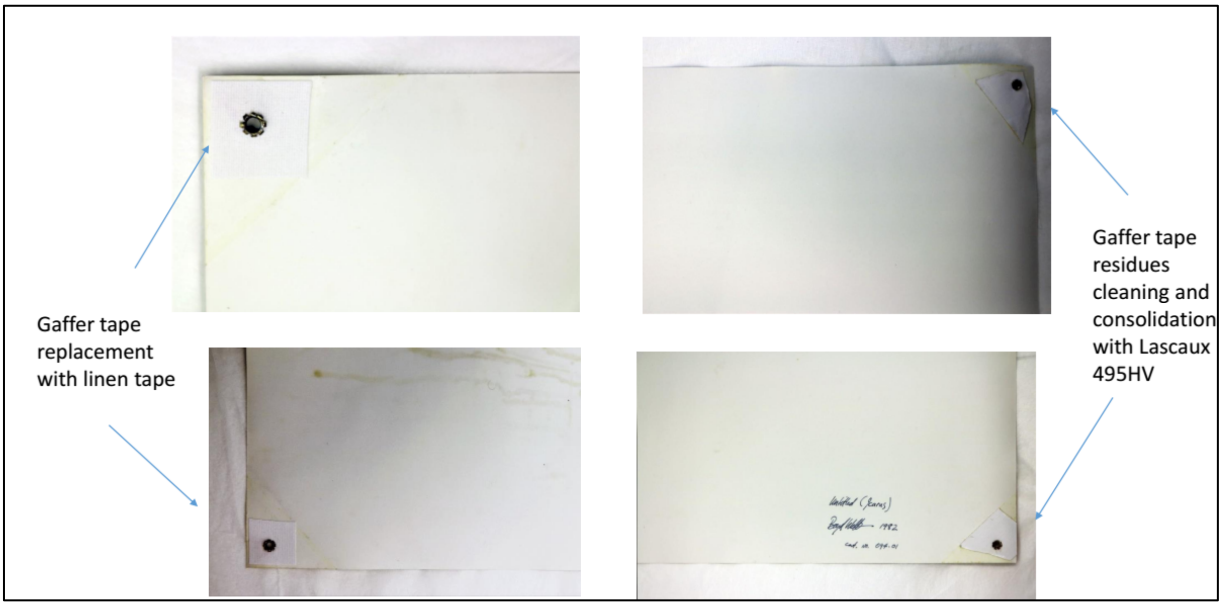

Fig. 8– Details of the four corners, after conservation, verso

Then the four nails were reinserted into the same holes of the plywood. "Icarus" was hanged. Last but not least, the frame was undusted, the glass cleaned, and the frame reassembled. The artwork returned into the gallery room, as the exhibition was still on.

Fig. 9– "Icarus" after conservation, details of the four corners, recto

Conclusion

In conclusion, this was indeed a challenging conservation assignment. The artwork returned stable to the gallery as soon as possible, as the exhibition was ongoing. The conservation lasted five days. The mounting of the photograph with nails onto a plywood was until now, an unknown method, that evoked a tailored made conservation strategy. On the transportation back to the Gallery, two art handlers were called upon, in order to keep the frame horizontally, distributing the weight homogeneously. Further instructions were given for the future storage and transportation of the artwork in the wooden crate, to stay horizontal, recto side face-up.

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UltraStable II

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Abstract

The first color photograph on paper was a carbon pigment print, and now, more than 150 years later, fine-art photographic printmakers continue to use the process to create color photographs of matchless beauty and permanence.

At the same time, renewed interest in historic ("alt") photo processes has also brought an increased awareness and appreciation of the unique features of the hand-made, exhibition-quality, color carbon print.

However, as the last commercially available pigment films were manufactured 1996, the lack of materials has limited the use of the process to those few printmakers capable of making their own color carbon print materials.

Until now.

Developed by Charles Berger and Tod Gangler, the Emulsion Flakes feature a "green", non-toxic chemistry, and provide all the necessary ingredients to make full color carbon pigment films. Just add water.

The new UltraStable II Emulsion Flakes will renew and revitalize fine art photographic printmaking world-wide and will play an important part of the yet to be written "History of Color Photography in the 21st Century."

Keywords: color carbon, pigment printing, ultrastablecolor, pigmented gelatin, emulsion flakes, polycolor heliochrome

Introduction

Less than 10 years after James Clerk Maxwell's 1861 demonstration of his trichromatic theory of color and light, the first "natural" color photographs on paper were made (1867). Called "Heliochromes" - color made by light - by one of its makers, Louis Ducos du Hauron, who replaced the finely ground black ash of Pointevin's Bichromate Pigment Process with red, blue, and yellow colorants to make pigment films that when imaged and superimposed, resulted in a full color photograph.

Fig. 1 - Louis Ducos du Hauron, *Still Life with Rooster*

150 Years Later

Now, 150 years later, the same pigment process continues to be used to make prints for a few top-tier artists and photographers whose work is exhibited in galleries and museums worldwide.

As the image is formed by pigments suspended in gelatin within discrete color layers, light penetrates deeply into the emulsion and both reflects and illuminates from within.

Fig. 2 – Paolo Roversi, *Guinevere in Red Dress*

Fig. 3 –Sarah Moon, *Oiseau 1*

Museums and photographers' estates have used the process to recreate the look and feel of early, iconic color pigment prints.

Fig. 4 – Madame Yevonde, *The Machine Worker In Summer*

Fig. 5 –Nikolas Muray, *Frida with Magenta Rebozo*

Process Features

Today's pigmented gelatin print is a hybrid of analog and digital technologies and is capable of the most accurate and detailed, color reproduction.

The unique surface of a carbon print - the characteristic gloss differential or “relief” that is a result of pigment build up in high density areas - brings a physical intimacy to the eyes of the viewer.
A carbon print can be transferred to a variety of fine art papers. These prints by Tod Gangler were made on papers including Fabriano Artistico and Arches Platine.
The unrivaled long-term display stability of UltraStable color carbon prints has been well established - receiving an unprecedented WIR Display Rating in excess of 500 years.

Current Status
Renewed interest in historic (“alt”) photo processes has brought an increased awareness and appreciation of the unique features of the hand-made, exhibition-quality, color carbon print. As such, the process offers a direct link from the binary world of digital photography back to its analog origins.
However, as the last commercially available color carbon print films were manufactured for UltraStableColor Systems in 1996, the lack of materials has limited the use of the process to those few photographers and printmakers such as Tod Gangler in Seattle and Calvin Grier in Spain who have spent years learning to make their own color carbon pigment films from scratch.
Until now.

Emulsion Flakes
The new emulsion flakes, developed by UltraStableColor Systems founder Charles Berger and master carbon printer Tod Gangler, using the original UltraStable™ formulations, contain all the ingredients to make four-color pigment films: cyan, magenta, yellow and black. Users simply add water to the flakes, mix and coat.

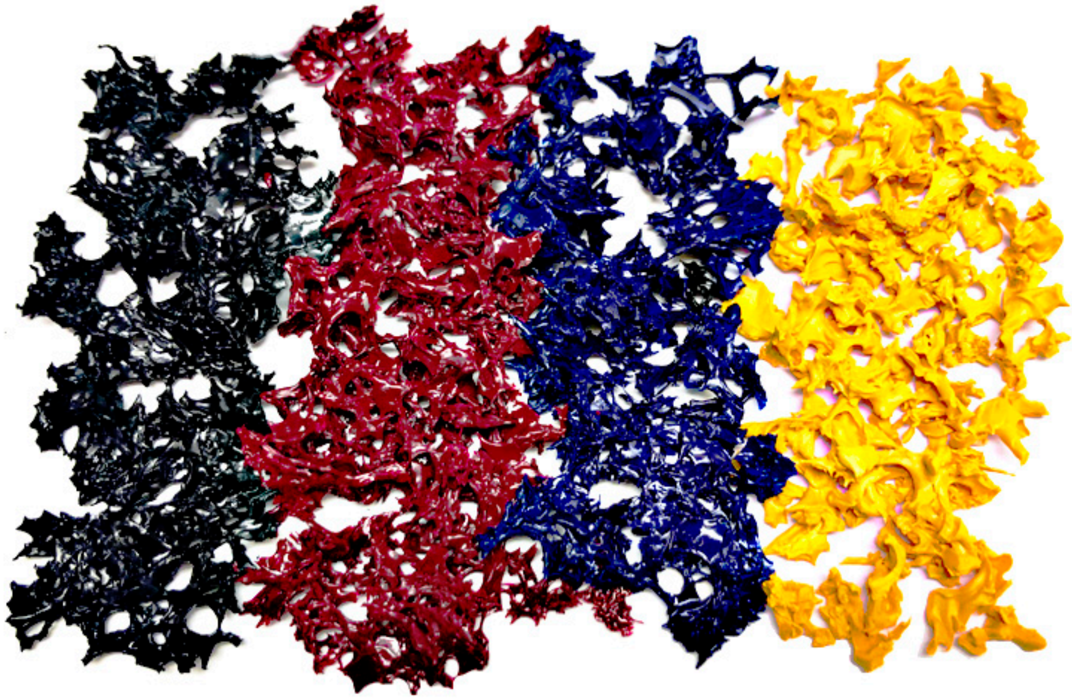
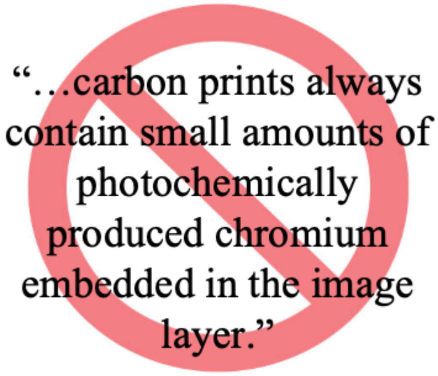


Fig. 6 – UltraStable Emulsion Flakes

Non-Toxic
UltraStable II Emulsion Flakes use a non-toxic and eco-friendly photosensitizer (DAS), unlike the traditional potassium dichromate - a proven carcinogen whose use has been restricted in the EU since 2017. In addition to resolving serious health and safety issues, these new, dichromate-free emulsions transform what was once a notoriously difficult and unpredictable process into a simplified and repeatable printmaking workflow.

Process ID: Analytic Signatures



Although it has been over a quarter century since UltraStable replaced the toxic dichromate chemistry that produces chromium with a non-toxic photosensitizer (DAS), the presence of Chromium in the image layer continues to be a defining characteristic of a "carbon" print. As X-Ray Fluorescence Spectroscopy of UltraStable color carbon will fail to report the presence of chromium, these prints cannon be identified as "carbon" prints.
This is clearly in need of correction.
As with traditional carbon prints, XRF Analysis will confirm the characteristic total absence of silver and microscopic (100X) examination will reveal pigments suspended in a gelatin binder.

Reimagining the Process: Polycolor Heliochromes
While the focus of the process has been on accurate image reproduction using camera-based negatives, the Emulsion Flakes also provide opportunities for artistic intervention in the creation of photographic images that the "experimental" uses of commercial sensitized materials, e.g., Lumigrams and Chemigrams, cannot.
By coating several light-sensitive pigmented gelatin emulsions in a single layer, it becomes possible to create a multi-color print with one exposure - significantly enlarging the visual possibilities of photographic printmaking. As such, the chance inflected PolyColor Heliochrome, with its accidental juxtapositions of form and color, is in direct opposition to both the predictable results of the digital toolbox and the rigid discipline of the historic Carbon process.
The PolyColor Heliochrome is the avant-garde version of the carbon process.
Used with camera-based images, the single-frame PolyColor Heliochrome challenges the authenticity of the photograph by bringing attention to the materiality of the photographic object and illustrates how the sensitized materials themselves influence presentation and comprehension.

Fig. 7–PolyColor Heliochrome

Fig. 8 – Charles Berger, *Artist's Gaze*

The unique gestural effects of the hand-coated PolyColor Heliochrome are most evident in the camera-less photogram, which is now multi-colored, rather than the usual white silhouette on a black background. Abstract and object oriented at the same time, the subject of the PolyColor Photogram is the emulsion itself.

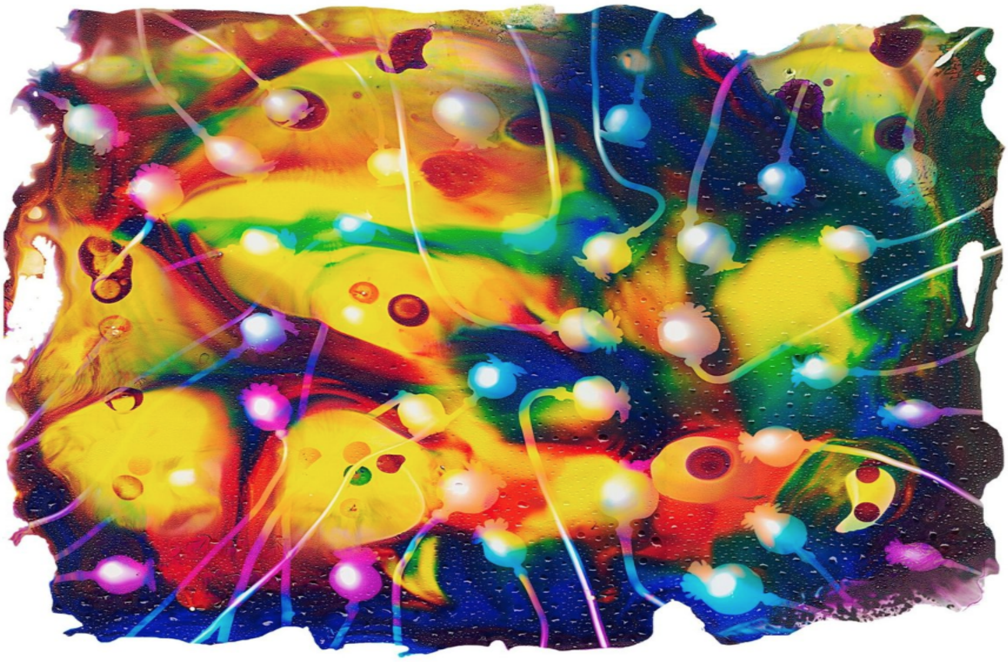


Fig. 9– Charles Berger, *Flowerings 4*

Conclusion

When the history of color photography in the twenty-first century is written, the nineteenth century Color Carbon Pigment Process will play a featured role.

Thanks to its superb image quality and permanence, along with its ability to adopt and adapt to the latest imaging technologies, the Carbon process remains in use today, long after other historic color print techniques have disappeared or become photographic novelties.

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Links

Art & Soul Photo https://artandsoulphoto.net/
Carbon Heliochrome www.carbonHeliochrome.com
Charles Berger Website www.charlesberger.com

A case study of the yellowing of an inkjet print by Tracey Emin

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Abstract

The Paper and Photograph Conservation Department at Tate has been investigating the damage of an inkjet print by Tracey Emin, after a bright yellow discolouration developed around the white borders of the print during an international touring loan. This prompted an inquiry into the cause of the yellowing, the possible solutions, and research into the wider problem of inkjet yellowing in cultural heritage collections. The following questions were posed as part of the investigation; Why did this print yellow – and what is the solution? Could this yellowing happen to other inkjet prints – and what is the solution?

In the case of the Tracey Emin print, a reaction between antioxidants and nitrogen dioxide has been identified as the most likely cause of yellowing. This paper will outline the steps taken to investigate the yellowing, including a review of the literature, testimonials from experts in the conservation field and comparison with a sister print held by The National Portrait Gallery, London. Tate's approach to the print will be discussed, including treatment options, the potential reprinting of the artwork, and the preventive measures put in place to protect other inkjet prints in the collection. The paper will also touch on other cases of inkjet yellowing, and the wider issue of the preservation of inkjet materials within cultural heritage institutions.

Keywords: inkjet, porous inkjet, inkjet yellowing, photograph conservation, preservation

Introduction

The last thing I said to you was don't leave me here II, is an inkjet print by Tracey Emin. The artwork was printed in 2000 on a cotton-fibre paper with a porous inkjet coating. Tate acquired the print in 2002 and according to our conservation records, it arrived in pristine condition, float mounted onto white museum board, and framed in an acrylic box frame. The print has been on display several times throughout our history of ownership and has remained in the original frame for both storage and display. Investigation into damage of the Tracey Emin print began in 2020 whilst the print was being prepared for an international touring loan. The print had developed a bright yellow discolouration around the white borders of the image whilst previously on loan in 2018 - the print had been on display for approximately 13 months when the discolouration was first noted. The print was removed from the frame on return from loan and has been stored in the conservation studio since then.

It was important that the yellowing of this print was investigated, and a solution found, not only so that the upcoming loan could go ahead, but from a conservation perspective it was vital that the cause of yellowing was understood, so that such damage could be prevented in the future.

Figure 13 - *The last thing I said to you was don't leave me here II*, Tracey Emin, 2000.

History and Deterioration of Inkjet Prints

Inkjet technology has been used to create fine art prints since the 1990s, and from the very beginning there have been concerns over the longevity of these prints. The first inkjet printers used dye-based inks which turned out to be extremely vulnerable to light and moisture (Benson, 2008 and Wilhelm, 2013), so from the mid-1990s, the industry sought to produce more stable pigment-based inks (Jürgens, 2009). The newer pigment-based inks had greater light, pollution, and environmental stability, with many predicted to offer greater permanence levels than traditional analogue colour photographic prints (Wilhelm, 2006). The inkjet supports however are still vulnerable to deterioration; inkjet coatings can crack from incorrect handling and environmental fluctuations, and some inkjet papers can yellow if exposed to pollutants (Jürgens, 2009).

Permanence testing of inkjet materials is routinely carried out by manufacturers, independent research institutes and independent companies. This has helped towards predicting the stability of inkjet prints somewhat. The effects of light, heat, humidity, pollutants and housing materials on the stability of inkjet prints have all been tested (Jürgens, 2009). This data can help cultural institutions to preserve inkjet materials in their collections as they inform decisions on light exposure, storage conditions, and appropriate enclosure materials. Predicting the permanence of inkjet prints is complicated however, as there are countless different ink sets and inkjet papers available on the market, and testing has revealed a huge disparity between permanence levels across different inkjet materials. As an example, light fading tests carried out by Wilhelm Imaging Research have shown that total fading of inkjet colourants can occur anywhere between 1 and 150 years of display, depending on the type of ink set and media used (Glynne, 2001). The vast range of inkjet materials, and in turn the large difference in their permanence levels, makes the preservation of inkjet prints a difficult task for cultural heritage institutions.

Yellowing of Inkjet Prints

Literature Review

The first step in this research was to undertake a review of the literature to understand why inkjet prints yellow. It is important to note that the yellowing of inkjet papers as discussed here, specifically relates to yellowing of the coatings applied to inkjet papers, which is different from the natural yellowing of the paper supports themselves which occurs over time. The literature points to a host of different reasons why yellowing can develop, including; light exposure

(Venosa et al, 2011; Venosa et al, 2016; Fischer et al, 2019), increased heat and humidity (Bugner et al, 2004; Bugner et al, 2005), degradation of optical brightening agents within the inkjet paper (Comstock and McCarthy, 2008; Reber et al, 2007), pollutants such as ozone and nitrogen dioxide (Burge et al, 2010; Burge et al, 2011; Fischer et al, 2019; Gordeladze et al, 2012; Kanazawa et al, 2004; Moeller, 2007), inappropriate housing materials (Mizen and Mayhew, 2001; Wilhelm, 2003), and absorption of antioxidants from plastic materials (Mizen and Mayhew, 2001; Wilhelm, 2003). It has also been reported that yellowing may not develop straight away after exposure to a damaging influence, but may develop sometime after, so the cause of yellowing may not be immediately obvious (Gordeladze et al, 2012). Certain types of inkjet papers are more susceptible to yellowing than others – the porous coating on some inkjet papers can readily absorb pollutants from the surroundings which can lead to yellowing (Gordeladze et al, 2012; Fischer et al, 2019; Moeller et al, 2007).

Inkjet Media

To understand why certain types of inkjet supports or 'media' may be more susceptible to this yellowing than others, it is important to understand their material structure. All kinds of different papers can be used as the base for inkjet media. Early fine art inkjet prints were often printed on uncoated papers, but since the 1990s, coatings, or ink receiving layers (IRLs), have been applied so that the inks are better received onto the substrate, creating a sharper and more stable image (Fischer et al, 2019; Jürgens, 2009). The two main types of IRL are porous and swellable; porous coatings are made up of fine mineral particles, often silica or alumina, in a binder of polyvinyl alcohol. The small gaps between the mineral particles create a surface of tiny pores which absorb liquid from the ink, leaving the pigment or dye particles close to the surface (Fischer et al, 2019; Jürgens, 2009). Swellable coatings are made from polymers which swell and absorb the inks, sealing the colourants into the IRL upon drying (Fischer et al, 2019; Jürgens, 2009). Both porous and swellable coatings can be added to many different paper supports, such as fine art papers, and also resin coated papers like those used for traditional analogue photography (DP3, 2022). The advantage of porous IRL's is that they quickly draw in liquid from the ink allowing for an instantly dry print, as opposed to swellable coatings which can take up to several hours to dry (DP3, 2022; Fischer et al, 2019; Jürgens, 2009). This open structure leaves porous inkjet papers vulnerable however, as pollutants from the surroundings are easily drawn into the coating layer which can initiate yellowing as well as deterioration of the inks (Fischer et al, 2019; Jürgens, 2009). The majority of inkjet papers sold for fine art purposes are now manufactured with porous coatings rather than swellable, due to the fact that they dry instantly (DP3, 2022; Moeller et al, 2007).

Impact on the Heritage Sector

The yellowing of inkjet prints is potentially a big problem for the cultural heritage sector, specifically the museums and institutions tasked with preserving them. A 2008 survey on the deterioration of digital prints within cultural heritage institutions, found the majority of institutions had seen deterioration of their digital print collection, and 30% of institutions had experienced paper yellowing – a large percentage considering that digital printing, including inkjet printing, is a very recent technology (Burge and Nishimura, 2008). Not only is this yellowing a common problem, but there are many potential causes, which makes this damage difficult to predict and therefore difficult to prevent. What's more, inkjet prints are being increasingly acquired by cultural institutions as the popularity for the technology grows amongst artists and photographers (Burge and Nishimura, 2008) and we know the majority of fine art inkjet papers now have porous coatings, which means the problem of inkjet yellowing could become more prevalent in collections in the future.

Conservation Testimonials

Contact with other photograph conservators in the field, from both the public and private sector, revealed that their experiences with the yellowing of inkjet papers largely corroborates what has been written in the literature. Conservators reported yellowing of inkjet papers after exposure to light – this was both sunlight which contains high levels of UV light, and museum lighting conditions with low light levels and no UV content. In the latter case, the yellowing was not immediately obvious, but occurred after the print had been stored in the dark for some time. This delayed staining of inkjet papers has also been demonstrated in accelerated light ageing tests (Wilhelm, 2003). Non archival housing and framing materials as well as pollutants from storage materials and the environment were also thought to be the cause of yellowing in some cases – it was commented that matt coated porous inkjet papers were more susceptible to this than others. One conservator reported that they had successfully removed yellow staining from the white border of an inkjet print by exposing the borders to indirect sunlight for just a few days, but warned that this staining could return if the print was subsequently stored in the dark. Tests by Wilhelm have demonstrated that this staining can indeed be bleached by light, and then return during dark storage (Wilhelm, 2003).

These testimonials from conservators speak to the commonality of the problem of yellowing, and its complexity. In many cases, it was impossible to say exactly what had caused the yellowing of an individual print - ‘real’ inkjet prints in collections may be exposed to many damaging factors throughout their lifetime, from mounting and framing materials to storage and display conditions, all of which influence how the print will age – and yellow. Unlike the scientific investigations outlined in the literature review, where variables are carefully controlled and measured, it might be difficult to say for certain why an inkjet print has yellowed in a real-life scenario.

Why did the Tracey Emin Print Yellow?

Considering the literature, testimonials, and the specific circumstances surrounding this print, it seems there could be several possible explanations for the yellowing. Light could have been a factor as the print had been on display for 13 months when discolouration was first noted. The paper contains OBA’s which could have degraded upon exposure to light or pollutants. The paper also has a porous coating, which could have drawn in pollutants and led to discolouration. However, the specific pattern of yellowing suggests that something in contact or close proximity to the print, such as the frame or mounting materials, caused the yellowing. The pattern of yellowing can be described as follows;

- Yellowing is solely on the white border – it has not extended into the printed image area (fig. 2)
- The yellowing does not cover the entire white border but is concentrated to a specific ‘band’ of discolouration around the border
- There are rectangular areas within the ‘band’ of discolouration which have not discoloured – these areas correspond directly to where Japanese paper hinges and adhesive have been applied to the verso, which has protected the recto from discolouring in these areas
- The verso of the print is still in pristine condition and has not discoloured at all (fig.3) – this suggests that it is the ink receiving layer that is yellowed, rather than the paper support itself

The frame construction was analysed in detail to investigate whether this could have caused the yellowing. Removal of some of the mountboard within the frame allowed us to see more clearly the mounting and framing materials. Figure 4 details the frame structure, which consists of an

oil board backboard to which a wooden subframe and central corrugated board support was attached. A sheet of white mount board was attached to the wooden subframe using double sided adhesive film, and the print was hinged onto this mountboard. The acrylic box cover was screwed into the subframe, and the frame was not sealed at the back.
If we compare the frame construction with the pattern of yellowing, it is obvious that the area of staining directly corresponds to where the wooden subframe and adhesive film sat under the print whilst it was in storage and on display (Figures 5 and 6). But could these materials have led to discolouration?

Wooden Subframe
Wood is known to off-gas and emit acids which can lead to deterioration and yellowing of cellulosic materials such as paper (Grzywacz, 2006), however the back of the paper, which was in closer proximity to the wooden subframe, has not discoloured, only the ink receiving layer has been affected. We know that pollutants are readily absorbed by porous inkjet papers, so it is possible that acids off-gassed by the wooden subframe could have been absorbed by the coating and led to yellowing of the IRL.

Double sided adhesive film
This type of film usually consists of a clear plastic carrier sandwiched between two layers of acrylic adhesive (Down et al, 2013). These films tend to have good ageing properties, and there is no sign of deterioration of the carrier or adhesive in this case. Several articles have expressed concern however, that antioxidants found in plastic materials could cause yellowing in inkjet prints (Afirm Group, 2021; Mizen and Mayhew, 2001; Wilhelm, 2003). The antioxidant, butylated hydroxytoluene (BHT), has been implicated as the cause – BHT is a phenolic antioxidant added to plastics and adhesives, like those found in tapes, to prevent ageing (Afirm Group, 2021; O'Loughlin and Stiber, 1992). Phenolic antioxidants are the most widely used antioxidants (Mills and White, 1987; O'Loughlin and Stiber, 1992). BHT is known to be highly volatile and can easily transfer into other absorbent materials, and when it reacts with nitrogen dioxide in the environment, highly coloured quinoid structures are formed. This is known as phenolic yellowing, which is said to be bright yellow in colour and can happen extremely quickly (Afirm Group, 2021; O'Loughlin and Stiber, 1992). Much of the research surrounding phenolic yellowing has been conducted by the textile industry as it affects fabrics that have been stored in plastic bags containing phenolic antioxidants (Afirm Group, 2021; Bangee et al, 1995). Some manufacturers of porous fine art inkjet papers have also warned of this phenomenon – a technical data sheet of a Somerset Fine Art Inkjet Paper with a porous coating, states that;

"Coated papers can react to organic solvents, plasticisers, and antioxidants. These products could be contained in tapes, plastic bags, dry mounting film and could cause discolouration of the print." (St Cuthberts Mill, 2022).

Fig. 2 – Detail of yellowing on white border

Fig. 3 – Verso of print

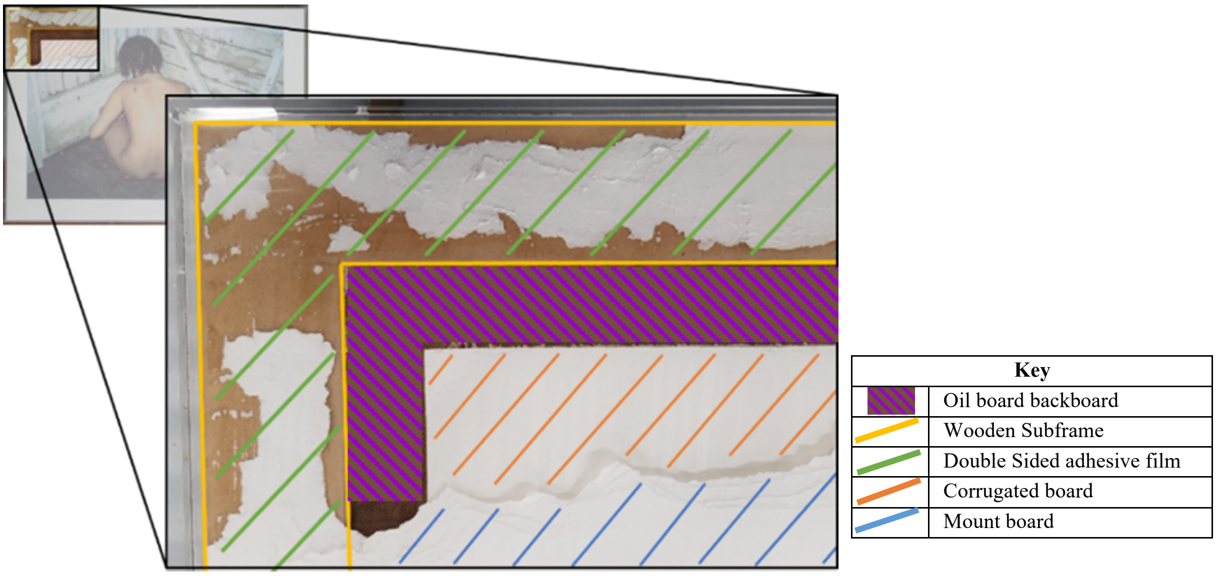

Fig. 4 – Detail of internal frame construction

Fig. 5 – Yellow rectangles outline the area of discolouration on the white border

Fig. 6 – Green rectangles outline the area where the wooden subframe and adhesive film sat within the frame

It is the writer's opinion that discolouration in this print was most likely caused by absorption of antioxidants from the plastic film. The position and pattern of discolouration corresponds directly to where the adhesive film sat under the print, the adhesive film is a likely source of BHT or another phenolic antioxidant, and the porous inkjet paper would have readily absorbed volatile antioxidants from the adhesive film. According to the literature, nitrogen dioxide would have to be present for the phenolic yellowing reaction to occur - nitrogen dioxide is a common pollutant in museum environments (Blades et al, 2000) and as the back of the frame was not sealed, nitrogen dioxide could have easily entered the frame and interacted with the antioxidants to form yellow compounds.
Of course, it is possible that other factors have contributed to this yellowing, for example pollutants and acids from the wooden subframe, light exposure, or degradation of OBA's within the paper, but antioxidants reacting with nitrogen dioxide seems to be the primary cause of yellowing in this case.

Sister Print
Our hypothesis was reinforced after visiting The National Portrait Gallery (NPG), London, to see the sister print of Tate's print. The NPG print was printed in the same year and on the same paper as Tate's, and it has also been on display several times since it was acquired in 2000, however it is still in pristine condition with no yellowing of the white border. The NPG print had been framed in a more traditional way however, with a wooden frame which had been fully sealed at the back. This reiterated our theory that it was the mounting and framing materials which caused the yellowing in Tate's print.

What is the solution?
The print cannot be displayed as the yellow staining is distracting and disrupts the aesthetics of the artwork. Although the simplest solution would be to cover the staining with a window mount, this would contradict the intended display specifications for the print, which is for it to be float mounted with the white borders visible. Therefore, other options had to be explored.

Treatment
The only known treatment for the removal of yellow staining from an inkjet print is light bleaching. Removal of the yellow staining would restore aesthetic harmony to the artwork and the image itself could be covered during bleaching to protect it from light exposure. However, the literature and conservator testimonials suggest that staining could return after light bleaching, and to the writer's knowledge, there has been no research on the long-term effects of light bleaching on inkjet papers. At this time, it is not considered a safe treatment for this artwork.

Reprinting
Aside from conservation treatment, the only way of reinstating the aesthetics of the artwork would be to reprint. A lot has been written in recent years about the practice and ethics of reprinting as a preservation strategy for photographic artworks (Marchesi, 2017; von Waldthausen, 2017). In certain cases, institutions are opting to reprint photographic works which are too damaged to be displayed. Tate has a Replication Advisory Group who guide decisions on the replication of artworks in the collection, and they have recently supported a research project with artist Rineke Dijkstra to reprint three faded chromogenic prints as inkjet prints. Reprinting seems to be the most appropriate option for the Emin print at present, and this is the likely route that Tate will take, as we cannot guarantee that any conservation treatment will permanently and safely remove the yellow staining on this print.

Could this yellowing happen to other inkjet prints?

The literature and testimonials from other conservators tell us that the yellowing of inkjet prints is a common problem. Worryingly, aside from the Emin print, the Paper and Photograph Conservation Department at Tate have witnessed several other cases of inkjet yellowing during the short time that research on the Tracey Emin print has been undertaken.

The first case was a set of thirteen inkjet prints that were sent to Tate for condition checking prior to acquisition – they arrived as pictured (figure 7) sandwiched between sheets of cardboard which had been secured with brown parcel tape. Yellow discolouration had developed on the white border of each print, corresponding directly to where the brown tape had been placed around the cardboard package (figure 8). In a similar scenario, a single inkjet print arrived at Tate, again for condition checking prior to acquisition. This arrived as pictured (figure 9) packaged in a cardboard folder using paper photo corners secured with masking tape. Yellow discolouration had developed on the print directly under where the masking tape had been placed (figure 10) – this was despite several layers of paper acting as a barrier between the masking tape and the print surface. In both scenarios, it is clear that tape has caused the discolouration, and it did not have to be in direct contact with the print surface, but close proximity within the packaging was enough for yellowing to develop. The last case is a set of inkjet prints by Sammy Baloji that Tate have recently acquired (figure 11). As part of the making process, the artist has applied an unknown adhesive to the verso of each print (figure 12). When Tate acquired these works, they all exhibited bright yellow discolouration on the printed side which corresponds to where adhesive has been applied on the verso (figure 13). In this case it was not tape, but adhesive which seems to have caused the yellowing. It is also important to note that these prints have previously been displayed pinned directly to a gallery wall, unmounted and unframed, meaning that pollutants could have interacted with the prints surface at some point.

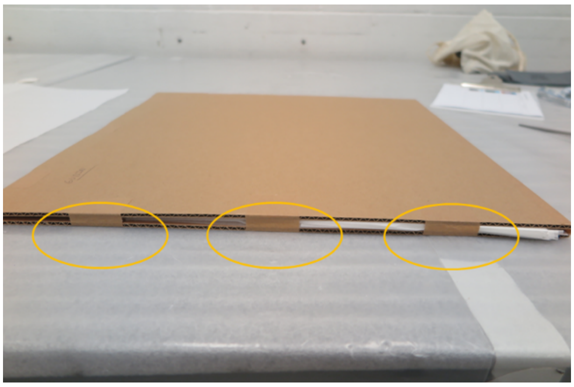

Fig. 7 – 13 inkjet prints arrived in cardboard packaging secured with brown tape around the edges

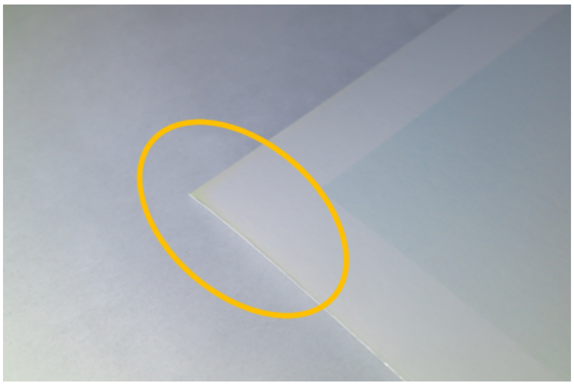

Fig. 8 – Yellow discolouration on one inkejet print corresponding to where tape had been applied on the carboard packaging

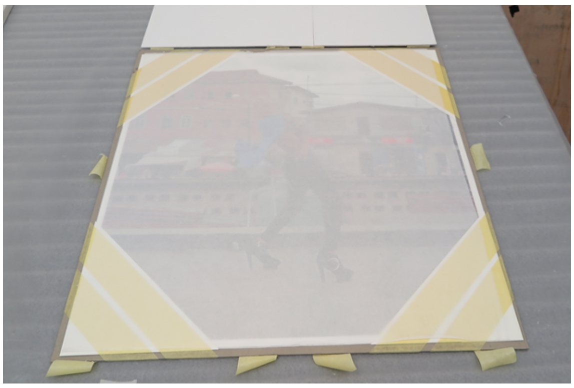

Fig. 9 – Single injet print secured into a card folder using paper photo corners and masking tape

Fig. 10 – Area of yellow discolouration across one corner of the inkjet print where masking tape had sat above in the packaging

Fig. 11 (left) – Inkjet print by Sammy Baloji
Fig. 12 (right) – Adhesive applied to the verso of print

Fig. 13 – Detail of yellow discolouration on printed side of a Sammy Baloju inkjet print

What these examples have in common, including the Emin print, is that they are all printed on porous inkjet paper, and tape and adhesive seems to be the primary cause of yellowing. In the case of the Emin and Baloji prints, pollutants and light exposure could have also been a factor. It is clear that yellowing of inkjet prints is happening in our collection right now. But what is the solution?

What is the solution?

Steps at Tate

The Paper and Photograph Conservation Department have taken several steps so far to try and prevent the yellowing of inkjet prints in the collection. We have revised our packing guidelines for inkjet prints arriving at Tate, which includes the following recommendations:

- No tapes or adhesives should be adjacent to inkjet prints in the packaging
- Any loose inkjet prints should be housed in polyester sleeves to protect them from other packaging materials - polyester is considered a safe plastic for use with inkjet prints (Image Permanence Institute, 2014; Jürgens, 2009) and will provide a barrier from pollutants or other materials within the packing which could lead to yellowing
- Packages should be properly sealed with polythene to prevent pollutants from entering

The department would also like to review our current mounting and framing practices for inkjet prints. As an example, we often mount photographic prints, including inkjet prints, using paper photo corners secured with Filmoplast P90 archival tape. So far, we have not seen any problems with the tape when used with inkjet prints, but like many tapes and adhesives, the exact material composition of the tape, and whether it contains antioxidants for example, is not known. We have seen how sensitive inkjet prints can be to tapes and adhesives, so it is important to know that the materials we are using are appropriate and will not induce yellowing.

We also intend to test light bleaching as a treatment option for yellowed inkjet prints – we plan to carry out microfade testing on the yellow staining of the Emin print to see if it is indeed fugitive to light, so that we can explore the benefits and drawbacks of this as a treatment.

Conclusion

The yellowing of fine art inkjet prints is a known problem in the conservation field, but there are limited published case studies detailing real-life scenarios of this damage. It is hoped that by sharing the experiences of one institution and specific instances of inkjet yellowing, this

research will make a positive contribution to the field and aid in our understanding of inkjet deterioration.
Throughout this research, the question of why the Tracey Emin print yellowed has been answered - most likely a reaction between antioxidants absorbed into the porous inkjet paper, in combination with nitrogen dioxide from the environment. A solution has also been found - in this case it is likely that the work will be reprinted. Hopefully, this research has also highlighted the complexity of inkjet yellowing in cultural heritage collections, namely because the diversity of inkjet materials and the many possible causes of yellowing, makes it difficult to predict and prevent this yellowing. Further instances of inkjet yellowing within our institution has prompted a reassessment of our own practices as a conservation department and has emphasised the need for due care and attention for the specific preservation needs of inkjet materials. We cannot assume that the appropriate practices and standards applied to analogue photographic prints, are also appropriate for inkjet prints.
There is fantastic research being undertaken in the cultural heritage field surrounding the deterioration and preservation of inkjet prints in heritage collections, as we have seen in the literature referenced above. Through continued research and collaboration, institutions, and individuals responsible for the care of inkjet materials will be increasingly equipped to deal with their complex preservation needs.

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Digital Unfading of Chromogenic Film informed by its Dyes' Spectral Densities

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Extended Abstract

Introduction

A significant challenge in the preservation of cinematographic heritage is the fading of the image dyes. This phenomenon primarily affects chromogenic film produced between the 1940s and 1980s, compromising its original appearance and commonly resulting in a pink/magenta cast. The gravity of this irreversible chemical deterioration has been highlighted in the film preservation community since the 1970s (Adelstein, Graham, and West, 1970; Miyagawa and Shirai, 1985; Wilhelm, 1993).

While chemical treatments have not proven to be adequate for the restoration of faded film, digital image processing has been used over the last decades to numerically reverse the fading. Gschwind and colleagues described the contribution of the dyes' side absorptions in the digital image capture and developed the linear bleach model (Gschwind, 1989; Gschwind and Frey, 1997), laying the foundation for the development of a spectral approach to digital dye reconstruction. Based on the linear bleach model, Ando et al. proposed a digital restoration method that uses correction matrices to account for the side absorptions, in which the matrix coefficients were determined with target reference colors (Ando, Hansuebsai, and Khantong, 1997). Chambah and Besserer, further attempted to remove the effect of side absorptions in the digitization process by testing the effectiveness of correction matrices based on both linear and offset bleach models (Chambah and Besserer, 2000). We proposed a method that allows to achieve more creditable results from digital unfading by using the spectral densities of the film dyes in two stages: (I) to quantitative determine the contribution of each emulsion layer to the R, G and B image formation and (II) to compute the supposed color aesthetics of the original film before fading.

A complete digital restoration method

This abstract presents a concise version of an already published work about a new material-based approach for the digital restoration of faded chromogenic colors (Trumpy and Chatterjee, 2022). The method reconstructs a supposed original look of film projection before fading based on two main assumptions about chromogenic film stock. **1** - Considering the film a non-scattering material, the Beer-Lambert law can be considered valid, so the overall spectral density of the film is the sum of the spectral densities of the individual dyes with weights corresponding to their local concentration. **2 -** The fading of a dye can be modeled as a single multiplication factor that uniformly reduces the spectral densities of the individual emulsion layer containing the fugitive dye.

To test this approach, a case study was conducted on a faded Agfacolor print from 1945 exhibiting a strong magenta coloration. This unique element—a 35 mm combined positive on a cellulose acetate base—was a projection print of the 'cultural film' "Panorama No. 4". Bibliographical research led to the determination of the optical properties of the dyes used in

Agfacolor positives during the production period of the film (Schultze, 1951). This finding was pivotal to determine the film element's spectral densities in order to reconstruct the original aesthetics of the film to the best of our knowledge.

The complete procedure unfolds in five steps, which are schematically reported in Fig. 1.

Image capture – The residual color information present in the "Panorama Nr. 4" film element was digitized with a scanner constituted by a 3-channel LED illumination system and a 16 MP monochrome camera. The sequential capture of each film frame with three RGB narrow-band images allowed minimizing the 'cross-talk' effect due to the dyes' side absorptions, thus capturing images whose correlation with the transmittances of the individual emulsion layers is highest (Trumpy and Flueckiger, 2015).

The information about the spectral densities of the film dyes (Schultze, 1951) and the spectral power distribution of the LEDs (measured with a spectroradiometer) allowed to quantitatively determine the contribution of light absorption of each emulsion layer in the three digital images captured by the scanner (Trumpy and Chatterjee, 2022). The contributions are reported in percentages in Fig. 1 on the 'captured images', indicating that the blue is a mix of consistent amounts of all three dyes; green has primarily magenta with some cyan and a small amount of yellow; red has primarily cyan with some magenta and a small amount of yellow.

Dye purification – Based on these percentages, a computational method is developed to obtain images corresponding to the individual emulsion layers of the film. This image processing method is called "dye purification" (Trumpy and Chatterjee, 2022).

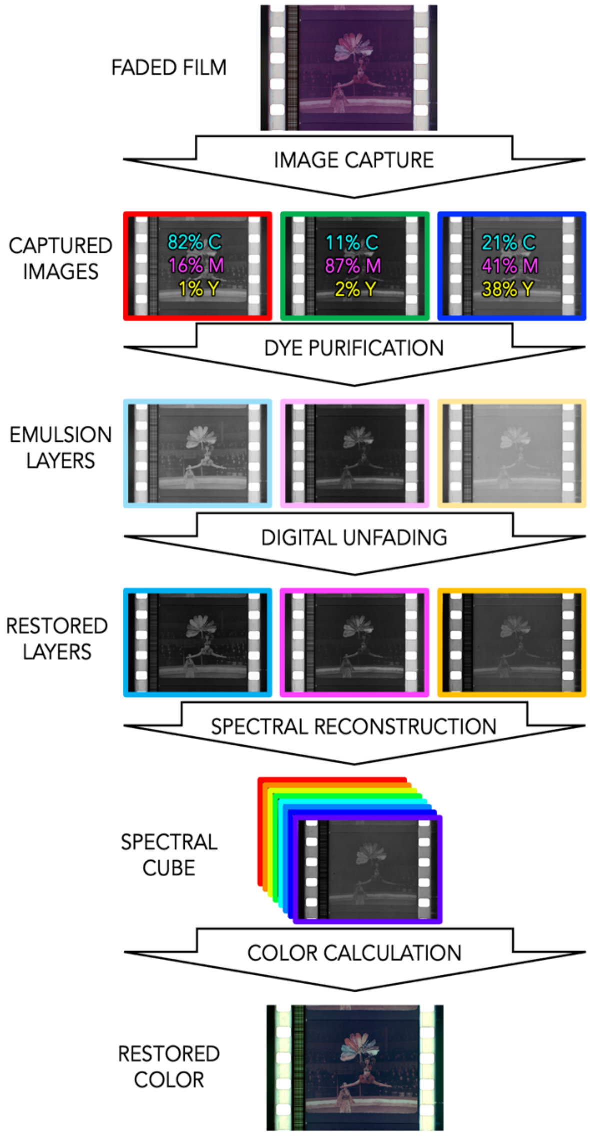

Figure 14 – Diagram depicting the five steps of the proposed spectral approach for the digital restoration of faded chromogenic film.

Digital unfading – The original absorptions of the individual emulsion layers are obtained numerically counterbalancing the fading of yellow and magenta, assuming that the unexposed parts of the film (i.e., the areas in between the frames) were originally black.

Spectral reconstruction – The restored images contain monochromatic transmittance values. To obtain the final aesthetic of the unfaded film, it is necessary to build a spectral cube in which each pixel contains the film transmittance in the full visible range. The original absorption spectra of Agfacolor positive material reported in the historical literature (Schultze, 1951) were associated with the restored images to create a hyperspectral cube that represents the optical properties of the film before fading in the whole visible range.

Color calculation – By leveraging the psychophysical properties of the human visual system, the final aesthetic of the restored film is calculated from the spectral cube performing colorimetric calculations (Trumpy, Hardeberg, George and Flueckiger, 2021).

Result
The current state of the faded Agfacolor print “Panorama Nr. 4” and the result of the digital restoration are reported in Fig. 2, illustrated by four selected frames.

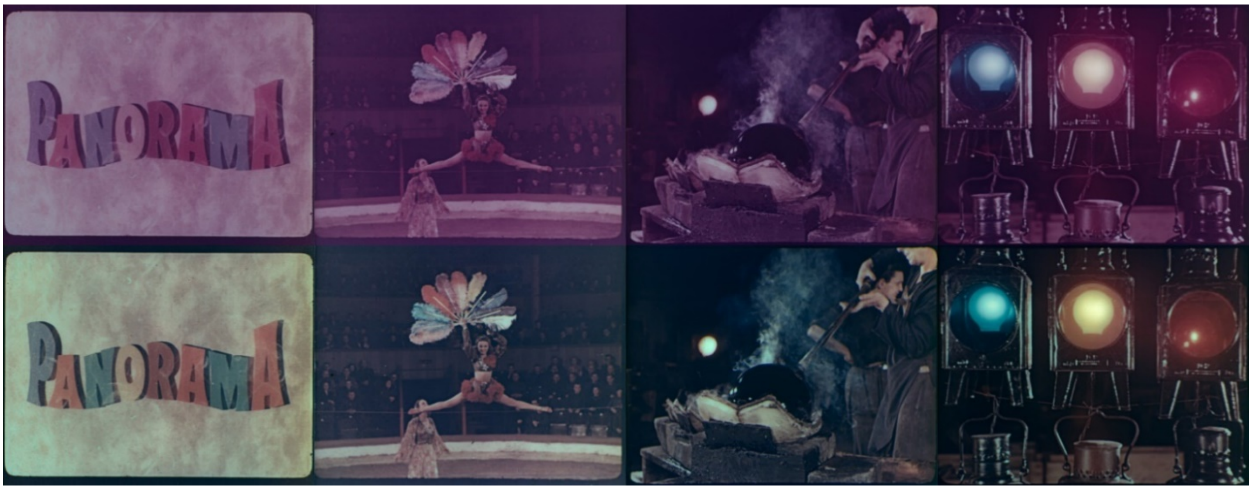

Figure 2 – *Top: Four exemplary frames of Panorama Nr. 4 as it looks today. Bottom: The supposed 1945 original colors resulting from the proposed spectral approach of digital restoration.*

Conclusion
The proposed digital restoration method is a material-based, quantitative approach to infer the original optical properties of a chromogenic film and reconstruct its supposed appearance before fading. The validity of the five-step method is based on the extraction of the residual color information present in the film with an image capture. Prior knowledge about the analytical spectral densities of the film allows the development of an image processing technique called “dye purification” that provides images corresponding to the individual emulsion layers. A selective restoration of the faded dyes is thus possible. The following steps of spectral reconstruction and color calculation allow us to finally reconstruct—to the best of our knowledge—the original aesthetics of the faded film. In the presented case study, historical literature aided the determination of the spectral densities of the dyes contained in the investigated Agfacolor material, which were imperative for the successful implementation of the restoration procedure.

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A method to predict the light stability of colour prints displayed under LED light with different spectral irradiance

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Abstract

The action spectra of three colour patches of an inkjet print were determined by the exposure with narrow band LED light. The action spectra provided allowed to make a prediction for fading of white light LED with different relative spectral irradiance (RSI). This approach was found to be superior to predicting damage potential by the correlated colour temperature (CCT) of the LED or by measuring total irradiance. The study confirmed that the most destructive spectral range in visible LED lighting is the short wavelength between 400 nm to 520 nm.

Keywords: action spectra, light stability, inkjet print, print display, LED Lighting

Introduction

To assess the damage of prints on display, the usual approach is to measure the total irradiance or illuminance of the display light and estimate damage from published data. This approach works if the relative spectral irradiance of the display light source and of the published data are very similar (Wilhelm and Brower, 1993). But if the relative spectral irradiances of two light sources are different, the total irradiance or illuminance is not suitable to predict damage (Baumann and Hofmann, 2004, pp. 699-704).

The V lambda curve used to calculate lux has a very low sensitivity in the blue region of the light spectrum in which damage potential to materials is often highest. Fig 1a and 1b show the relative spectral irradiance of typical light sources normalized to 500 lux. Measured with a lux meter, all four curves would read 500 lux. Due to their different spectral irradiance in the short wavelength region, they would fade sensitive materials differently.

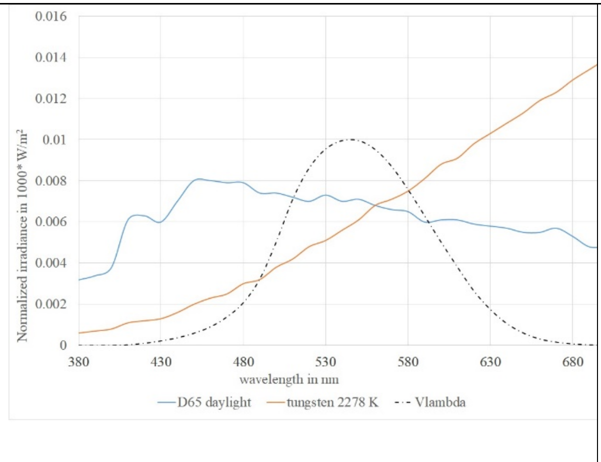

Fig. 1a D65 and tungsten irradiance normalized to 500 lux, V Lambda

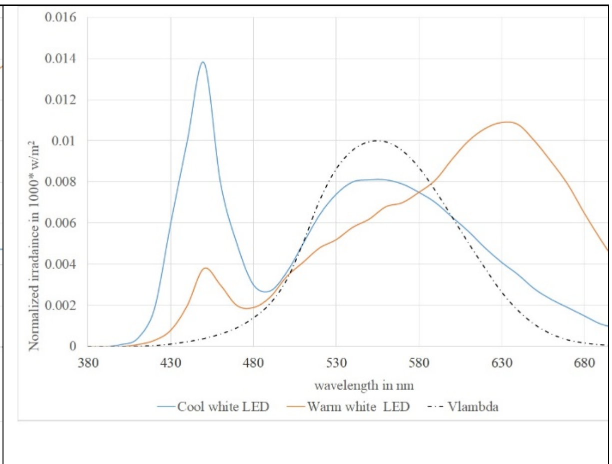

Fig. 1b white LED irradiance normalized to 500 lux

Traditionally, indoor lighting was a mixture of window glass filtered daylight and tungsten halogen or fluorescent tube light. A wealth of published data existed for these types of lighting for photographic materials. Modern indoor light often comprises of LED lighting. It is difficult to specify a typical relative spectral irradiance (RSI) for LED lighting, as many different types of LED are available. This means that light stability has to be investigated for many different LED lighting conditions.

The method described is another approach to predict fading for white light LED. The fading of inkjet colour patches is measured under narrow band LED exposure. This allows to derive action spectra which are used to predict light fading under various lighting conditions with different relative spectral irradiances.

Experimental set-up

The experiments were done in a light exposure chamber with nine pairs of narrow band LED in the range of 385 nm to 620 nm and four 4 types of white light LED (6500 K, 5000 K, 4000 K and 2700 K). The temperature of the sample plane was held at 24 °C +/- 2 °C and 45% r.h. +/- 7% r.h. The test sample was a dye-based ink print on nanoporous RC glossy paper. Three printed patches of each yellow, magenta, and cyan at density about 1 and the paper white were investigated. A thin polyester foil prevented pollutants to be absobed into the nanoporous surface of the sample during exposure. After exposure, the fall-off from the middle to the edges of a printed medium grey of 20 mm diameter was less than 10%.

The relative spectral power distribution of each LED was measured with an Ocean Optics 2000 spectrometer. The total irradiance of each LED was determined by a power meter at the sample plane. At fixed time intervals, the sample was removed from the chamber and the exposure for every LED was calculated from the power measured and the time elapsed. The reflectance spectra of the exposed sample as well as the CIELAB colour coordinates (D50,2°, no filter) were measured at every step.

Action spectra of colour and patches

An action spectrum is defined as a change as a function of an excitation wavelength (van Ackere et al., 2001, pp. 213-217). In the following description of the method, only the magenta patch is shown. To derive the action spectra for the magenta colour patch, the changes for each excitation wavelength have to be plotted as a function of exposure. As an example, the density changes (D-D0) for one excitation wavelength, 405 nm, for the magenta peak at 560 nm is shown in Fig. 2. The two curves (Pos1 and Pos2) are the experimental results of each of the two LED of 405 nm.

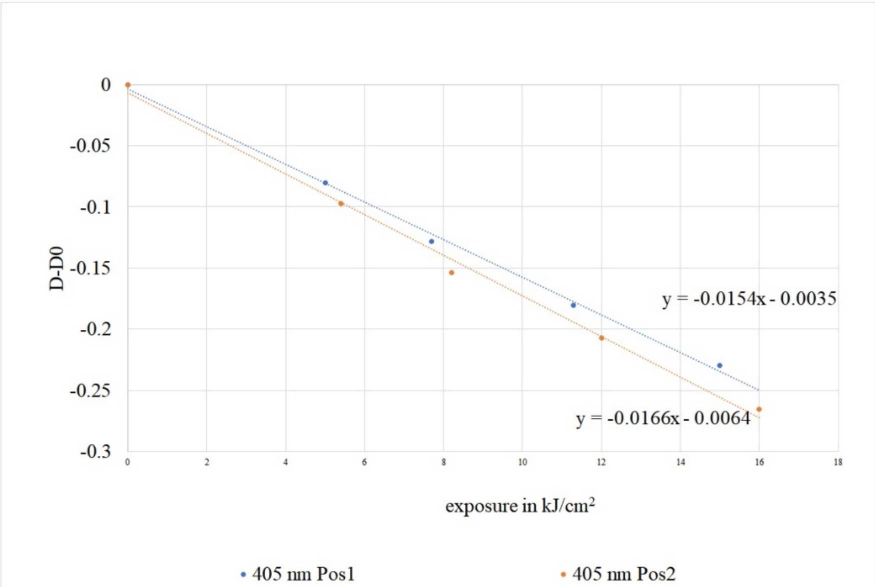

Fig. 2 –Density change of magenta peak on magenta patch as a function of exposure

The negative of the slope of the curve in Fig. 2 represents the sensitivity of the colour patch to light of 405 nm wavelength. To determine the action spectra, the sensitivities of the colour patch to all narrow band LED light have to be measured.

The procedure was repeated for all three colour patches. The resulting action spectra for the cyan, magenta and yellow patch are shown in Fig. 3a, the absorption spectra for those patches in Fig. 3b.

For the magenta and the yellow patch, the action spectrum resembles the absorption spectrum albeit with higher sensitivity at shorter wavelength for magenta. The inkjet cyan does not degrade with light absorbed in its principal wavelength of 600 nm but only with light shorter than 450 nm, which has been reported in the literature for phthalocyanine colorants (Lerwill et al, 2014, pp. 457-463).

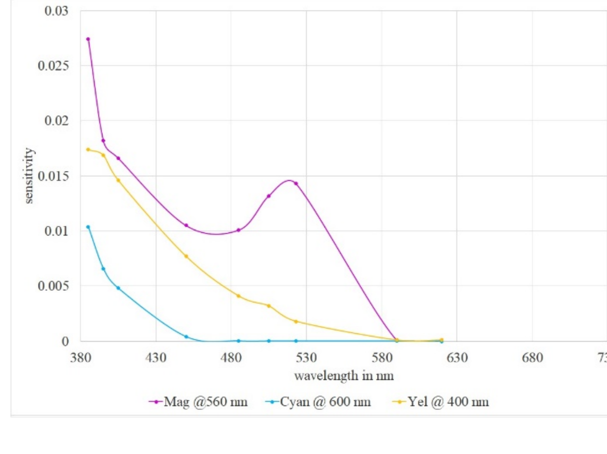

Fig. 3a – Action spectra of C,M,Y patch

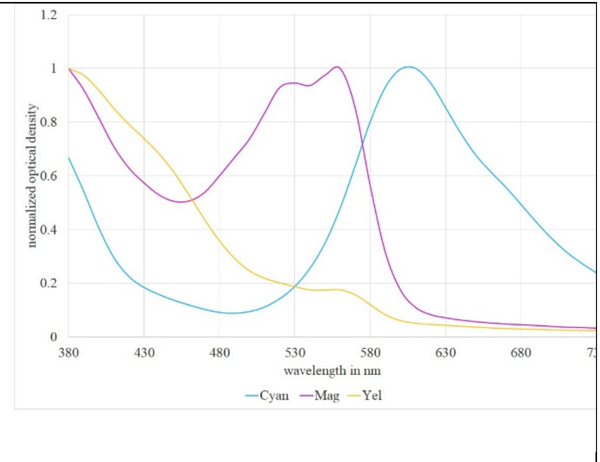

Fig. 3b – Normalized absorption spectra of C,M,Y patch

Prediction of fading for white LED light

For colour fading, white light LED can be composed as a sum of narrow band colour LED. A factor analysis provides the amounts of coloured light that makes up the white light. The overall fading under white light is the sum of the individual narrow band colour fading contributions weighted by the factor derived from the factor analysis. The calculations below are again shown for the fading of magenta only.

The changes of the magenta patch at 560 nm for 20 kJ/cm^2 exposure were calculated from the action spectra above and compared to actual fading at for 20 kJ/cm^2. For the LEDs of CCT 4000 K, 5000 K and 6500 K, the predicted fading was between minus 0.18 and minus 0.23 density, which is inside experimental error of the actual fading of minus 0.15 to minus 0.26 density. The predicted fading for the LED of 2700 K was less, minus 0.12 to minus 0.15 density, inline with the actually observed fading of minus 0.1 to minus 0.18 density units. The two LED at each wavelength were evaluated separately to provide the tolerance limit above.

With the exception of the white LED with CCT 2700 K, all other white LED generate similar fading in the magenta patch. This rather surprising result, as it does not shown an effect of the CCT of the LED, stems from the fact, that the 6500 K, 5000 K, and 4000K white LED have a similar RSI in the most critical spectral region of 400-520 nm. For those three LED, the ratio of the maximum blue peak in the range 440 nm to 450 nm and the green peak at 555 nm is between 1.1 and 1.5 whereas the LED of CCT 2700 K has a ration of blue peak to green peak of 0.7. This ration seems to be an important indicator of damage potential.

Conclusions

Neither the total illuminance or irradiance alone nor the total irradiance in combination with the CCT of white light LED are suitable to predict the damage potential for inkjet prints. In addition to the total irradiance, the relative spectral irradiance, in particularly the RSI in the range 400 nm to 520 nm, is crucial to predict damage. This confirms a study done white light LED from Ishizuka et al. (2019b, pp. 192-196) which found that the height of the blue peak and excitation wavelength rather than the CCT of the LED correlated with the fading of the prints. For the prediction of display life, more colour patches than those used in the study would need to be investigated.

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Pace by Nino Migliori: examination, analysis and treatment of a contemporary color photography experimental artwork

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Keywords: Nino Migliori, The Walls Series, Chromogenic Color Print, Photographic Materials, Experimental Contemporary Photography, Color Photography.

Extended Abstract

The aim of this paper is to illustrate the work devoted to the study of the execution technique of *Pace* by Nino Migliori and the characterization of its constituent materials. This complex artwork of experimental contemporary photography was created by the renowned Italian photographer in 1973 and is part of the MAMbo – Bologna Museum of Modern Art's permanent collection since 1975. In particular, the present work intends to focus on the study phase which preceded the conservation treatment performed on *Pace*, given the particular nature of the artwork in which the photographic materials and the media of contemporary art coexist in a unique and complex interaction. Therefore, an in-depth research on its execution technique, structure and components was deemed necessary in order to plan and perform an adequate conservation treatment.

Fig. 1 The artwork framed (diffused visible light) and unframed (raking light) before the conservation treatment.

This study was conducted as a part of a master's degree thesis project carried out at the Fine Arts Academy of Bologna which, especially in the last few years, has dedicated constant and particular attention to photographic and contemporary materials, with a focus on color photography.

Pace consists of a large format c-print (100 x 100 cm) mounted on an aluminum panel by the author himself but, among this common type of contemporary photographic mountings, it represents an interesting and unusual case. Most of the work was done to investigate the structure of the artwork and to characterize the materials used by the artist.

The research was divided in three phases, each with the aim to analyze a particular matter of the object. The first phase entailed a thorough literature search on the series of *Walls*, to which

Pace belongs, conducted in order to understand and contextualize the artwork within the author's production. Nino Migliori started shooting in the late 1940s and to date he is one of the most active experimenters in Italian photography. His heterogeneous production is made up of both canonical works in documentary style and incredible experiments such as the one of the *Walls* series. It can be considered one of the founding series of his production and during the thirty years of shooting walls, from 1949 to the late 1970s, Migliori has investigated the wall surface in an original way and from different points of view. The research cleared out that *Pace* was made during the last years of Migliori's research on the wall concept and that, among the works of the same years, it is definitely among of the most experimental ones.

Subsequently, during the second part of this study, a few interviews were carried out with the aim of gathering information on the artistic and social context in which the photographer conducted his experiments. In this phase, there was the opportunity to discuss with Paolo Barbaro from CSAC (The Study Centre and Communication Archive - University of Parma), who has collaborated for years with the author, the photographer himself Nino Migliori and the Director of the Nino Migliori Foundation, Maria Nella Truant. Having the chance to discuss with all of them was an incredible opportunity and definitely a turning point of the research. This allowed to reconstruct precisely the process behind the creation of *Pace*, by providing fundamental insights for the study of the execution technique. On this occasion, it was made clear that the print was in fact not only applied on a secondary support, using vinylic-based adhesive applied with a brush, but it was also manipulated by the photographer himself, who experimented on the artwork by applying sand of different grain sizes above and below the print to reproduce the wall's surface. Nino Migliori also made use of other media such as chalk, varnishes, and synthetic paints to emphasize some graphic elements of the photograph as to give it a realistic appearance. The complexity of the artwork's execution technique and the use of sand have probably contributed to exacerbate some conservation issues, which are in any case frequently observed on this type of mountings, such as detachments of the photographs from the underlying metallic panel and subsequent planar distortion of the prints. Therefore, this part of the study turned out to be fundamental for the reconstruction of the creation process and the identification of the causes of deterioration.

Eventually, in the third and last phase, the more technical aspects of the artwork's creation were addressed, focusing on the materials characterization and the identification of the component layers stratigraphic sequencing, by using both non-invasive and invasive diagnostic techniques. First, non-invasive investigations were carried out, such as photographic documentation in diffuse and raking visible light, UV fluorescence investigation, microphotographic analysis with digital microscope and chemical-physical measurements of contact angle, pH and ionic conductivity of the surface. Then, after micro-sampling the print and the superficial layer, some invasive investigations were carried out in order to define the stratigraphic sequencing and to characterize the constituent materials. To identify the stratigraphic sequencing, the micro-samples in polished sections have been observed using a polarizing microscope and a scanning electron microscope (SEM). Through these analyses it was possible to observe the thin layers of the samples and to identify the stratigraphic sequencing of both the superficial layer and the print. To characterize each layer, it was necessary to compare the data gathered through an EDS Microprobe and FT-IR spectroscopy analyses. These analyses allowed to observe and characterize the thin layers of the samples, enabling to identify the exact stratigraphic sequencing and to confirm that the color photograph was a chromogenic print, as hypothesized during the previous stages of the research. The knowledge gained through these investigations turned out to be of fundamental importance for the selection of suitable materials and intervention methods ahead of the conservation treatment.

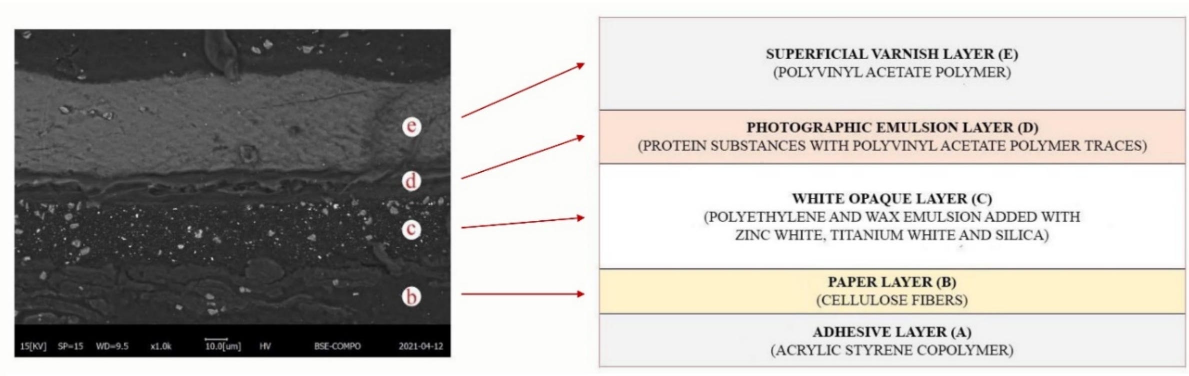

Fig. 2 Scanning electron microscope (SEM) image in which layers e, d, c, b can be identified (left) and graphical representation of the stratigraphic sequencing of the chromogenic print and surface layer. Layer a cannot be detected in the SEM image since the superficial layer was missing in the analyzed sample.

To perform a safe and effective conservation treatment, it was necessary to elaborate a new intervention methodology, developed specifically to treat the severe alterations observed on the artwork, bearing in mind its peculiarities as a photographic object and concurrently a contemporary work of art. Before the treatment, the c-print was unevenly detached from the underlying aluminum panel and solving this problem was in fact the main focus of the treatment. The methodology elaborated to address this issue consisted in two phases: the first one concerning the solvent reactivation of the original adhesive and the second one involving the addition of small amounts of Plextol® B500 adhesive in demineralized water (1:1 ratio). The use of the solvent made possible to reactivate the original adhesive, allowing the re-adhesion of the c-print detachments on the aluminum panel, while the addition of small amounts of a conservative adhesive in some specific areas helped to restore the adhesion where the original glue amount was not enough, hence inefficient. Both the solvent and the new adhesive were applied by brush along the margins and by injection with a syringe in the most internal areas. At this point, an adequate amount of weight and pressure was applied on the surface until the complete evaporation of the solvent or the drying of the new adhesive, to ensure the adhesion of the print to the aluminum secondary support. During this phase, a layer of non-woven fabric sheets or Melinex® sheets, and felts was placed between the artwork and the weights, with the aim of protecting its delicate surface.

Fig. 3 The artwork framed (diffused visible light) and unframed (raking light) after the conservation treatment.

In conclusion, it may be said that this multi-disciplinary approach was essential not only to understand how the artwork was made and how the interactions and connections between its different layers and materials worked, but also to provide the necessary knowledge to plan a safe and effective conservation treatment.

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Contributions to the Characterization of Chromogenic Dyes in Colour Slides

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Keyword: Chromogenic reversal films, colour slides, chromogenic dyes, characterization, chromatography, Infrared Spectroscopy, Raman Spectroscopies

Extended Abstract

Chromogenic reversal films (or colour slides) are first-generation positive transparencies. These were used for various purposes, namely as an artistic medium, especially from the 1960s onwards.

The chromogenic process is grounded on colour separation principle to reproduce a real scene, using superimposed emulsion layers coated on base (Pénichon, 2013). Each emulsion layer is composed of colour couplers, silver halides and sensitizing dyes within a gelatine binder. During processing, the colour couplers, initially colourless, react with the developer which has previously been oxidised by silver development to become dyes. After processing, the blue sensitive layer reproduces the yellow (Y) elements of the reproduced scene, the green sensitive layer reproduces the magenta (M), and the red sensitive layer reproduces the cyan (C). At the end of the processing, all silver is removed (Current, 1987).

Although each manufacturer employed its own colour couplers, all the industry worked with materials with similar structures (Reilly, 1998) The most important classes of Y couplers are pivaloylacetanilide and benzoylacetanilide. Later, other classes of Y couplers have been employed, such as cycloalkanoylacetanilides and malonanilides. M couplers are normally heteroaromatic compounds; the major classes are pyrazolones and pyrazoloazoles. Most C couplers are substituted phenols or naphthols. In general, the dyes resulting from the reaction of M and Y couplers with the developing agent are from the azomethine family, while those resulting from C couplers are from the indoaniline family (Rauch, 1973). Schiff base is one of the most important functional groups present in the three dyes, which is associated to the imine bond created between the molecule of the colour coupler and that of the activated colour developer. The Schiff base is an essential link in the conjugated system, being responsible for the absorption of the dye and therefore for its colour (Jesper, 2015).

Chromogenic materials, in general, are intrinsically vulnerable to chemical degradation, having poor long-term stability. Chromogenic dyes are highly susceptible to oxidation and hydrolysis, both induced by light (light fading) and/or relative humidity and temperature (dark fading) (Wilhelm and Brower, 1998). Continuous contact with environmental agents gradually disrupts the chromophore molecules, leading to the formation of colourless degradation products, responsible for the fading of the image (Reilly, 1998). Since the three dyes present in a film have a different molecular structure, they also have a different degradation rate. Therefore, these materials are prone to shift the original colour balance. Residual colour couplers are also vulnerable to oxidation, producing yellowish species (yellow stain) (Bergthaller, 2002). This is especially visible in the highlight areas of the image (Wilhelm and Brower, 1998), where residual colour couplers are present in higher quantity (Tuite, 1979). Furthermore, the interaction between residual colour couplers (nucleophiles) and dyes (electrophiles) can accelerate dye fading (Tuite, 1979). Improper processing can also decrease dye stability and/or enhance staining levels (Wilhelm and Brower, 1998). Over the years, it has been demonstrated

that degradation products generated by dark and light fading can be different, since the two degradation courses might lead to different disruptions of the chromophores (Bergthaller, 2002). The same film can be very unstable when exposed to light and quite stable in the dark (Wilhelm and Brower, 1998).

During the present investigation, a gap of knowledge regarding the conservation of chromogenic materials was detected. Up to now, there are several references describing molecule structures, degradation pathways and preservation guidelines. Nonetheless, there is still no methodology to identify the dyes present in a specific work. From this premise, a research study was carried out focusing on the characterization of chromogenic dyes, taking as case studies slide-based artworks by the artist Ângelo de Sousa (1938-2011). Two different 35 mm chromogenic reversal films used by the artist were selected: i) Kodak Ektachrome 160T Professional (EPT), and ii) Fuji Fujichrome Provia 400X Professional (RXP). The pursued methodology sought to test the efficiency of some of the most common analytical techniques used in the study of cultural heritage. Both non- or micro-invasive techniques were explored. Based on the straight analysis of emulsion layers and on the isolation of the different dyes composing the chromogenic material, several procedures were proposed to molecularly describe the dyes found in chromogenic reversal films. Different techniques, such as Thin-layer Chromatography (TLC), High-Performance Liquid Chromatography with Diode Array Detector (HPLC-DAD) and linked to Mass Spectrometry (HPLC-MS), and Infrared and Raman Spectroscopies, were compiled.

Raman spectroscopy has shown the ability to characterize chromogenic dyes. Micro-samples were collected from the borders of the chromogenic reversal films under study, to analyse C, M and Y emulsions separately. The confocal microscope of the equipment was used to select the desired coloured areas. The dyes from EPT and RXP samples produced different Raman spectra (Figure 1).

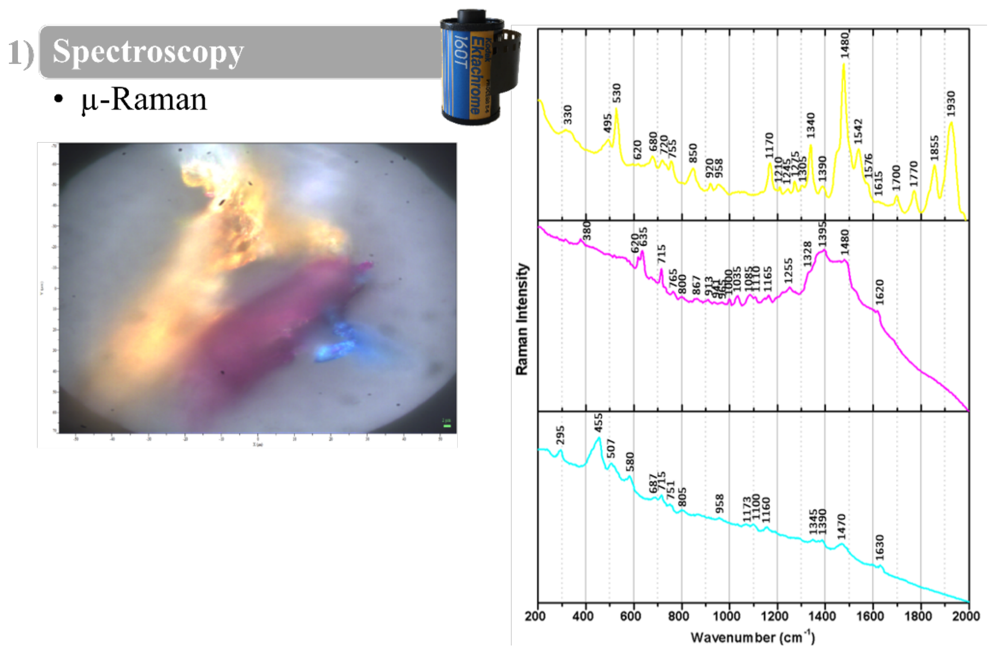

Figure 1 – Analysis of Kodak Ektachrome 160T Professional (EPT) using µ-Raman spectroscopy (1st approach).

Chromatographic techniques also proved to be powerful tools to isolate and characterize chromogenic dyes. As a major disadvantage, all tested chromatographic techniques require the collection and destruction of a small sample. However, considering that the borders of chromogenic reversal films can be used to remove a sample without compromising the image, and that the analysis of one sample can bring insights into several works (of the same model/batch), collecting a sample can be easily justified. TLC has the advantage of giving immediate and easy to interpret information, by displaying coloured spots in the TLC sheet. By calculating the R_f of the separated dyes, additional information about the compounds under study was gathered. Knowing that every molecule has a specific R_f value for a specific solvent and solvent concentration, TLC analysis provides evidence of the identity of the compound. Additionally, the time and the cost associated to this type of analysis is substantially lower when compared with liquid chromatography. Most importantly, by using preparative TLC, the separated compounds can be isolated and used for further analysis. In the present study, the isolated dyes were characterized with IR spectroscopy. The collected IR spectra provided fingerprint spectra of C, M and Y dyes from EPT and RXP samples.

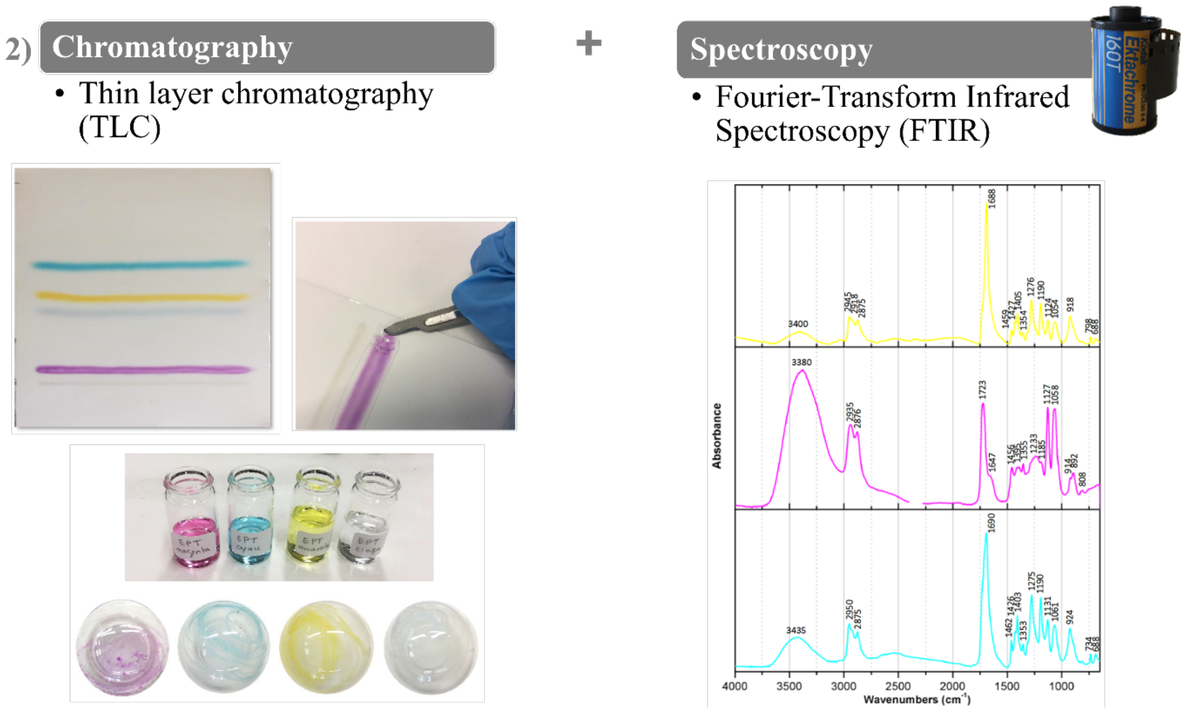

Figure 2 – Analysis of Kodak Ektachrome 160T Professional (EPT) using TLC for the separation of the dyes, compiled with FTIR spectroscopy (2nd approach).

HPLC has also been traced as a useful technique for the characterization of chromogenic dyes. As in TLC, the R_t associated to each dye in a specific HPLC equipment separated with a given elution program offers additional information about the molecules. Linked to DAD, the absorbance spectra of each dye can be observed. The shape and maximum of the absorbance spectrum of a dye in the visible region can provide a clue to differentiate and characterize the different samples. Based on the shape of the M dyes, it is proposed that M from EPT is from the pyrazolone family. The absorbance spectra collected in DAD also worked as background information for the analysis with MS. Thereby, the peaks of interest (dyes) were selected and analysed with MS. The isotopic profiles of the accurate masses attributed to M and Y dyes from the EPT film, respectively, indicate that the colour couplers associate with these dyes may have some chlorine atoms in their structures.

The main difficulties encountered within the investigation, was the inexistence of references to support the assignment of the obtained results to specific families of chromogenic dyes. Although the tested analytical techniques have shown promising results, building databases of chromogenic dyes for Raman and IR spectroscopies, HPLC-DAD, as well as MS, might be the key for the identification of these materials.

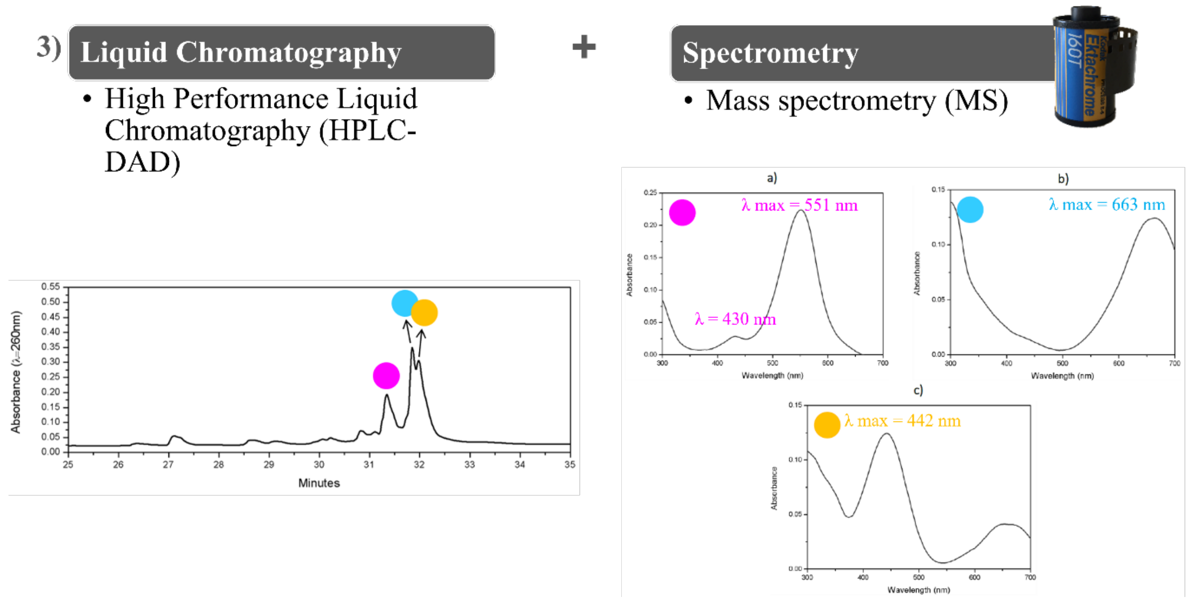

Figure 3 – Analysis of Kodak Ektachrome 160T Professional (EPT) using HPLC-DAD for the separation and characterization of the dyes, compiled with MS (3rd approach).

Nevertheless, promising results were achieved with this approach, opening new paths for the understanding these materials. Yet, this was only a preliminary study and needs further development.

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On the identification of colour photographic processes

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Abstract

For a preliminary screening of colour photographic processes, a visual inspection can be conducted to identify the used printing process and establish the subsequent investigations more consciously.

The visual inspection protocols derived from the literature do not offer a completely easy reproducible practice as some require the use of specific instruments with excessive costs. The following study aims to define a more inclusive procedure that exploits portable and inexpensive instrumentation. The methodology proposed is composed of four steps for the study of prints, from the macroscopic to the microscopic scale. The procedure's applicability was proven by analyzing a set of photographs: the result is a diversification of the collection both in terms of materials and formats. Furthermore, since the prints come from uncontrolled conservation contexts, it was possible to observe the forms of degradation typical of this condition.

To present the project, an open-access website called "Color photographic processes – Preliminary identification by visual exam" (https://mips.di.unimi.it/wp/) has been created.

Keywords: Colour photography, Identification, Conservation.

Introduction

Photographic prints combine subtractive dyes to create all colours using different subtractive processes. These processes share a dependence on the light sensitivity of silver halides, while their primary difference lies in how the dyes are formed and deposited (Weaver, 2014; Messier, 1999). Some features differ from one process to another, allowing us to identify the printing procedure, such as the order of the CMY layers, the type of support, the border, the structure of the image and the forms of decay that afflict the prints (Lavedrine, 2003; Wilhelm, 2003; National Film Preservation Foundation, 2004). The four processes considered in this study are: the dye coupler process, the dye destruction process, the dye transfer process and the internal dye transfer process.

Materials and Methods

Instruments

Optical instruments used in this project differ from the others used in literature for their portability and affordability. The apparatus has been chosen considering magnification capacity and consists of 10x magnifying glasses and two portable microscopes (PocketMicro 20x-60x LED Lighted Zoom Microscope, CARSON; MicroBrite Plus 60x-120x LED Lighted Pocket Microscope, CARSON).

The identification protocol

The proposed methodology derives from the state of the arts; the sources used are Graphic Atlas (Image Permanence Institute, 2017) and the information given by conservators Gawain Weaver (Weaver, 2014 and 2020; Weaver & Long, 2009) and Paul Messier (Messier, 1999). The novelty of this protocol lies in the fact that it considers the forms of degradation as fundamental in the identification of unique characteristics of the single process.

A four-step methodology is used: I. Print observation: preliminary visual examination of the print; it considers the type of support, colours and tones of the image, the formats, the border and the backprint; II. Surface observation: visual examination of the surface using the proper light angle of incidence on the image surface to define the surface sheen and texture; III.

Magnifications observation: visual exam through portable optical instruments to define image structure and layers; IV. Decay and damage: description of the forms of alteration and degradation and evaluation of the state of conservation.

Protocol's application

The applicability of procedure was proven analyzing a set of seventy photographs, dating back to the period between the mid-60s and 00s. The prints come from uncontrolled conservative conditions, which is the reason why almost all photographs are affected by typical forms of deterioration of incorrect handling, exposure and storage.

Conclusion

The primary objective of this work is defining a more inclusive procedure for the preliminary identification of colour photographs that exploits a portable and inexpensive instrumentation.
The procedure has been developed considering the state of the arts. In this way, the established protocol was modified in order to obtain an accessible and easily reproducible methodology, whose strengths are simplicity, practicality in the use of the instruments and the affordability and attainability of tools. The need for portable instrumentation, however, has resulted in the impossibility of obtaining digital images of the enlargements, preventing the collection of exhaustive photographic documentation in support of the descriptions given during the Magnifications observation.
It is created an open access website, "Color photographic processes – Preliminary identification by visual exam", to show the processes, their history, the protocol, the characteristic forms of alteration and degradation and the application to a real collection.

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"The stuff that dreams are made of." – Color and Cinema between creation and restoration. Notes for a history and a road map for research.

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Abstract
Since 1895, through the analog and the digital eras, color is among the many narrative and aesthetic tools cinema language used in its creative process to shape a unique multi-sensorial experience for its audience. Over these years, numerous cinema color techniques, technologies, aesthetics, and ideologies came and went. One thing that stayed the same is that color in cinema more than a technology is a complex system made up by many components: filmmakers' ideas and intent, negotiations with the audience, technologies (such as film stocks, chemicals, cameras, printers, developing machines, projectors), and laboratory processes and practices. Taken individually, none of these elements tells the *whole story* of color use and experience in cinema. Much of cinema color technology history is not recorded in books, journals and patents and often not even remembered (as so much of it relies on individuals' practices and memories), therefore a new, more comprehensive approach is called for in research to make possible the restoration of color cinema (which is, the recreation of its effects on the audience through modern, totally different means).

Keywords: color, cinematography, film technology history, film history, film restoration, color film, color processes, history of color technologies.

Introduction, or "To know that we don't know..."

"*Cinema has never had a phase when it was not in color: colors were there, immediately. Immediately as a deliberate addition, a supplement, contingent by nature, thus a fortiori implying intent and purpose.*" (Aumont,1995, p.30, *my translation*)

Not only color is present from day one in the history of cinema, but its role has always been much more complex than a mere device to improve the "realism" of cinema experience. Cinema has always been very much aware that nothing is less "*natural*" than cinema colors and derived meaning (narrative, emotional, aesthetical) from this "unnaturalness" of film colors and that sort of "*interference zone*" created by the chasm between cinema's inherently unnatural colors and their interplay with viewers' perception and cultural references of colors in the real world. Color in cinema has always had a wide range of functions, effects and meanings going beyond the mere intent to technically reproduce, record and simulate the "real world" and into the realms of language, narrative, aesthetics, culture, and ideology. It is not possible to study cinema while ignoring color or considering it *just* a technical addition, as it was a continuous presence whose characteristics and functions changed constantly in a mutual interplay between creative intent and technical possibilities and limitations (the keyword here being "*mutual*"). To study cinema and its colors implies to study film works under conditions that reproduce as faithfully as possible those for which they were conceived. This in turn means to *represent past color systems correctly in the modern environment,* which is the definition of "color restoration". To this aim, a deeper knowledge (or more precisely a complete characterization) of the hundreds of cinema color systems and processes is a necessary precondition. As essential to research as they might be, such characterizations of past and present cinema color environments simply do not exist today, at least not with the granularity and detail that is necessary to the task. As we plead the case of the urgent necessity of such an approach to the study of cinema color(s) we propose some reflections towards a roadmap for research, and a methodological approach

***In principio erat color*- A walk through cinema color history.**
Preliminarily, we should reacquaint ourselves with the main '*geological eras*' in the history of cinema color. (Fig. 1).

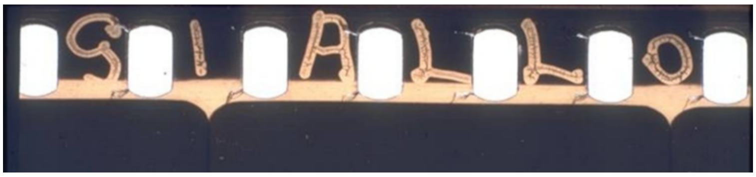

Fig. 1 -instructions for tinting on a Cines film from the mid1910s (author's collection).

1. Applied colors (1895 – mid to late 1920s). Already with the Lumière Brothers and G.Méliès, cinema starts applying dyes (broadly termed *anilines)* to B&W positive images (which provided density modulation) by using techniques derived from photography or textile and printing techniques ((hand-painting, tinting and toning, mordanting, stencil coloring).
In practice, every shot or scene was separately printed onto B&W film and processed before applying coloring; the resulting separate, colored positive segments were finally assembled following detailed instructions (a.k.a. positive cutting). Although cumbersome and labor-intensive, these processes rapidly became omnipresent and very soon films were nearly all 'colored' at distinct levels of complexity. Color effects became very sophisticated, with dozens of dyes and combinations of tinting, toning and stencil coloring, the latter reaching very high levels of 'realism. Çolor was a key element of cinema's language, aesthetics, and marketing strategies. From the mid-1920s, applied colors were slowly pushed aside by a combination of factors: language and aesthetics were changing; longer films and post-war globalized cinema market imposed higher productivity, forcing labs to automatize and streamline their workflow. When the advent of sound-on-film made positive-cutting impossible, manufacturers offered pre-colored film stocks compatible with soundtracks, but by then cinema had moved on from applied colors.

2. "Natural" (i.e., recorded) color systems, Additive, (A) – the 1900-10s. Not yet two decades old, cinema started researching systems to "*record the colors of nature*" - as opposed to simulating them by applying colors on B&W images. At the time, additive synthesis was the obvious choice. With the concept being already known to photography and performed on Magic Lanterns, all the early results came from there: Friese-Greene, Gaumont's Chronochrome, Kinemacolor, Technicolor1. All systems were based on the simple principle of filming 2 or 3 B&W separation negative images through fixed or rotating filters, and to recombine the resulting positive images in projection through corresponding filters by either subsequent frames projection or superimposition on screen. Ingenious as they might have been, additive color systems failed to have a real impact on cinema at large and did not make it into the 1920s (except for some late *zombie* returns, like *Francita*). Few films were produced per process as it was soon clear that audiences were not excited enough by the idea of "*natural* colors" to endure the many obvious technical limitations the systems suffered from. Firstly, film emulsions were not really fully panchromatic yet, leading to doubtful color reproduction, even more so because most were 2-color systems. Secondly, subsequent exposures through rotating filters (e.g., Kinemacolor) showed serious color fringing due to temporal parallax, while those (like Chronochrome) who avoided temporal parallax by exposing three frames at once through a special lens holding 3 RGB filters, suffered from color fringing due to *spatial* parallax. By

introducing the so-called '*beam splitter*' (or *prism divider* - an optical device that allowed the exposure of two frames at the same time, through the same lens), Technicolor solved all parallax issues, only to find out that superimposing two images on the screen was tricky at best: "*Dr.Kalmus has said: " I concluded that the operator would have to be a cross between an acrobat and a professor.*" (Cornell-Clyne, 1951, p.12)"
Finally, additive systems were uneconomical: they required special projectors and they used twice or thrice the amount of film stock. Additive was out and would return only with electronic and digital imaging.

3 "Natural" (i.e., recorded) color systems, Subtractive (B), non-chromogenic. (in practice Technicolor 2 to 6: 1920s-1980s, semi-revived 1990s).
Capture: 2or 3 B&W negative film images thru 3 color filters (=RGB negatives) / Reproduction: positive film w/ (R>)C/ (G)>M /(B>)Y images obtained by dye- transfer (a.k.a. 'imbibition') onto blank film (with or without a low density B&W 'key image').
By the mid-1920s (just a decade or so after the failure of additive systems) the landscape of cinema technology is changing: 35mm film format is fully standardized 16mm is just born, cameras are increasingly motorized (same as projectors), continuous developing machines (which at the same time allow and impose a great deal of control) are in use, film printers are semi-automatic with more precise and constant exposure control, standards are written and maintained by organizations like SMPE-Society of Motion Picture Engineers, (founded 1913). In short, the whole workflow of exposing, processing, editing, printing, and projecting films is fast becoming more controlled, automatized, and standardized, more like a modern industry than a homemade craft. Still, past experience and experiments (like applied colors and additive color systems) are not forgotten but form a vast legacy of techniques and technologies: the 'additive way' might have proven a dead-end, but very useful lessons had been learned: 2-color separation was 'barely good enough', but 3-color would be ultimately needed; recombining 2 or 3 filtered images in projection led to endless problems In short, subtractive process, with CMY-colored images somehow combined on one piece of film *and* on the same frame was clearly the way forward. It was only logical that to find a practical solution to bring color back to the screens, cinema would first turn to its recent past, to tried and tested technologies and processes that could be refined thanks to the new 'industrialized' cinema environment. After all, additive systems showed how to produce B&W color separations without parallax, while applied colors taught how to turn a B&W positive image into a colored one by toning or mordanting. Technicolor was therefore the company best positioned to win the race, and it did. Adrian Cornwell-Clyne's "Colour Cinematography" is still the one 'book that says it all' about cinema color history and technology up to 1951, containing a wealth of information as well as carrying the point of view of a direct witness of cinema color history in the making. No wonder that his is the best description of what Technicolor achieved: "*This famous process owes more to engineers than to chemists, seeing that to work it successfully nothing new to photography had to be made, all its elements were ready to hand, nothing new had to be invented that was not mechanical, or that was more than refinement upon existing practice. [...] Why was this? Because the film was printed not by the action of light upon a sensitive substance but by the mechanical transfer of dye from a matrix in relief—a true type of printing.* (Cornwell-Clyne 1951, p. 451)
In other words, the subtractive, non-chromogenic color process that dominated cinema from the 1930s until 1980 belonged in reality *more in the 19th than the 20th century*.

4. "Natural" (recorded) color systems (C) – subtractive color systems /chromogenic monopack (mid-**1930s-today)**: various 'families' from Kodachrome reversal process to Agfacolor and derivates, then Eastmancolor, and derivates.

Capture: 3-layer monopack negative film and/or reversal w/internal filtering, and integral color masking (only Eastmancolor and derivates). Reproduction: positive 3-layer (CMY) monopack color positive film w (R>)C/ (G)>M /(B>)Y images from color negative.

The Technicolor process undoubtedly provided cinema with a quite effective (and visually stunning) solution to the problem of bringing color film to the audience, but the solution was fundamentally limited to one provider and one market (the US for high-budget productions), so, in a sense, it was a one-shop, small-scale, pre-industrial craft when compared to the system that cinema had built around B&W, which was a highly standardized, mass-production, high-output, fully globalized industry where anybody (big-budget or amateur) could buy a camera (*any* camera), a roll of film (*any* B&W film), expose the film, have it processed, printed and projected (or commercially distributed) anywhere in the world. In this sense, the cinema industry felt that something was still amiss, that it needed to build for color the same fully integrated ecosystem it had built for B&W, that it needed something else than Technicolor. Simply put, ***cinema needed a true color negative/positive system***.

With this goal in mind, researchers (at (Eastman Kodak - pushed by the US industry, and at the infamous IG Farben - under Goebbels' orders) went back to the drawing board and started literally from scratch, as if the previous three decades of color cinema had not existed. Back to scratch meant Ducos du Hauron who in 1897 introduced the concept of a multilayer emulsion - the "*Polyfolium Chromodialytique*". From there, they slowly moved forward to the research and patents (ca.1907-1914) by Benno Homolka (who discovered the first true color developer) and Rudolph Fischer who applied Homolka's discovery to the concept of multilayer color-coupler development. Once Kodak and IG Farben overcame the problem of dye couplers wandering around the emulsion, integral tripack or monopack color film was born as Kodachrome and Agfacolor (both in the1930s). The fundamental difference in concept between Kodachrome and Agfacolor being that in the former dye couplers were added in the developer bath, while in the latter they were inside the emulsion.

After the initial excitement, monopack negative/positive processes were judged more closely, and the awful truth became soon apparent: they were not suited for cinematography, not without improvements. Again, Cornwell-Clyne is precise in his analysis: "*The weakness of processes employing an original record in colour lies in the difficulty of making duplicate master negatives without obtaining unacceptable degradation or distortion of colour and/or loss of resolving power. In general, as is now well recognized, magentas have excessive absorption of blue and, to a lesser degree, of green, while cyans also have excessive absorption of blue and green.*" (Cornwell-Clyne, 1951, p388).

Since the late 1920s, rather than a negative>positive process, cinema is a negative > duplicate positive > duplicate negative > positive process. For the system to work, the end-result (in terms of contrast, grain, resolution, color reproduction) of a positive printed from a negative and a positive printed from a duplicate negative must be ideally identical, and realistically '*close enough*' (the extent of 'enough' varying with the date, the place, and the cost of printing). By the late 1940s, this multi-generational system worked perfectly for B&W, so any color system was expected to achieve the same. Obviously, any distortion, deviation or degradation in parameters encountered in the Neg/Pos process would be amplified exponentially in a multi-generation process. This was less critical for reversal films (they are usually not printed), or for films for which so few prints are made that they could be all printed from the original negative, as it in the case of isolated Third Reich. But for a new color system to be considered successful in the postwar world, an effective multigeneration process was '*condicio sine qua non'* and the very reason why Agfacolor was not good enough, just like other ingenious but ultimately irrelevant systems (e.g., Gasparcolor, Dufaycolor, etc.). Therefore, years were spent finding turnaround solutions to counterbalance the absorption distortions of the monopack film until at the end of the 1940s Kodak's technology of ***integral color masking*** was mature enough to be

introduced, first in the Ektacolor negative, and at last (!) in Eastmancolor *'for professional motion pictures*'. It is the beginning of the last chapter of analog color cinematography: unmasked color materials derived from Agfacolor will still have a short life, but Eastmancolor will soon come to dominate, either directly from Kodak or licensed to others.
When Eastmancolor appears, there is indeed a sense of '*end of history*'- that cinema had solved the recorded 'natural color' problem. And in fact, not much will happen for decades except for new Eastmancolor emulsions....

5 Digital intermediate workflow (1990s- ca2010)
Capture on 35 or 16mm color camera negative > scan at 2k, later 4k > complete digital postproduction > film-out onto negative/intermediate film > positive prints made from film-out negatives (a.k.a. "digital negative). Correlation between image characteristics at shooting and those at projection: very low to zero. Each production had its workflow, with different equipment, image processing (e.g., 3D-LUTs) to the extent that it became a system 'proprietary to each laboratory. Color science entered the labs (after many years), but the process was really dominated by 'visual matching' of different displays, including film projection. All digital cinema technologies (scanners, film recorders, digital projection, color imaging software, etc.) have origins in in this phase.
In retrospect, the 1990s were an interesting, if confused and confusing decade for color cinema. On the photochemical front, Technicolor *'threatened'* to return, with various ideas or actual attempts to revitalize it; although it never happened, the idea itself had some consequences. Directors and cinematographers who were shown the new Technicolor trial prints were awed to see how saturated the colors were, and how much details were retained in the shadows compared to a standard Eastmancolor print. Kodak feeling threatened responded with new products with improved contrast and saturation. A bleach bypass'' process was proposed and sometimes used to increase contrast and improve blacks on Eastmancolor prints (similar to what Technicolor used to do 50 years earlier by adding a low-density B&W '*key image*' to the CMY colors). Bleach by-pass went away, and Technicolor never returned, but an important seed was planted in many creatives' minds: after five decades of domination, Eastmancolor's qualities were questioned, perhaps there were ways to improve its images, there was *'life after Eastmancolor'*.
Besides, digital imaging was entering cinema, at first too slow and costly for anything but SFX. But technology went fast and in 1998 the first feature film post-produced in what later was called "Digital Intermediate-D.I." was released. D.I. came to an end in early 2010s when film distribution on 35mm all but disappeared. Despite its short life, there are few key concepts and ideas that are important to retain from D.I...
First, in those years analog color film was the *'alpha and the omega'*. The ideal D.I. setup was to be perfectly transparent: the final result, once recorded back to negative and printed onto a positive film, was to *'look and feel'* 100% just like a positive derived from an all-film workflow. All techniques, software and hardware aimed at that result. Scanners, for instance, were tuned precisely (in terms of exposure, internal image processing, filters, optics, etc.) for the color camera negative *of the time,* having troubles scanning anything but current Kodak camera negatives. This is relevant today because the whole spectrum of technologies (from digital cameras through digital projection) and know-how that are still in use today come straight from there, from a 'film is king' era.
Then, because a D.I. environment implied input and output on film that were totally different from everything digital happening in between, there was an enormous need to understand the relations between analog film images and their displays, and digital images and theirs. In other words, color science for digital *and film* entered the film lab, for the first time in decades.

The fast embrace of the D.I. by directors and cinematographerswas due to the higher degree of creative freedom but also to that idea of '*going 'beyond Eastmancolor*' mentioned earlier that one could somehow stretch the limits of Eastmancolor towards a new aesthetics. It was the beginning of the end for photochemical film colors.

6. Full Digital capture and projection (dominant from 2010) **or, happily back to additive!**
After 115 years, dyes were no longer involved in the creation of colors on a cinema screen: it happened sometimes around 2010 (the exact date varies in different countries) when film distribution turned 100% away from 35mm positive prints. The switchover in the cinemas was extremely fast, and behind the scenes an important side effect is that color science became suddenly less relevant because an all-digital chain meant the world was again in a WYSYWYG mode: ***who cares about the gamut of Eastmancolor or Technicolor if everything is DLP?***

A question of granularity.
Such a high-level, macro-history walk through history of cinema color/s is hopefully useful to structure the discourse, identify key concepts and major shifts but a serious approach to the research necessary to characterize past cinema color systems and map them faithfully into modern systems and displays implies a much greater level of granularity in order to take into account not only the hundreds of color systems, but also the variables and variants *within* each system. We need to consider a picture that is even more complex than often assumed, at least in most of the existing literature.

Granularity 1: how many colors systems?
Proposing a precise figure for the number of color systems in cinema history is the first, difficult methodological hurdle. What do we count precisely? Are we counting actual patents or references (knowing that some could be just ideas, never realized)? And to what extent do we group them? Does Technicolor count for one or six, or more? How many branches on the Eastmancolor family tree? How many applied colors do we have? Does each formula for tinting and each for toning count as one separate process or do we group them somehow? And so forth...
Whatever the rules defining a comprehensive list, we must think in terms of hundreds, not dozens of entries. A simple list of dyes and processes used in the 'applied colors' era runs up to more than 300(!). It is reasonable that the answer to this question cannot come at the start, but only at the end of a proper, thorough research, based on objective characterizations telling us where the demarcation lines lie between one system and the next, one emulsion and the next.
Another serious methodological question is how to define and then approach *variants and variables* within one system. The easiest example is the one that concerns different emulsions from one specific system and/or one manufacturer. Manufacturers kept track internally of changes in their products but not always made them public. We cannot rule out more or less subtle changes to the chemistry of color film stocks simply because they were not advertised. And proprietary processes like Technicolor had little reason to advertise changes. While the fundamental principle of Technicolor did not change much in different times and plants, we also know that different dyes were used or tested, or at least we cannot exclude it. So, can we really characterize just one Technicolor film? Which one? From when and where?
The opposite might turn out to be true: after closer inspection, it is very much possible that we discover that differently branded emulsions (from one manufacturer or across certain manufacturers) might turn out to be very similar in their chromatic responses (i.e., actual gamut). We simply do not know – yet.

Granularity 2: how many variables and factors to consider?

Last, we enter the least discussed among the many issues that should be considered when it comes to characterize/map the actual chromatic response, or gamut, or chromatic characteristics of cinema colors. This is even truer if we broaden our view to include ***all*** factors at play: in fact, it is not just a matter of the actual piece of film that is projected, we *have to* consider *at least* the characteristics of the projectors and their light sources, as well as those of the screens and the ambient.

Furthermore, for a number of reasons (as easy availability of data from published or written sources) research on color systems and technologies focused almost uniquely on characteristics of commercially manufactured film emulsions (i.e., different types of film stocks), and even more precisely on their *standard* or *nominal* characteristics as defined by the manufacturer or inventor. When a color system consisted in a process, like Technicolor, or applied colors, or additive systems, research too often limited itself to a description of the *mechanics* of the system.

Finally, because they are not well known and complex to define, two key aspects were until now underestimated, if not totally overlooked: ***system complexity*** and ***process variables***.

System complexity. A cinematographic work, or (to simplify in our specific case) a cinematographic color image on a screen is the result of a number of processes within a given workflow (filming/capture, developing/processing, printing, projection etc.). Each workflow's process or step is then characterized by various components (equipment, film stock, chemicals, etc.) that concur in its completion. The result of each process in a workflow derives from the interaction of all components needed to complete that specific process. Furthermore, each process' results are informed by the results of any other preceding (or anyhow influencing) process, and in turn they inform the following process(es), and so forth, until the last step (projection). We can define the level of *system complexity* as the number of processes, of process components, and the number of interactions among processes. Intuitively, the greater the system complexity, the higher the number of end-results of a given system.

The result of two identical processes (e.g., *camera negative processing*) that make use of different components (e.g., different developing machines and film emulsions) will obviously give different results. The extent of the difference of the two results will depend on the characteristics of each component (how 'good' the two processing machines are, and the characteristics of the two negative films). Furthermore, the results will also depend on how these components interact concretely at the moment the processes take place. For example, one processing machine could run too fast or too slow, its temperature not precise, etc. An older machine would have a wider 'error' range than a newer one. Plus, the resulting off-standard processing parameters can have different effects on two different emulsions. This type of variations within a specific process we define "***process variables***" and depend on the actual components and how they are affected by their interaction.

In our example of negative processing we can define process1A as using a processing machine Pm1 on exposed negative Neg1 (which is informed by the previous process of filming with a given camera). A second process1B will use a machine Pm2 and a different Neg2. The two end-results of the two processes 1A and 1B in their actual instantiations will be the result of processing machine 1 which allows variables X (depending on type and model) and Neg1, while process1B will be informed by processing machine 2 (with variables Y), and Neg2. The end results of the two processes will be two fully processed negatives (we can call them Neg1AX and Neg 2BY) that will move on to the next process of the workflow – whatever that is. In other words, each of the two negatives will become the first component of the next process. Assuming that what follows is a printing process, then the other components will be a printer (Pr1) with specific characteristics and variables, that are different from another printer Pr2. If for example

one of the two is an optical printer, it will increase contrast and grain on the resulting duplicate. A contact printer will have a different effect.
The following schema summarizes the example. Where IM indicates the intermediate film:

- Process1A [Neg1*Pm1] *variables X = Neg1AX
- Process1B [Neg2*Pm2] *variables Y = Neg 2BY
- Process 2A Neg1AX * [Pr1*IM1) * variables W = IP2AW
- Process 2B Neg 2BY *[Pr1*IM1) * variables Z = IP2BZ

To complete an actual workflow, we must consider the processes preceding and following the ones described above: first filming (with different cameras and negatives), then the processing of the two intermediate films, which will produce two different Duplicate Positives whose characteristics will depend on the actual process of printing multiplied by the process of development (different machines and variables), etc. These duplicate positives will then be printed onto intermediate film stock, then processed to produce two duplicate negatives), and then from the resulting Duplicate negatives, positive prints will be printed onto positive film stock that, once processed, will result in viewing/distribution prints.
The actual (real) characteristics of the end-results i.e. the positive viewing/distribution prints will be the compound result of each process that led to their production (starting with capture). They are in fact the summation or compound product of all the previous processes, their specific components and their variables: In short, they depend on both the ***system complexity***, and on each **process *variables***.

Conclusions: A complex system, not a piece of film.
Nominal, or standard characteristics of film emulsion, in other words the ones we can read on patents, or literature or on the manufacturer's technical data sheets are designed and verified in a research laboratory environment, (be it at Kodak or IG Farben) or under strictly controlled conditions and almost never in a multi-step process. They are precious sources of information about the theoretical response of a given emulsion, and can define the range of process variables for that specific emulsion: (e.g.., how much does the contrast or grain, or curve of the blue sensitive layer change with the increase of temperature?). What a data sheet will ***never*** tell us is the compound effects of the whole workflow from camera negative exposure to its processing etc. down to the positive printing and processing and (even less) projection on a Xenon lamp or a carbon arc light-source.
Simply put, the challenge in front of us is "***just***" this: "*What is the methodological approach to characterize the results of the* ***whole actual system*** *and not simply of one component, so that we can then map it into a modern display?*
There is primarily the matter of the techniques/instruments of analysis of the actual images on film, but also of the projection environment. Furthermore, there is the issue of how to account for the *variables within the system*. We know for a fact that ***any*** piece of film we analyze is the result of actual system variables (as defined above) that may (or not) have affected it to an extent that makes the film at hand non fully representative (or just partially representative) of a given color system.
In conclusion, on the one hand a characterization precise enough to allow the needed mapping into modern displays *must* take fully into account what we defined earlier as "*system complexity*" and "*process variables*" - without which the characterization would simply not be realistic. On the other hand, the adopted methodology must be strong enough to precisely identify the effect of process variables so that they can be "*calculated out*" of what we can define as a "***standard model for color system X or Y***".
For all the above reasons, the process of characterizing cinema colors cannot be limited to literature, but this *must* be combined to an analysis of reliable surviving witnesses (i.e., prints that we know are not faded, or suffered a processing problem so that they, e.g. have totally

wrong RGB curves). Luckily, archives all over the world conserve enough prints (and projectors, and printers, and other equipment) together with their corresponding negatives to imagine a statistical approach to cinema color **systems** characterization.

Hopefully, further discussions and analysis can be undertaken about the problem at hand and a methodology, which is still lacking (despite the millions thrown at improbable research projects in the last decade).

The outline of an agenda for theoretical and applied research is there, as the need for a more 'scientific' approach to cinema color mapping across systems and displays – a.k.a. *color film restoratio*n – so that finally scholars and audience can study and enjoy cinema colors on reliably faithful reproductions. Finally.

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Maxwell's Disappointment/Sutton's Accident

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Keywords: Maxwell's colour theory, wet-collodion, 19th century photography and optics, RGB, Tri-colour Photography, UV light

Extended Abstract

May 17, 1861, James Clerk Maxwell delivered a lecture at the Royal Society where he demonstrated, using a lantern slide projection, his theory for colour perception in the human eye via the additive colour process known today as RGB. Three images from three separate lantern slide projectors were projected onto a surface. The same colour filters with which the object had been photographed where then placed in front of each projection lens, carefully realigned, and what has been called "the first colour photograph" was supposed to have been created. It was a series of happy accidents, during capture and exposure, and a misinterpretation of the results - mostly long after the event itself - that has invented this commonly referred to fictional "First Ever" title.

Figure 15: Tri-colour wetplate photograph – digitally scanned and coloured from three wet-collodion glass plate photographs; creating a false tri-colour image. Image copyright Paul Elter.

In 1852 James Clerk Maxwell, while still in University Cambridge, Trinity College studying Mathematics, he developed an interest in Thomas Young's theory of colour and perception and influenced by experiments of his Professor J.D. Forbes, Maxwell began his famous experiments using a top fitted with various colour patterns. It wasn't until 1855 after Maxwell had graduated; that the results of these experiments were delivered in his first paper on the subject entitled "*Experiments on Colour, as Perceived by the Eye, with Remarks on Colour Blindness"* to the Royal Society of Edinburgh and would become the grounds for all future experiments and the beginning of humanities relationship with RGB. It was another 5 years till Maxwell presented another crucial paper – "*On the Theory of Compound Colours & Relations of the Colours of the Spectrum"* in which Maxwell expands on the subject of colour and perception giving us the complete formulations on RGB and the human eyes perception of the visible colour spectrum. Sometime in 1860 it became clear that Maxwell was desirous of a way to demonstrate, physically in a more visual manner his thought experiment. Maxwell then contracted Thomas Sutton the eminent and distinguished photographer; editor in chief of the publication *Photographic Notes* (1856-67) and inventor of the panoramic/wide angle lens and camera and the first SLR camera - to physically manifest his colour theory and create the B&W slides necessary to demonstrate his theory. It was these three glass plate lanternslides that on that evening on May 17th 1861 which Thomas Sutton had - created using the fastest photographic emulsion of the time wet-collodion, or wetplate that became legend. Or so the story goes…

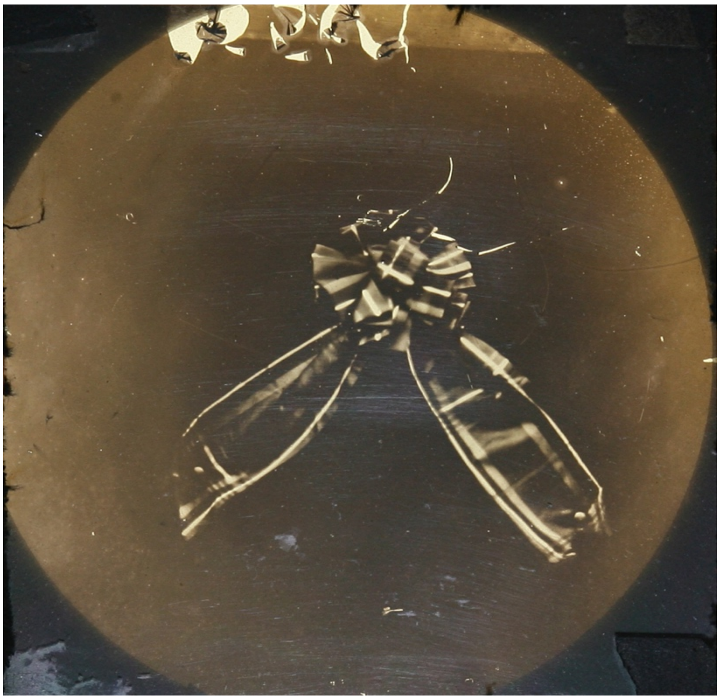

Image 2: Detail of the Red slide from - Sutton's original lantern slides for Maxwell's lecture at the Royal Institution, images provided by the Cavendish Laboratory in Cambridge where the lantern slides reside.

One would expect that a breakthrough of this magnitude being demonstrated publicly for the first time in history would attract attention of every contemporary scholarly publication and that even some of the daily newspapers would have written about such a great discovery - A way of capturing and representing the world in full colour? Contrarily, there was virtually nothing written about it in the academic or popular press. By retelling the historical details in their chronological order and through a series of experiments with historically correct emulsions, we will clearly outline the errors and where they occurred and what was really the outcome of this photographic experiment.

ChromaLuxe and New Generation Helios Inks Applications for Long Term Display of Photographic Images

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Abstract
Dye sublimation printing is a technology that dates to the late 1950s. The first large scale use of this technique came in the 1960s and 1970s and utilized ribbon transfer. In the 1990s digital sublimation printing became widely used for fabrics. Since digital sublimation printing utilizes disperse dye colorants, the surface which is to be printed must be permeable to the dyes when subjected to heat and pressure. Coatings on hard, rigid surfaces can make them receptive to the necessary dye infusion. Early hard surface objects decorated by dye sublimation included products such as cups, coasters and name badges. In 2006 Universal Woods began development of coated metal substrates suitable for dye sublimation printing. The product, tradename ChromaLuxe, has since undergone continuous improvement through extensive research to understand interactions among components of the coating, the inks, and the individual dyes in the inks. Since dyes are not known for long term light permanence, extensive research into stabilization technology was also necessary. This information, in conjunction with a partnership with Kiian Digital, a major global sublimation ink supplier, has identified coatings with optimized light permanence for use in ChromaLuxe metal panels as well as a new generation of hard surface sublimation ink (Digistar Helios) which addresses the permanence shortcomings of standard hard surface sublimation inks. Ongoing Independent light permanence testing of this substrate/ink combination at Wilhelm Imaging Research (WIR) is projecting results comparable to (or superior to) existing long-life products. These results and the inherent superior physical durability of the metal substrate would seem to make this combination a viable candidate for long term display of photographic images. This discussion will further detail these developments.

Keywords: ChromaLuxe, dye sublimation, diffusion, light permanence, xenon, WIR, Digistar Helios

Introduction

The term “sublimation” seems to date back to France in the 1950s when certain dyes were observed to sublimate or change from solid state directly to gaseous state when heated to elevated temperatures. Although the term persists, there is debate about whether true sublimation is involved. Many believe the process is dye-diffusion, even though “dye sublimation” seems to remain the preferred term.

The earliest commercial use of dye sublimation for photographic images was technically known as Dye Diffusion Thermal Transfer (D2T2). This process utilized dyes that were heat transferred from a ribbon carrier. D2T2 produced very good photographic quality and visually resembled traditional chromogenic prints but were at least somewhat light and moisture sensitive. The D2T2 process has been largely replaced by digital dye sublimation printing for photographic applications.

The major use of digital dye sublimation printing remains to be textiles, but usage on hard surfaces is growing rapidly with the introduction of coatings for hard surfaces which make them receptive to the necessary dye infusion. The initial hard surface substrates were items such as cups, coasters and name badges where image permanence is not generally a major requirement.

In 2006, after seeing market interest in the use of sublimation for photographic images on metal substrates, Universal Woods began the development of coated panels (tradename ChromaLuxe) for this application. The disperse dye colorants utilized in digital dye sublimation printing do not typically yield long-term light fade resistance and many years of research and development was necessary to identify the proper combination of materials necessary for good image permanence. Historically, the light permanence of dye sublimation inks has been assessed only on individual inks by the Blue Wool Test, which does not account for any negative interactions that may occur between the individual dyes in mixed colors. The continuous improvement process for ChromaLuxe has identified the interactions among hard surface coatings and individual sublimation inks (components as well as dyes) to produce optimized hard surface coatings. In addition, joint efforts with a major global sublimation ink supplier (Kiian Digital of the JK- Group) has also identified a new generation sublimation ink set designed to produce superior mixed color light permanence in ChromaLuxe substrates.

This paper will further detail the results of this development effort and the resulting long-term light permanence results achievable utilizing ChromaLuxe in conjunction with the new generation Helios sublimation inks. The dramatic difference in mixed color performance compared to standard hard surface inks will be shown in detail.

Test Procedures

The test procedure for our evaluations parallels that utilized by the Image Permanence Institute at the Rochester Institute of Technology (RIT), which performed the initial independent testing of ChromaLuxe. This method is like that described in ISO 18937. Our testing was performed using a Q-Sun Xenon Test Chamber equipped with window glass filters (Window Q) to simulate daytime sunlight through a window. No additional filters were utilized. Light intensity in the chamber was set to 50,000 lux at 420 nm. Chamber temperature was controlled at 25° C and relative humidity at 50 %. Standard test targets consisted of cyan (C), magenta (M), yellow (Y), neutral (K), red (R), green (G), and blue (B) patches at ten levels of color intensity for each. Test targets were measured for ISO Status A cyan (R), magenta (G), and yellow (B) color densities utilizing an X-Rite 528 Spectrodensitometer. Results were recorded as % loss of color density versus time for 0.6 initial color densities in the CMYK squares and 0.5 color densities in the RGB squares. Since individual target squares do not usually correspond exactly to 0.5 or 0.6 initial densities, the closest color density patches were used to estimate the target densities by interpolation. The C, M, and Y squares were followed for cyan, magenta, and yellow densities, respectively, and the K squares were followed for all three densities. The R, G, and B squares were followed for each of their two primary color densities, i.e., magenta, and yellow from R, cyan and yellow from G, and cyan and magenta from B.

Although not the primary focus of this discussion, a parallel project to develop an outdoor version of ChromaLuxe was undertaken in the same time period. Much of this initial work was done by the late Bill Leek, a consultant of Universal Woods. Bill identified alternative sublimation inks that did not exhibit the same negative interactions as the standard hard surface inks. He also did the initial outdoor conditions Xenon testing as well as Florida exposure testing. The Xenon Test Chamber conditions utilized for this testing were 0.68 W/sq.m. at 340 nm light intensity, 32° C. chamber air, 50 % RH and 55° black panel temperature. These conditions were also used to prepare the exposed images shown later in this presentation which compare the new generation Helios ink to a standard hard surface ink.

A test of indoor light permanence under fluorescent lighting conditions has been ongoing for more than a year at Wilhelm Imaging Research (WIR). Test conditions are 25K lux at 420 nm, 24° C. chamber air, and 50% RH. The testing is being conducted both with and without various filters. Color density measurements versus time are like that described above for CMYK.

Results and Discussion

The results shown here represent the current commercial generation of ChromaLuxe HD. The light intensity of the Xenon exposure for indoor testing (using only window glass filters) is significantly more severe than it would be if the L37 filters recommended by ISO 18937 had been utilized, but such filters are not commercially available for the Xenon test chambers utilized in our testing. Light through a window glass filter is equivalent to that impinging that upon a wall opposite a window. The L37 filter more closely mimics the average light anywhere in a room illuminated by daylight. Testing with a small piece of L37 filter about 1 to 2 inches above a sample has shown significantly slower loss of color density. The charts in figures 1 and 2 compare the CMYK color density loss results for ChromaLuxe HD, which is optimized for indoor use. Since ISO 18937 does not define failure points, and there is no universal consensus in the industry as to the most appropriate failure points, we have arbitrarily placed a reference line at 25% loss of Status A color density. This allows comparisons to be made between standard hard surface ink and the new generation Digistar Helios ink.

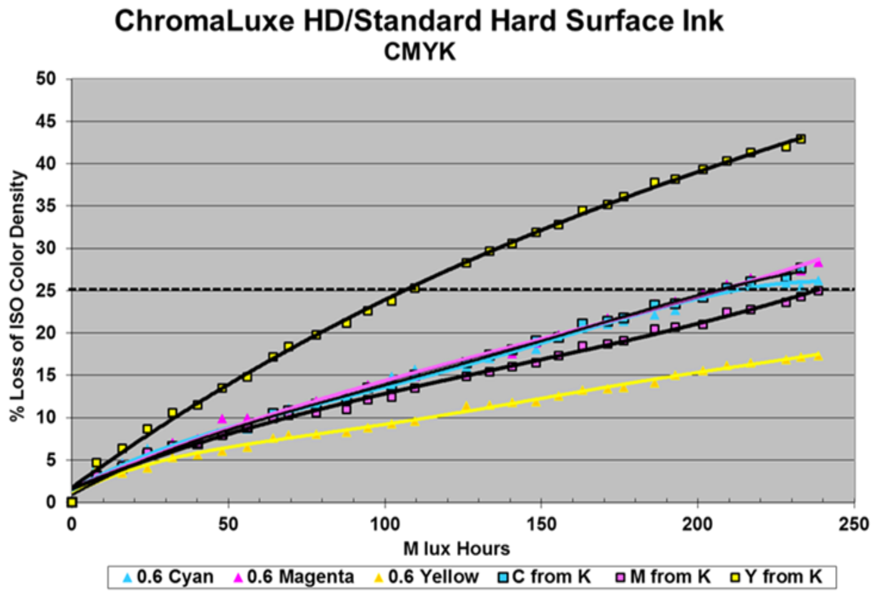


Fig. 1. ChromaLuxe HD / standard Hard Surface Ink.

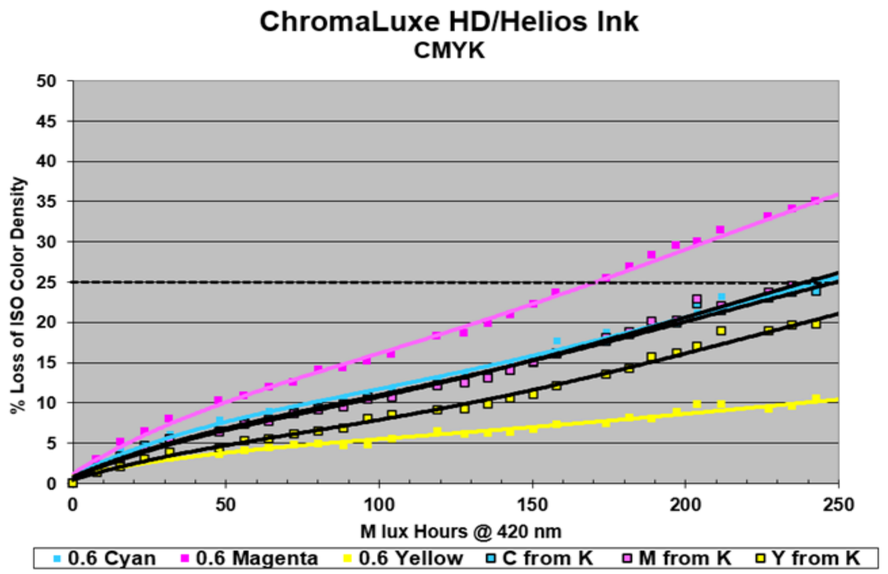


Fig. 2 ChromaLuxe / Helios Ink.

In the CMYK data, there is a dramatic difference in the Y from K (black line with yellow markers).
In the RGB data in figures 3 and 4, there is a similar dramatic difference in the Y from R (red line with yellow markers) results.

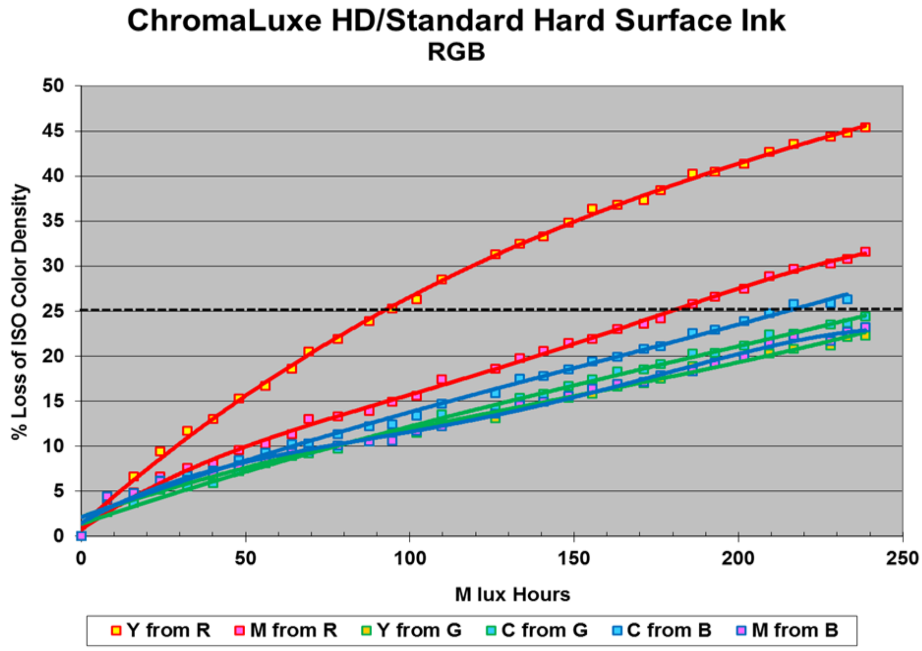


Fig. 3 ChromaLuxe HD / Standard Hard Surface Ink.

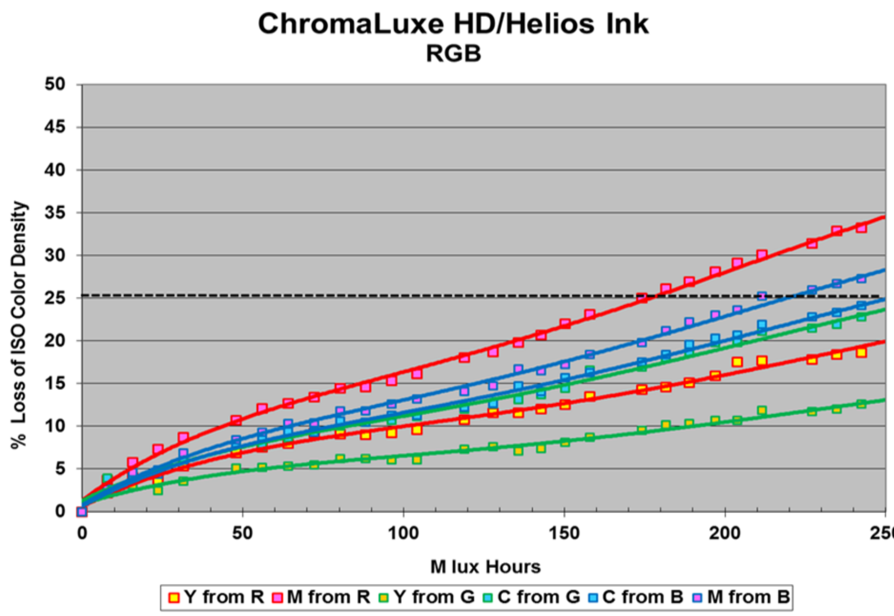
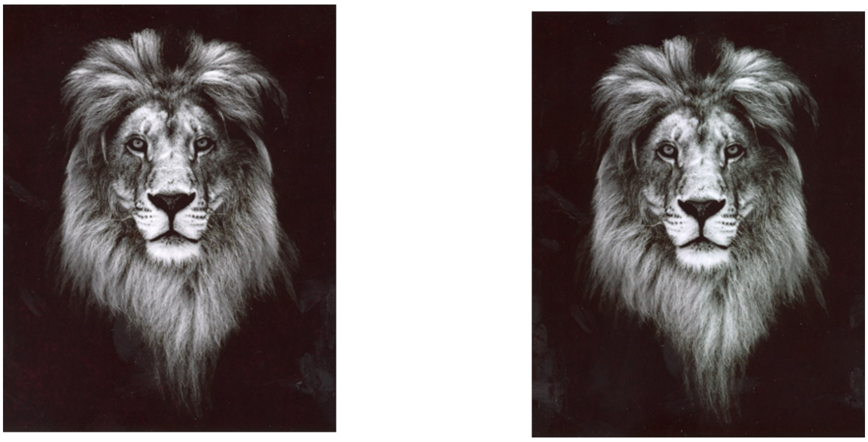


Fig. 4 ChromaLuxe / Helios Ink.

The CMYK results show the pure yellow ink from either ink set to be the most lightfast. However, in mixed colors (particularly black or red), the results for the Standard Hard Surface ink set show yellow to be the least lightfast, presumably due to negative interactions between the yellow ink and the other inks.

Standard Hard Surface Ink



Helios Ink

Fig. 5 Exposed Images Showing Y from K Difference Between Inks

Images in figures 5 and 6 show the visual result of the differences in color density loss performance between the two types of inks. The images on the left are unexposed and the right-hand half of the images on the right have been exposed in a Xenon Chamber under the harsher outdoor conditions. The version of ChromaLuxe optimized for outdoor conditions (ChromaLuxe OUTDOOR) was utilized for these images.

The loss of yellow color density from black can clearly be seen in figure 5, and the loss of yellow color density from flesh tones in figure 6. The same trend is seen for ChromaLuxe HD with indoor test conditions, although the exposure time required to reach the same result is much longer.

The most recent results of the ongoing indoor fluorescent testing at WIR in shown in figures 7 and 8. Results are shown for ChromaLuxe HD with Helios ink, ChromaLuxe OUTDOOR with Helios ink, and ChromaLuxe OUTDOOR with Standard Hard Surface ink. Image lifetime is defined as the time to reach the first of the WIR standard endpoint criteria from the CMYK test parameters previously described. The chart shows the percentage of allowable color density loss remaining based upon those WIR criteria. For simplicity, only the criteria most rapidly approaching their endpoint are shown for each coating/ink combination. Results with a glass filter are the standard WIR reporting format, but we have also included bare bulb results to show the results with no type of filter or overlay. The chart represents predicted remaining lifetime under 450 lux lighting. Less intense lighting would yield proportionately longer lifetimes.

Standard Hard Surface Ink

Helios Ink

Fig. 6 Exposed Images Showing Y from R Difference Between Inks

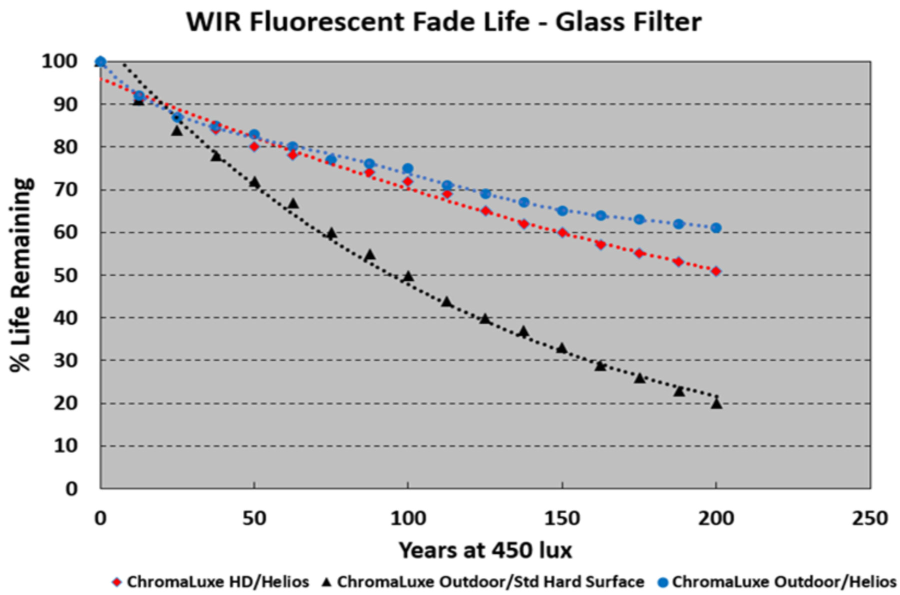


Fig. 7 WIR Fluorescent Fade Life – Glass filter

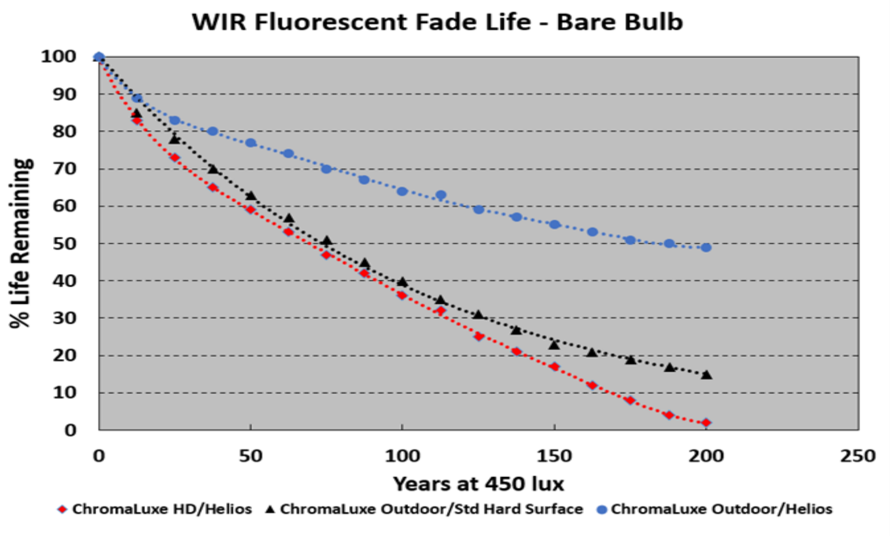


Fig. 8 WIR Fluorescent Fade Life – Bare Bulb

Conclusions

Development efforts spanning more than a decade have produced a body of knowledge identifying both positive and negative interactions among polymer materials, light stabilizing materials, ink components, and disperse dye colorants. This information was utilized to optimize ChromaLuxe coatings systems for both indoor and outdoor environments. In addition, a new generation sublimation ink (Kiian Digital Dijistar Helios) has been developed to address the major weaknesses in Standard Hard Surface inks as identified by this research.

ChromaLuxe metal prints are well known for vibrancy and depth of color due to the individual dye colorants being present within the coating layer as mixed, solid solutions rather than as individual dots on the surface as in the case of pigment inks. Since the substrate has superior physical durability and resistance to environmental factors such as surface abrasion, humidity, ozone and water contact, images can be displayed without the need for framing or face-mounting with glass or acrylic. Surface lamination is also not necessary for physical durability. As the WIR results in figures.7 and 8 show, the use of glass over the ChromaLuxe HD/Helios combination will produce even better light permanence. The higher level of light stabilizers in ChromaLuxe Outdoor allows the same level of light permanence with or without glass. ChromaLuxe physical durability in combination with the light permanence performance shown in the ongoing WIR indoor fluorescence testing would seem to make ChromaLuxe a viable candidate for long term preservations of digital photographic images.

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Definite Identifiers of Silver Dye Bleach Prints

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Extended Abstract

Keywords: colour photography**,** Cibachrome, chromogenic reversal prints, identification, azo dyes

Introduction

Among diverse contemporary colour prints, silver dye bleach prints and chromogenic prints share similar visual characteristics; both use an integral tripack emulsion that displays a continuous tone with visible image structure (Graphics Atlas, no date). They are often printed on identical supports and hence display identical surface finishes (Figure 1). However, their image dyes differ, resulting in varied light and dark stability behaviours (Meyer and Bermane 1983, pp. 121–125) and dissimilar reactions with water (Bermane, 1985, pp. 105–108). These types of prints therefore have distinctive needs in conservation and restoration. Despite this, their differentiation is difficult as revealed in a mixed-method questionnaire survey conducted for a master's thesis (Chun, 2020, pp. 174–223).

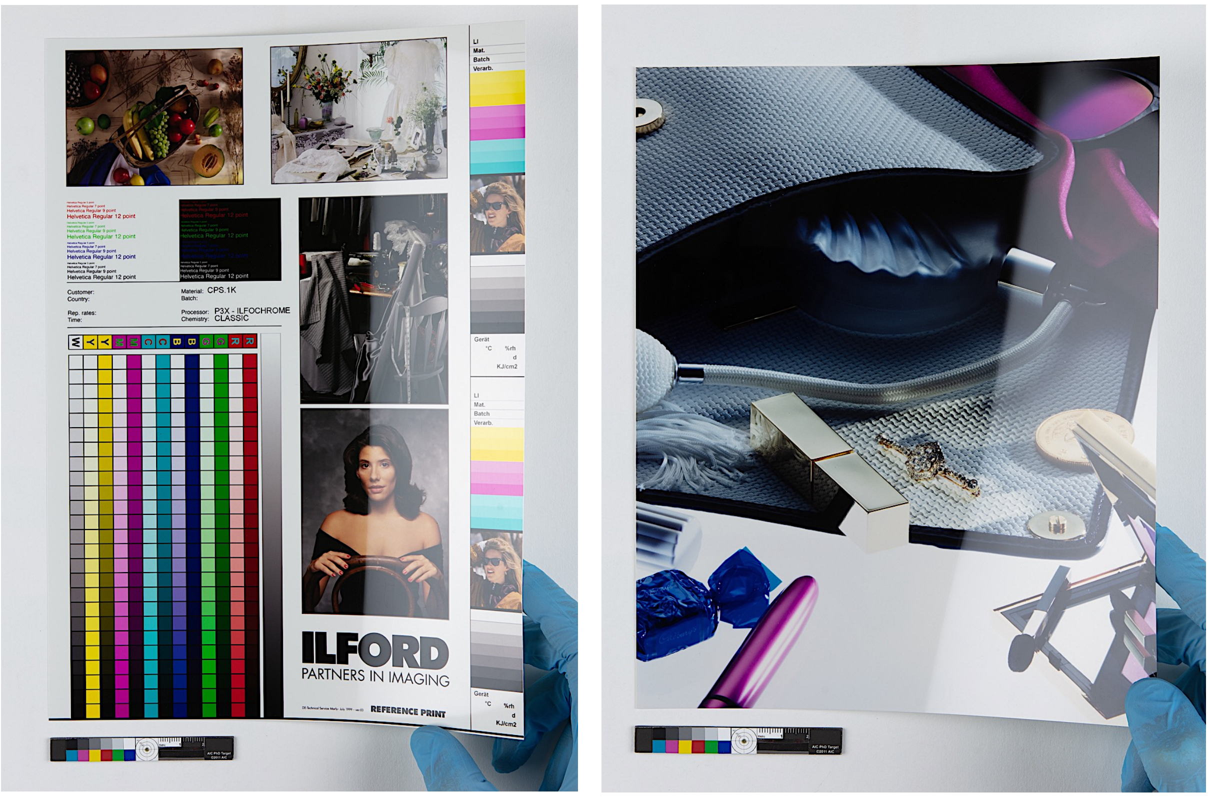

Fig. 1. *Left,* Photographer unknown (ca. 2000). Ilfochrome CPS.1K [Photograph]. A silver dye bleach sample print on voided polyester support; *Right,* Photographer unknown (ca. 2000) IlfoColor IL.1K [Photograph]. A chromogenic sample print (negative-positive) on voided polyester support. Both are courtesy of Martin Jürgens (Rijksmuseum), photo-documented by S. F. Chun under daylight 5000 K soft boxes using a Canon EOS 5Ds fitted with a 24–70 mm lens. These two prints made using different processes have similar visual characteristics and identical supports and gloss.

Most participating photograph conservators expressed uncertainty about determining, even though they already referred to the identification methods compiled in established conservation sources. This uncertainty in differentiation was one of the multiple reasons why these types of prints were still being stored together in most of the institutions polled. The underlying causes of this uncertainty likely contributed to the problematic differentiation but was previously under-researched. Therefore, the purpose of the present thesis was to understand this causation to determine practical methods and tools to differentiate these types of prints. This article, derived thereof, presents the research results.

Previous literature revealed that ca. 99% of colour prints are chromogenic (Fenech *et al.*, 2012, p. 411) and have more variants than silver dye bleach prints (Pénichon, 2013, pp. 161, 207)). Since this research aimed only at differentiating silver dye bleach prints and chromogenic prints, as long as the minority—the silver dye bleach prints—could be determined, the majority would be subsequently differentiable. Thus, for efficiency, the silver dye bleach prints were the principal to address. Within this print type, only Cibachrome (renamed Ilfochrome in 1992) was used as a reference (Cibachrome Association, no date) as these were the dominant products in history (Pénichon, 2013, p. 216).

The first objective of this study was to understand the material properties of each print type, collect as many identifiers of silver dye bleach prints as possible, and examine the identifiers to determine whether they were unique to silver dye bleach prints yet inapplicable to chromogenic prints. These unique identifiers were referred to as 'definite identifiers', as opposed to 'indefinite identifiers'; whereas the former could discriminate, the latter were common to both print types. This research concluded that using definite identifiers alone could effectively discriminate. The outcome was a flowchart to guide differentiation.

Silver Dye Bleach vs Chromogenic

Cibachrome was launched in 1963. These silver dye bleach prints are known for image quality and stability resulting from their distinctive designs in both the component materials and the chemical development (Reilly, 1998, p. 7). These prints appealed to diverse sectors, from NASA (United States, 1974) to artists like Jeff Wall and Irving Penn (Metropolitan Museum of Art, no date).

Silver dye bleach is a 'positive-positive' process—meaning, a print is a positive reproduction of the original colour transparency. Silver dye bleach is the only colour print material that incorporates preformed image dyes (azo dyes with aromatic rings) in the gelatine emulsion before use. This emulsion has an integral tripack construction; each layer incorporates, from top to bottom, the corresponding azo dyes of one of the three subtractive primary colours (yellow, magenta, and cyan) (Keller, 1993, 134–136). Support materials are limited to cellulose acetate (Coote, 1978, p. 25), cellulose triacetate, polyester, and resin-coated paper (Cibachrome Association, no date).

The signature of the silver dye bleach process is to reduce unwanted azo image dyes using metallic silver. In a developing bath, the exposed silver halides are reduced to metallic silver to form a negative black-and-white image. This step is followed by bleaching. The bleach catalyst shuttles back and forth between the silver atom and the azo dye, bleaching a ring-form halo in situ (Fujita, 2004, p. 542). Upon completion, the site becomes an emptied hole and no longer contains dyes or silver atoms (Hofmann-Sievert, 2019). Consequently, bleach holes are definite identifiers of silver dye bleach prints.

The chromogenic process was introduced by Kodak and Agfa, respectively, around 1936 (Keller, 1993, p. 3). It is used in two manners: as a negative-positive process or a positive-positive (i.e., reversal) process. The former prints a positive image directly from a colour negative, and the latter prints a positive image from a slide using two exposures and two developments to reverse the process. Both negative-positive and reversal print materials lack colour dyes before use; colour dyes are formed only during processing, when the oxidised colour developer reacts with the colourless colour couplers (i.e., the dye-forming organic compounds) (Keller, 1993, pp. 118–123, 129–130). The dyes formed are typically azomethine dyes; the colour-forming process creates the signature dye clouds. However, the morphologies of dye clouds vary from product designs and processing conditions (Fujita, 2004, p. 279). In an exposed, developed colour negative print, the order of dye layers from top to bottom is cyan, magenta, and yellow. In an exposed, developed colour reversal print, from top to bottom, is yellow, magenta, and cyan (Keller, 1993, pp. 120–121).

Materials and Methods

The material properties of contemporary colour prints are proprietary. The first research method, archival research, therefore consulted patents in addition to early product presentations (Meyer, 1965, 90–97); manufacturer handbooks (Coote, 1978; Krause and Shull, 1982; Shanebrook, 2010); and scientific literature by Keller and Fujita. This search was combined with an object-based study. The main study objects were an Ilford manufacturer sample set dated ca. 2000 and the Andrew W. Mellon Foundation conservation digital print reference set dated 2006. The former contains ca. 30 sheets (8 in × 10 in) of silver dye bleach prints (Ilfochrome and Cibachrome) and chromogenic prints (IlfoColor).

The second method aimed to collect identifiers to the max. Three popular photograph conservation sources were selected for collecting customised identifiers: Pénichon's *Twentieth Century Colour Photographs*; Graphics Atlas; and the Photographic Materials Group Wiki. In addition, a mixed-method questionnaire survey was conducted to also unearth underused and unpublished identifiers. In this regard, the targeted respondents were diverse professionals from the art and heritage conservation, printing, auctions, and nanotechnology fields in Europe, the United Kingdom, and the United States. Consequently, this survey was sent by email. The key question was to ask the participants to propose identifiers they used or would use for identifying silver dye bleach prints and to prioritise the identifiers starting from the one perceived as most indicative.

The third method dichotomised the collected identifiers into 'definite' or 'indefinite' by visual examinations. Repeatedly proposed identifiers were combined as a single entry, and the final entries were arranged in tables according to the frequency proposed and the priority perceived, respectively. Part of the methods and tools used, were penned in the selected conservation sources, and the others were indicated in the survey responses. Diverse materials and instruments were used during the examinations, including water droplets, light sources (light emitting diode, fluorescent, incandescent), digital 3D microscopy (Hirox KH-7700, RH-2000), and spectrophotometry (GretagMacbeth Eye-One). Destructive or nondestructive but invasive experiments were attempted on test materials donated by the first and second authors of this paper, and noninvasive examinations were conducted on the Ilford and Mellon sample sets and the private collections of the third author. Most examinations were single experiments conducted by the first author alone, except for a redshift observation and the collection of spectra, in which both the first and the second authors engaged.

Result

The archival and object-based research clarified that both silver dye bleach prints and chromogenic reversal prints used resin-coated supports with semi-gloss and glossy finishes in addition to polyester supports. Both print types were confirmed using the positive-positive process and had identical orders of dye layers.

Based on the previous sources and the Ilford manufacturer sample set, Ilford produced four silver dye bleach product lines over the years. There were ca. 11 chemical processes compatible with ca. 34 silver dye bleach print materials coinciding in time. However, previous inventories lack either the chemical processes or their production end dates. In The Focal Encyclopedia of Photography, an early print material (Cibachrome-A, ca. 1974–1981) and the chemical process P30 were mismatched (Pers, 2007, p. 710); the latter was introduced only in ca. 1981 (Graphics Atlas, no date).

Back print is the brand or product name (identity) that printed on the verso of a print. This research found that back print was absent on both print types on polyester support. For silver dye bleach prints on resin-coated supports, back print was often missing.

Fourteen identifiers were found in the three selected conservation sources. Among them, 11 (78.6%) overlapped the entries of the survey. The rate that the identifiers from conservation sources were adopted, was high. One of the three entries, exclusive to the conservation sources, was 'redshift'.

The survey response rate was high (62.5%), as 20 out of 32 professionals participated. Multiple responses were abundant in tips and questions concerning differentiation, and some responses even arrived alongside additional long emails. After categorising, there were 23 entries of identifiers. Among them, 11 (47.8%) overlapped those from the conservation sources, and 12 (52.2%) were exclusive to the survey. A spider chart was used to include the frequency of the proposed identifiers, ranging from 1 to 11 (Figure 2).

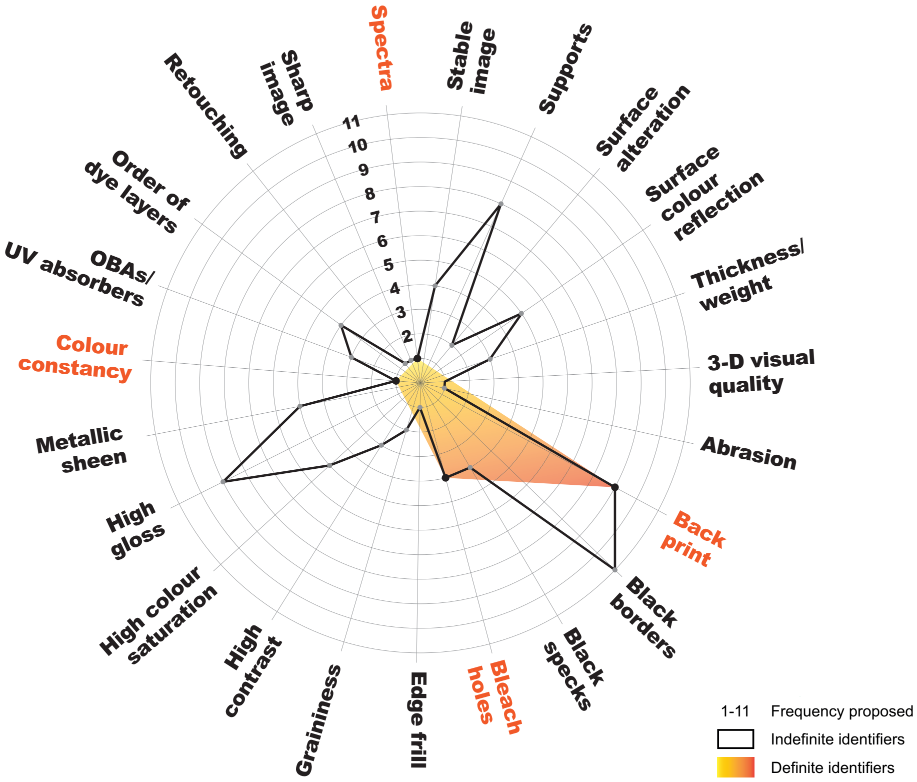

Fig. 2. Spider chart of definite and indefinite identifiers collected from a mixed-method questionnaire survey. Illustrated by S. F. Chun.

Examinations were conducted on 15 identifiers collected in both manners. The original thesis contains details of each experiment. In short, the identical support materials used for the two print types nullified the identifiers concerning the support materials, such as 'high gloss'. 'High colour saturation', 'high contrast', and 'sharpness' were determined as indefinite identifiers because they were dependent on multiple factors, such as product design, the quality and subject of the original slides or negatives, and the processing conditions. Since both silver dye bleach and chromogenic reversal use a positive-positive process and hence have identical orders of dye layers, any identifiers concerning process and layering—such as 'black borders', 'black specks', and 'surface colour reflec-tion'—were nullified. Further, the presence or absence of optical brightening agents and ultraviolet absorbers alone could not discriminate, because silver dye bleach prints and chromogenic prints have vast varieties, and coatings are proprietary and unrevealed. 'Edge frill' and 'Thickness/weight' were not examined due to inadequate materials to support determination.

The examinations, however, demonstrated that five identifiers were definite, as opposed to 19 (17%) that were indefinite. These five were 'back print', 'bleach holes', 'colour constancy', 'spectra', and 'redshift'. Except for 'back print', the other four definite identifiers were the properties of the image azo dyes. Additionally, Figure 2 indicates in orange, that the frequency proposed was much higher for indefinite identifiers than for definite identifiers.

Discussion

The Ilford manufacturer sample set allowed for an object-based comparison of the two types of print materials, many of which displayed indifferentiable appearances, which can be difficult to imagine without references in hand. Previous sources, such as Pénichon and Graphics Atlas, mentioned the similarities between silver dye bleach prints and chromogenic reversal prints. In this study, however, these similarities were, for the first time, explicitly inferred to have nullified any identifier correlating to process or layering.

Over the years, the same chemical process was designed to be compatible with multiple print materials (Hofmann-Sievert, 2019). This one-to-many relationship coinciding in time was not yet clarified in the current sources and could be improved. In this study, four pairing tables were compiled to present these relationships per product line. Different Cibachrome and Ilfochrome print materials had different light-sensitivity, granularity, sharpness, contrast, colour saturation, and chemical stability. This finding agrees with the uncertainty aroused during practicing differentiation.

The high response rate of the survey and the heated written responses implied that participants were interested in this conservation and restoration issue. The rate of participants either using or who would use the identifiers was very high, suggesting that the three popular conservation sources influenced the choice of identifiers made by the survey participants. Much fewer definite identifiers than indefinite identifiers were used or would be used. This also explained why differentiation had been uncertain.

Redshift was tested as a definite identifier, but the change in colour can be destructive and therefore is not recommended. As a last resort, spot tests should be constrained to imperceptible areas. The observability of bleach holes depends on the scale of the magnification and the density of the image. The colour constancy test needs neutral grey references. Non-sample prints may not contain a near-grey image colour; thus, visual comparison can be impracticable. Observing the remission spectra is definite, objective, and readily achievable compared to observing bleach holes or colour inconstancy. Although the application of a spectrophotometer is instrumental, it is nondestructive and thus is still practicable.

All these findings were integrated into a colour identity flow chart to highlight the relationships between the choice of identifiers and the determinations (Figure 3). To begin, once we can determine a print is colour and has no misregistration, we can exclude mechanical processes (e.g., halftone prints). If the print has a continuous tone with clear image structure and texture, then we can exclude the dye diffusion processes (e.g., Polaroid and dye diffusion thermal transfer). We may then assume this print is either a silver dye bleach print or a chromogenic print. Then we arrived at three entry points: processing, layering, or dyes. Here onwards, the dense green dotted lines link one identifier to two colour processes, which means this identifier is ambiguous. The loose grey dotted lines lead to the chromogenic process. The solid orange lines lead to the silver dye bleach process. In short, this flowchart shows that the identifiers related to processing and layering will not draw solid, definite identification of silver dye bleach prints, but the identifiers related to image dyes will.

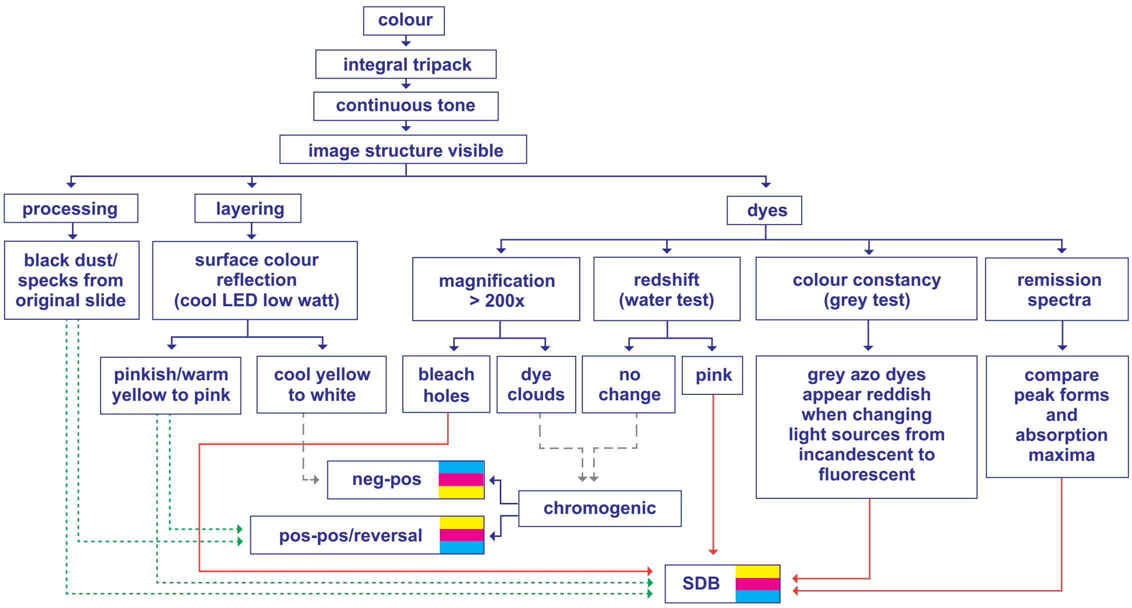

Fig. 3. Identification flowchart. *Source:* Created by Suk Fong Chun.

Conclusion

The realisation of the close similarity between silver dye bleach prints and chromogenic reversal prints can significantly narrow down options of identifiers. The main recommendation concluded is to deviate from indefinite identifiers to save time and effort. However, even though this proposal is supported by the results drawn from empirical examinations, it is still a fundamentally novel approach and needs a clear introduction. In this regard, a step-by-step disseminating plan may be helpful. The earliest communication tool could use this flow chart, which illustrates the relationships between the choice of identifiers and the determinations at a glance.

The next step would be to panel-test this model extensively. Since most the examinations were single experiments conducted solely by the first author, double-blind experiments with more participants would be essential in the future to build a larger dataset to improve validity. Of the four definite identifiers, one was destructive, one was tool-free but image-colour-dependant, and two were tool-dependent. Therefore, future research for more ways of identifying azo dyes is desirable. If more definite identifiers can be established in future studies, then this flowchart can extend readily with the existing layout. Likewise, the pairing tables are readily extendable once more product information is confirmed.

'Identification of colour processing is one of the weaknesses of the field', Lavédrine. (2020). With this in mind, this flowchart maybe considered as the main contribution of this research. Ideally, it shall guide a definite differentiation between silver dye bleach prints and chromogenic prints. A perhaps potential contribution is the paring tables, as they can improve the accuracy in dating silver dye bleach print materials if the model names and the chemical processes are already recorded in a museum database.

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An Evaluation of the Suitability of Microfade Tests for Color Photographic Prints from Modern Digital Printing Technologies to Historic and Contemporary Analog Color Printing Systems

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Abstract
This work describes the results from preliminary studies evaluating the suitability of microfade testing (MFT) for assessing the light stability of a wide range of color photographic prints. Evaluated prints ranged from dye-based inkjet and contemporary chromogenic, to historical prints made from dye diffusion-transfer and dye diffusion media (instant photos). A xenon light MFT unit was used to determine the range of light stability exhibited by the selected prints. Results showed that the fading rates of the conventional chromogenic prints, comparable to that of blue wool scales 3-5, are near the sensitivity limit of what is detectable by the MFT instrument in reasonable experimental time. Alternatively, some of the dye-based inkjet prints showed a high light-induced fading rate, exceeding that of blue wool 1. MFT was able to further identify the most fugitive colorants in these prints and to reveal how the history of previous exposure might influence its light stability in the future. Because of the breadth of observed behavior, we sought to further probe the limits of MFT for photographs by developing a method to determine if key references and the assumptions of reciprocity will hold. The method examines the degree of linear correlation between the initial fading rates of a sample tested under different light intensities. We validated this method using blue wool scales 1 and 2, along with an actual color print. The results shown that the reciprocity holds in the tested range of very high light intensities of 1-8 kW/m^2. In addition, the slope of the linear correlation of this test print compared to a blue wool scale revealed that MFT results based on the relative fading rates between test samples and blue wool references may no longer be valid under the lower light intensities typically used for exhibition in cultural heritage institutions.

Keywords: Microfadeometry, Microfade, Microfading, MFT, Xe-arc, lightfastness, reciprocity, dye inkjet, pigment inkjet, chromogenic photographic print, blue wool, bluewool.

Introduction

The original microfade testing system developed by Paul Whitmore (Whitmore, P.M., et al. 1999; Whitmore, P.M. 2005) in the 1990s focuses light from a high-intensity xenon arc lamp into a tiny spot with an extremely high intensity and short exposure duration, stopping the test before fading is discernible by eye. It is thus considered a quasi-noninvasive test method. It has become widely practiced in cultural heritage collections care as a screening tool to identify objects that contain fugitive colorants and require careful consideration when displayed or loaned to other institutions (Beltran, V. L. 3/2018).

A major challenge for cultural heritage institutions with color photographic collections is that prints include a wide range of printing technologies, from modern digital prints, to conventional analogue as well as historical prints. This includes inkjet prints of different colorant types (dyes or pigments), prints made on historic and contemporary chromogenic papers, on media using silver dye-bleach processes (Cibachrome, based on azo dyes), on media using dye diffusion-transfer and/or dye diffusion technologies (instant photos) from Polaroid, Kodak and Fujifilm, as well as ChromaLuxe, D2T2, Kodak Dye Transfer, and more. With diversified printing media and technologies comes an extremely wide range of light stabilities, >1000:1 from the most to the least light-stable media (Wilhelm, H. *et al*, IS&T, 3/2007). Yet, there are few reports in the literature that have systematically examined a broad range of photographic media and their lightfastness using MFT methods, with either Xe-arc or LED light sources. This is one of the key objectives of this study. Initially, this work focused on determining the light stability of a wide range of prints with a Xe-arc light source MFT, in reference to a blue wool scale (ISO 105-B02, B08). Subsequently, we sought to further undertand the strengths and limitations of MFT when examining photos of such a wide diversity. For example, could MFT data reveal the leading causes of light-fading in a print, as well as demonstrate how the history of light exposure on a fugitive print might impact its current light stability.

Finally, a major need for cultural heritage institutions is the ability to be able to realiably interpret and translate MFT test results at a high light intensity and short duration to behavior at lower light conditions with much longer durations for displays, in order to determine risks and appropriate light budgets for their print holdings. Such projections rely on the reciprocity principle. Instances of reciprocity failures for prints were first documented in 1993 (Wilhelm, H. and Brower, C. 1993; pp. 67-76). Therefore, reciprocity failure becomes a potential risk that needs to be assessed when working with the MFT for these materials (Hoyo-Meléndez, J. M. and Mecklenburg M. F. 2011). Light intensities in MFT can reach as high as 2-6 Mlx (Beltran, V. L. 3/2018), which is 20 to 50 times higher than direct outdoor sunlight. Accelerated light aging tests conducted using a conventional light fading chamber at Wilhelm Imaging Research (WIR) are generally maintained at 25 Klx, or for selected print materials, at 1.35 Klx, and tested at this lower level for much longer periods. For comparison, display illumination for photographs in museums is typically in the range of 50 to 250 lx. One of the key objectives in this study is to develop a method that may be used to assess the risk of reciprocity failures across light sources with a wide range of intensities. We will also explore if the same method can be used to assess the validity of using blue wool reference systems across different light levels.

Experimental

Equipment and Materials

Experiments were conducted using an MFT in the configration of the original Whitmore system (Whitmore, P.M., *et al.* 1999, Fig.1), with a xenon-arc lamp powered at 70W. Two bandpass filters were used to remove UV/IR components from the light source as shown in Figure 1: Spectra-Physics UV long-pass filter 59470 and Asahi Super Cold band-pass filter YSC0750 (used to replace the original water filter). The detected spectral signals of reflected light from the test sample were recorded by CDI Spec32 (Control Development). MFT fading curves were plotted using "Spectral Viewer^{TM}" (v2, from GCI).

Quantitative measurement of light intensity and the spectral power profile were made using a spectrophotometer from Allied Scientific Pro, Model SRI-2000UV (Fig. 1). The spot-size of the focused light was determined to be ~0.5mm. The irradiance within the focused spot was determined to be $\boldsymbol{E_e}$ ~8 kW/m^2. The corresponding visual brightness under the given spectral power distribution was $\boldsymbol{E_v}$ ~1.8-2 Mlx with a color temperature of *CCT* ~5700K.

Light intensity reductions were accomplished using neutral density (ND) filters from Edmund Optics, rated 0.3 OD (cat. #: 88-276) and 0.6 OD (cat. #: 19-300). By combining these two ND filters, four levels of MFT light intensity $\boldsymbol{E_e}$, were acheived in a range from 100% (full strength) down to ~12.5%.

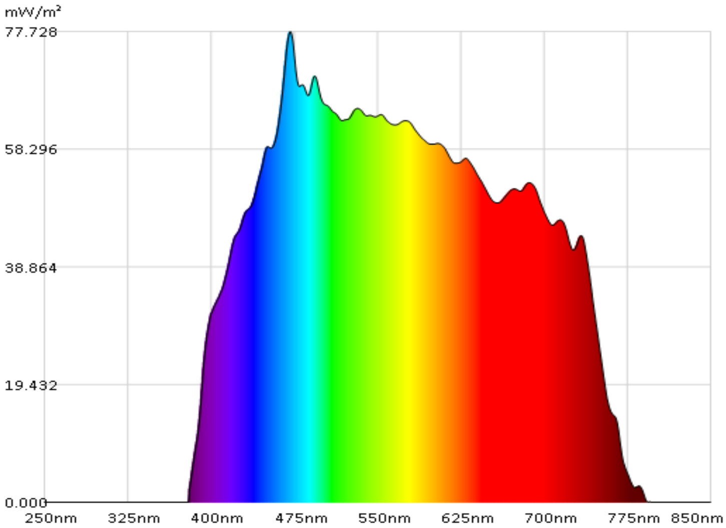

Fig. 1. Spectral power distribution of the filtered Xe-arc light used for MFT.

Blue wool (BW) reference cards were obtained from Talas (lot #: 110121/Sb, received in Jan. 2021). Ten color photographic prints (detailed in Table 1) were selected from *"The Wilhelm Analog and Digital Color Print Materials Reference Collection,"* which spans a 51-year period from 1971-2022. All samples were stored in the dark at ambient room conditions after printing. Two types of standard test target images were used as shown in Figure 2.

Sample ID #	**Imaging Technology**	**Light sensitive materials** (ink/media)	**Paper substrate**	**Manufacturers**	**Year printed**	**WIR Light Stability** (estimated # of years)
11	Chromogenic	Fujicolor Crystal Archive Digital paper Type DPII	Integrated	Fujifilm (Netherlands)	1/2015	18
12	Chromogenic	Kodak Pro. Endura Premier Paper-E Lustre	Integrated	Kodak Alaris	1/2015	17.9
4	Chromogenic	Ektacolor 74 RC	Integrated	Kodak	3/1984	11
2	Integral Instant	Polaroid SX-70	Integrated	Polaroid	7/1978	10
28	Chromogenic	Agfacolor Paper, Type 4	Integrated	Agfa	~1980	6.0
27	Peel-apart instant	Polacolor ER, Type 669	Integrated	Polaroid	8/1984	3.7
26	Integral Instant	Fuji FI-10	Integrated	Fujifilm (Japan)	1/1982	2.6
24	Integral Instant	Kodak PR-10 (original version)	Integrated	Kodak	3/1979	0.5
29	Inkjet	Esyink (dye-based aqueous ink)	GOGI Glossy photo paper	Ink: Esyink Paper: GOGI	11/2006	0.35
35	Inkjet	KMP ink (dye-based aqueous ink)	KMP Fotopapier Photo Professional	KPM	7/2009	0.21

Table 1. List of samples selected for use in this MFT study.

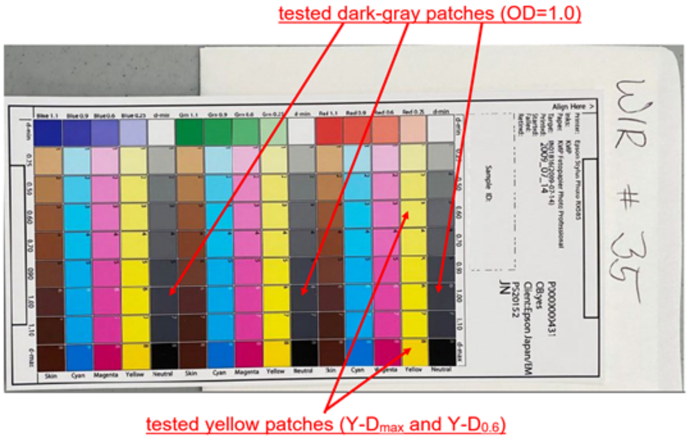

Fig. 2a. WIR Calibrated Digital Triplicate Test Target

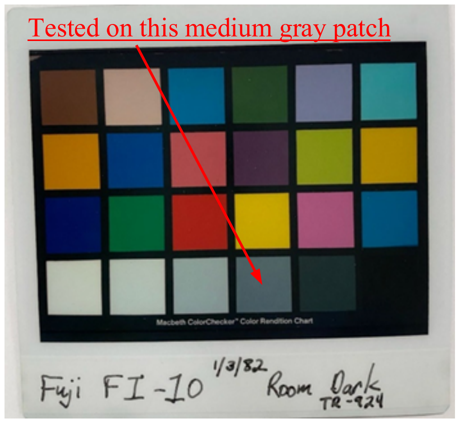

Fig. 2b. Macbeth ColorChecker

Lightfastness Test

To conduct the MFT test, the 0.5mm light spot was focused on one of the color patches selected for exposure (red arrows in Fig. 2). The rest of the photo was protected by a black masking sheet with a ~2mm diameter window for exposure. Total exposure duration was set to 10 min., with a data recording frequency of every 60 sec. Color parameters in CIELAB color space, L*, a* and b*, were reported by the Spec32 software, from which the color-shift, ΔE_{76}, was calculated.

Method development for assessing reciprocity

By definition, the total light energy dosage (J/m^2) = $\boldsymbol{E_e}$ (W/m^2) X $\boldsymbol{t}$ (sec.), where, $\boldsymbol{E_e}$ is irradiance, and $\boldsymbol{t}$ is exposure duration. Therefore, for the same light energy dosage, one can trade higher $\boldsymbol{E_e}$ with shorter exposure $\boldsymbol{t}$. This is the basic principle of reciprocity. Light fading of a colorant, **ΔE**, should be proportional to the light energy dosage, i.e., $\mathbf{\Delta E} = \mathbf{k}\,(\boldsymbol{E_e} \text{ X } \boldsymbol{t})$; where, **k** is a rate constant associated with a light induced photo-chemical reaction, determined by the intrinsic chemical properties of the colorant exposed. In MFT, the light intensity $\boldsymbol{E_e}$ is constant during a test. Therefore, one can derive the rate of MFT color-fading based on the above **ΔE** equation as:

$$\boldsymbol{d}(\Delta E)/d\boldsymbol{t} = \mathbf{k} \cdot \boldsymbol{E_e} \quad (1)$$

From Equation 1, a linear relation between the rate of color-fading, $\boldsymbol{d}(\Delta \mathbf{E})/\boldsymbol{dt}$, and the light irradiance $\boldsymbol{E_e}$ is expected if the reciprocity principle holds. As such, a method to assess the risk of reciprocity failure can be implemented by verifying the degree of linearity of the curve of fading rate $\boldsymbol{d}(\Delta \mathbf{E})/\boldsymbol{dt}$ vs. $\boldsymbol{E_e}$, where, the fading rate may be obtained from an MFT fading curve of ΔE vs. $\boldsymbol{t}$.

However, an MFT fading curve of **ΔE** vs. $\boldsymbol{t}$ is often not linear. It slowly plateaus after longer exposure, indicating a gradual reduction in fading rate (as demonstrated in Fig. 3). This fading rate reduction signals the kinetic constraint of a chemical reaction, i.e. the limited supply of the reactant in the photochemical degradation reaction. This kinetic constraint is minimal in the early stage of fading. Therefore, the initial fading curve shows good linearity and is most likely representing the intrinsic behavior of colorants. To obtain the initial fading rates, we increased the data collection frequency from 60 sec./each data in normal fading test mode to 10-30 sec./each data depending on the light intensity. The linear portion of the early data points were used to determine the initial fading rates.

To validate this method using MFT, we selected a dye based inkjet print (sample ID # 35 in Table 1) along with blue wool 1 (BW1) and blue wool 2 (BW2). From their fading charts of **ΔE** vs. $\boldsymbol{t}$, we obtained their initial fading rates, $\boldsymbol{d}(\Delta \mathbf{E})/\boldsymbol{dt}$, under four different light intensities

E_e, from 100% (full strength) to ~50%, ~25% and ~12.5%. We then plotted this data set of ***d***(ΔE)/***dt*** vs. ***E_e***, and performed linear regression for each sample to determine the degree of linearity. Based on Equation 1, a high regression coefficient should be observed if reciprocity holds in the tested range of light intensities.

Results and Discussion

MFT fading curves obtained from different photographic print technologies

Figure 3 shows a comprehensive summary of the fading curves of all ten prints selected. The span of fading rates of the samples covered almost the entire latitude of Xe-light MFT, from the least fugitive, Fujicolor Crystal Archive DPII estimated comparable to blue wool 5, to the most fugitive, a dye-based inkjet print using KMP inks which tested above the fading rate of blue wool 1. The fading rates of the tested instant photographic prints are between blue wools 1-3. The initial fading rate of Kodak Ektacolor 74RC was much higher (near blue wool 1), but after ~1-2 min. it quickly decreased to between blue wools 2 and 3. This could be indicative of uneven fading rates among the colorants inside the gray patch. In general, the fading rates of the tested chromogenic prints are comparable to or better than blue wool 3, placing them at the edge of the detector's capabilities for a 10 minute test. Consequently, only a limited range of imaging materials, from fugitive to highly fugitive, may be suitable for testing with MFT to assess their light fastness. This range is comparable to that of blue wool scale 1-4 (ISO 105-B08), or as classified by Robert Feller as "Class T" and "Class C", and perhaps up to the low-end of "Class B" (Feller, R. L. 1994). MFT will struggle to differentiate the relative light fastness of prints with light stabilities better than modern chromogenic prints, due to the constraint of the detector signal to noise ratio and test exposure duration (less than a few hours).

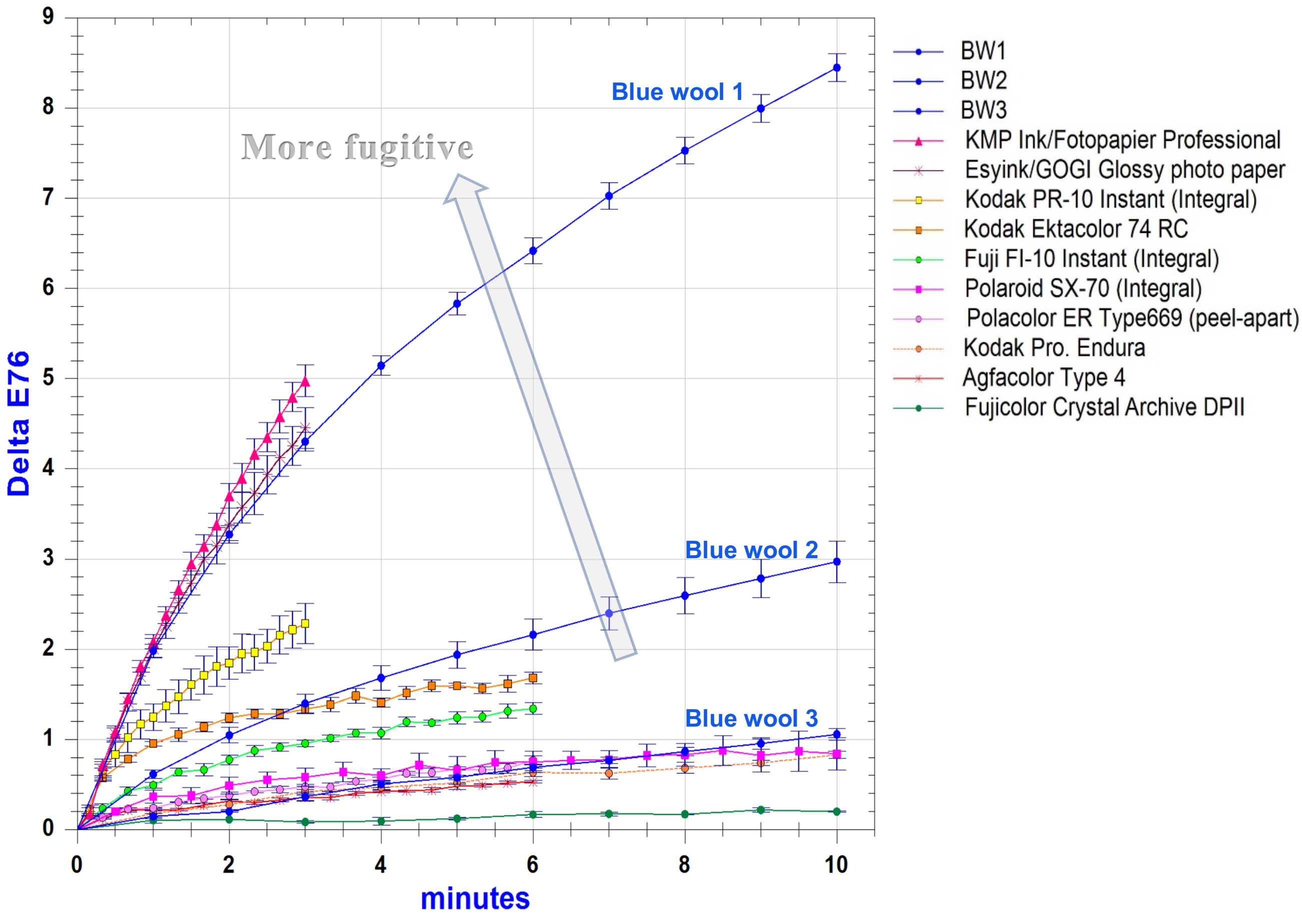

Fig. 3. MFT fading charts on gray patches of all tested samples: □E76 vs. exposure time at 100% intensity, E_e ~8 kW/m^2

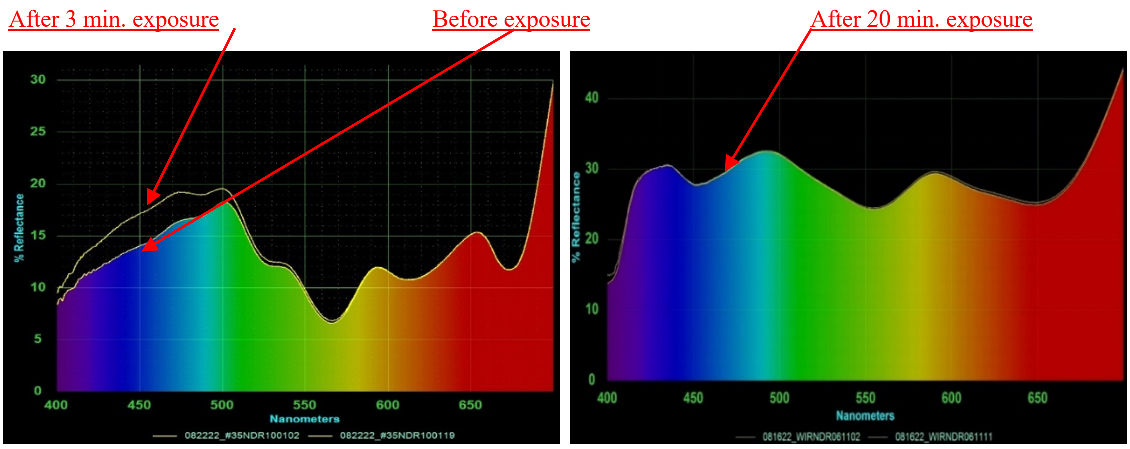

Fig. 4. Comparison of reflective spectrums collected by MFT on an exposure spot in a gray patch before/after test. Left: the most fugitive print (3 min. exposure); Right: the least fugitive print (20 min. exposure).

Using MFT to identify the leading cause of color fading in a photographic print

MFT also offers insight into key questions and mechanisms of fading for fugitive prints once identified. By analyzing the reflective spectrum changes of the gray patch before and after light exposure, one may obtain information regarding which colorants inside the gray patch are likely contributing to most of the detected color-shift, ΔE_{76}. Figure 4 compares the reflective spectrum changes between the most and the least fugitive prints among the ten tested. The most fugitive print (left) clearly showed significant increase in blue reflection after 3 minutes of light exposure, indicating the loss of yellow absorption inside the exposed spot. Therefore, the leading cause of the high fading rate in this print is likely the loss of the yellow colorant. In comparison, the least fugitive print among the ten showed little change in the reflective spectrum across the entire visible range, even after 20 min. of exposure (~7x higher light dosage).

To confirm that the large ΔE_{76} on the gray patch of the most fugitive print was indeed caused by the fading of the yellow colorant in it, the change in the b* component during exposure was also examined (Fig. 5). In CIELAB color space, b* represents the color balance between blue and yellow, a higher b* value corresponds to more yellow colorant in the image spot. The loss in b* of ~4.5 units represents almost all of the ΔE_{76} shift observed in Figure 3 (ΔE_{76} ~5 units in 3 minutes).

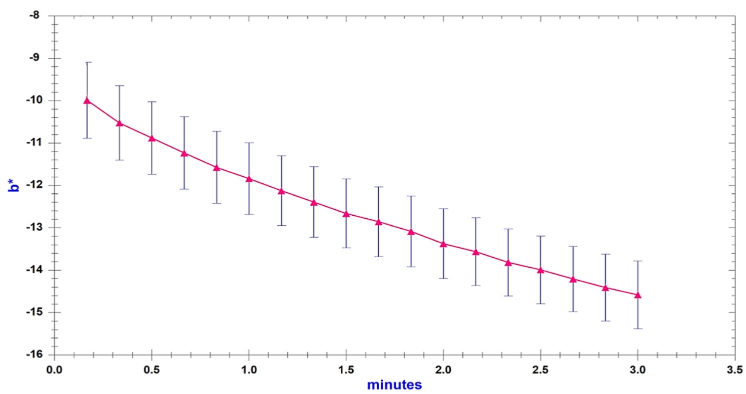

Fig. 5. b* shift from the most fugitive print.

Using MFT to understand the impact of light-exposure history on photographic prints

MFT can also be used as a tool to understand the impact of light-exposure history on fugitive photographic prints, especially as previous exposure might impact its future fading rate. The previous work identified that the yellow colorant was the major contributor to the color shift of the gray patch in the most fugitive print. We then tested a yellow patch (Y-$D_{0.6}$) in that print with repeated MFT exposure on the same spot. Figure 6 shows the fading curves of the tested spot after 5 repeated exposures. The slope of the fading curves represents the fading rate. The chart clearly shows that the fading rate was progressively reduced after each round. Figure 7 reveals the changes in the reflective spectrum of the Y-$D_{0.6}$ patch test spot, which confirmed the progressive loss of yellow, but with a reduced magnitude after each 10 min. exposure.

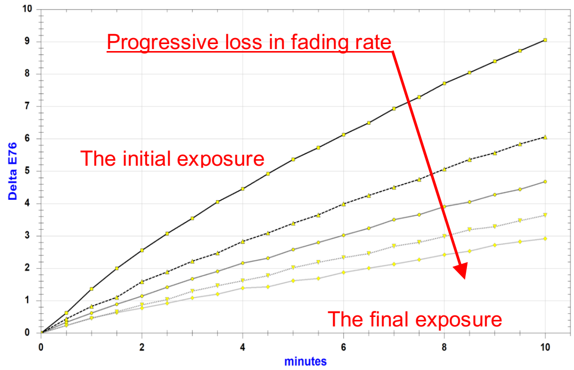

Fig. 6. MFT fading curves of the Y-$D_{0.6}$ patch.

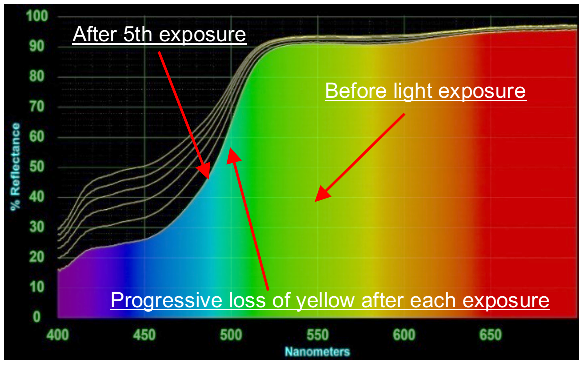

Fig. 7. Reflective spectrum change of Y-$D_{0.6}$ patch

Using MFT to assess reciprocity

Following the method developed for assessing reciprocity described above, we obtained the initial fading rates, i.e., the slope of the linear regression fitting each curve in the initial exposure period under four light intensities for BW1, BW2 (Figure 8) as well as the gray patch of the most fugitive print (Figure 9) shown below.

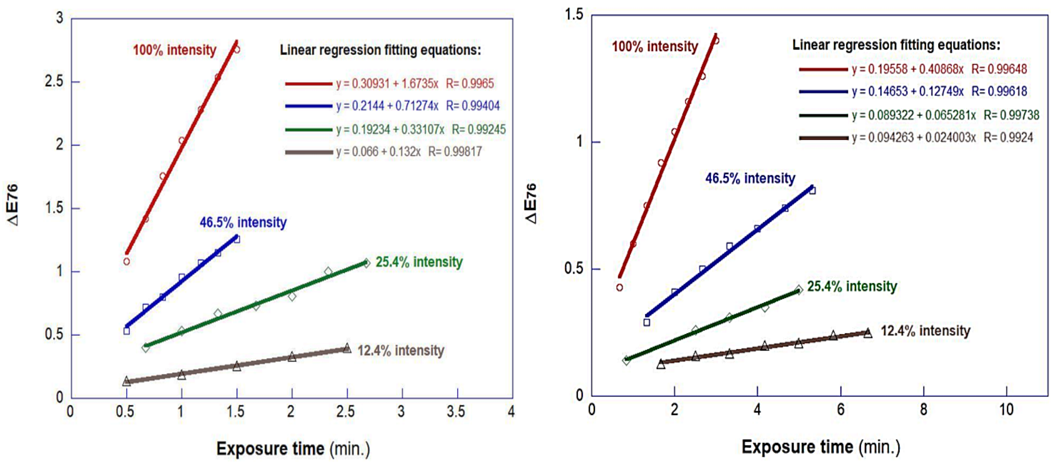

Fig. 8. The initial MFT fading curves of BW1 (left) and BW2 (right) under four different light intensities

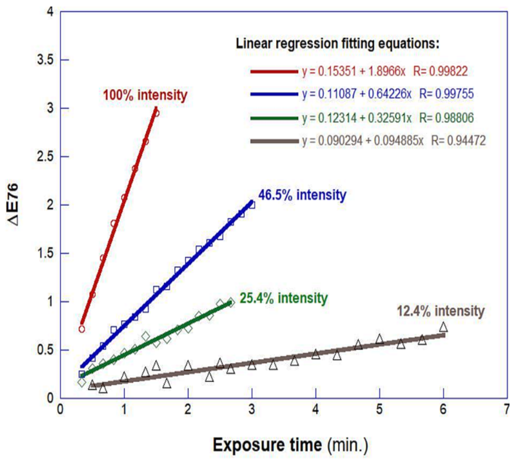

Fig. 9. Initial MFT fading curves of a print sample

From Linear Fitting of Fading Curve Plots

ND filters	Intensity (%)	*Ee*-measured (kW/m²)	Initial Fading Rates, $d(\Delta E)/dt$		
			BW1	BW2	Test print
0.3+0.6 OD	12.4	1.01	0.132	0.024	0.095
0.6 OD	25.4	2.07	0.331	0.065	0.326
0.3 OD	46.5	3.79	0.713	0.127	0.642
None	100.0	8.13	1.674	0.409	1.897

Table 2. Data derived from linear regressions in Fig. 8 & 9

All four curves for BW1 and BW2 in Figure 8 show strong linearity (R > 0.99). The linearity of the fugitive test print in Figure 9 was marginally lower under the 12.4% reduced light intensity (R ~0.94), but still meaningful. Table 2 is a collection of the initial fading rates of BW1 and BW2, as well as the test print, along with the measured light intensities E_e when different ND filter combinations were used.

Subsequently, using the data in Table 2 we plotted the four initial fading rates $d(\Delta E)/dt$ versus the four light intensity levels, E_e, for each sample and examined the linearity of the resulting lines through regression fitting. Figure 10 demonstrates that the linear correlation coefficient R was greater than 0.99 in all cases. We thus concluded that reciprocity holds well within the range of the four tested very high light intensities. The slopes of these lines represent the rate constant, **k**, of their colorant fading under different light intensities.

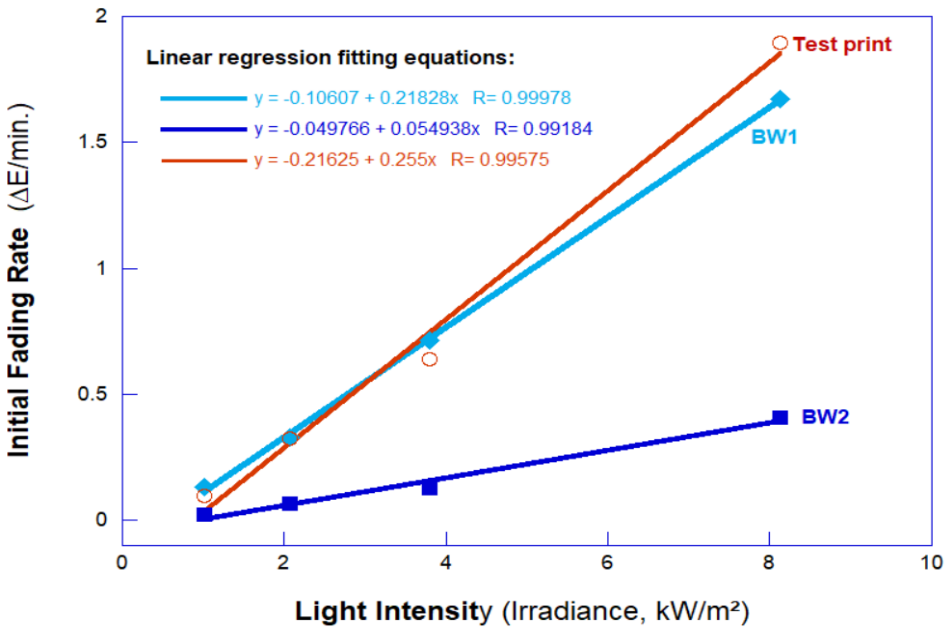

Fig. 10. The linear correlation charts of initial fading rates, $d(\Delta E)/dt$, vs. light intensity, E_e

It is interesting to note that the line representing the test print (red) crossed that of BW1 at ~3 kW/m^2 (Fig. 10). As such, one can predict that the relative fading rate of the test print vs. BW1 will not hold under lower light intensity. It may in fact fall below that of the BW1 under a lower light intensity, because the test print has a steeper fading rate vs E_e curve, i.e., the reduction of its fading rate is faster than that of BW1 when the light intensity becomes lower. This has important implications for how this data might be used to determine display lighting budgets that balance access and preservation.

Conclusions and Future Work

MFT was useful for examining a wide range of photographic prints and was most successful highlighting very fugitive examples, although prints made from many modern digital technologies proved to be highly stable and are therefore possibly beyond the testing latitude of MFT. For fugitive or highly fugitive color photographic prints, the MFT is capable of revealing the primary cause of light fading when testing gray color areas of an image sample (usually a mixture of all colorants). Two approaches may be used, either examine the changes in reflective spectrums of the gray patch before and after MFT exposure, or examine the relative fading rates of the components in ΔE_{76}, Δa^* or Δb^*. MFT may also be used to acquire the signature absorption or reflection spectrum of an individual dye in a print. Further, MFT may be used to examine the impact of the history of light exposure on the residual fading rate of a highly fugitive photographic color print.

In order to extend the MFT technique to be able to answer questions most pertinent for collection care and exhibiting color photographic prints, a method for assessing the risk of reciprocity failure in MFT was developed and validated using an actual print sample. A theoretical linear relation between the initial fading-rates, $\boldsymbol{d(}\Delta\mathbf{E})/\boldsymbol{dt}$, under different light intensities $\boldsymbol{E_e}$ was derived and supported by data collected from BW1, BW2 and a highly fugitive inkjet print. During the validation process, we demonstrated another useful application of this method. It can reveal if the relative fading rates of a test print versus one of the blue wool scales (BW1 or BW2) will hold or not when the light intensity is reduced from the MFT level to a much lower level, based on the slopes of the linear correlation **k** between the blue wool reference and the test sample.

Going forward we plan to compare test results from this Xe-arc light MFT system to an LED MFT system. This will allow us to extend the reciprocity test results across a much wider range of light intensities, by comparing MFT test results to those from a conventional light fading test chamber using the same type of light source (LED). We will collect more test data on other types of photographic prints, such as D2T2 prints, Indigo and electrophotography prints, UV-curable inkjet prints, dye-sublimation prints (ChromaLuxe). We also plan to develop a method that can differentiate MFT induced yellow dye fading and the potential bleaching of yellowish stains formed on prints during dark storage. These current and future method development efforts highlight the value and importance of reference collections for testing in order to most effectively understand MFT data and interpret it for valuable collection items, and to make the informed decisions for their care and enjoyment by the public.

Acknowledgements

The authors are grateful for help from Dr. Lindsay Oakley during the busy microfading testing days, as well as her comments made during the development and revision process of this paper. The authors are also grateful for shared expertise from Dr. Bruce Klemann, in the interpretation of the measurement results from SRI-2000UV Spectrophotometer.

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Interferential colour photographic plates from the 19th c. to the 21st c.: characterization and preservation

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Extended abstract

Keywords: interferential photographic plates, Lippmann process, colour photography, unmounted plates, collections.

Introduction

Lippmann colour photographic plates (Lippmann, 1891) have been of great interest to physicists up to the present day. It is undoubtedly the physical principle of recording colours by interferences in the sensitive material that motivates many physicists to explore the spectral nature of these images (Baechler *et al.*, 2021). Less work has been published on the preservation of these plates (Giatti, 2021; Gold, 2021; Gold, 2022; Martin and Sandrin, 2022). Indeed, until recently, these plates have been little presented to the public, outside the academic or educational fields. In 2021, the Preus Museum (Norway) opened a temporary exhibition of interferential plates (Gold, 2022), while Photo Elysée, Museum for Photography (Switzerland) which has the largest collection, with 138 plates, will exhibit plates by G. Lippmann in 2023 and has initiated a catalogue raisonné of Gabriel Lippmann plates worldwide by Pauline Martin, Nathalie Boulouch and Carole Sandrin. *Lille Université* in France also plans in 2023 a temporary exhibition of plates by Auguste Ponsot who improved the process. *Sorbonne Université* in Paris owns a collection of more than forty interferential plates coming from the *Laboratoire des Recherches Physiques* which was directed by Gabriel Lippmann himself. The university has just decided to create a Lippmann colour museum around this emblematic collection. It is therefore an understatement to say that there is a new real craze for the exhibition of interferential plates. It is in this context that we consider our modest contribution on the materiality of the plates and their preservation.

It is true that many of these plates are in a very good state of conservation and that they retain their brilliant colours. However, these photographic objects show various types of alterations that could be due to handling errors, ageing of the packaging materials, or from the ageing of the plate materials (Lamotte, 2014). We have little information on their conservation, their capacity to resist exposure to light and pollutants, humidity and temperature variations according to the nature of the image layer and mounting. On the whole, up to now, these plates may have not been exposed too much, even if some of them have been widely manipulated and even sometimes projected.

Of course, the major obstacle to the material characterization of the interferential plates is the prism affixed to the image layer. This glass prism, which is a device to help the visualization of the colours of the photograph, constitutes a material barrier that limits the analysis by most spectroscopies and some microscopies, as the beams cannot pass through such a thickness of glass. We have chosen to follow two avenues that we are just beginning to explore. Firstly, we are interested in historical interferential plates without prism, and secondly, to work on contemporary plates.

Characterization of seven plates from the collection of *Société Française de Photographie*

The collection of the *Société Française de Photographie* (SFP) has twenty-five plates listed. These plates have a very diverse iconography: still lives, reproductions of works of art, a landscape and six spectra. We have studied seven interferential plates of them without prism and, it must be said, with few colours! This shows the secondary function of the prism for the good conservation of the plates. These seven plates are of three different formats, rectangular or square in shape, and with varying thicknesses. Figure 1 shows one of the spectra in reflected light on a black background (left) and on a white background (right). One can see that the colours do not match with the ones of a solar spectrum.

Five plates are classified as "Lippmann plates", designating their process, without knowing their exact origin. Two plates may be attributed to George Goddé (1856-1909), distinguished member of SFP who won a competition organised by the Société for other interferential plates in 1900.

Fig. 1 – Interferential plate seen in reflected light on a black background (left) and on a white background (right). Anonymous plate, attributable to Georges Goddé. frSFP_0251im_0005, Société Française de Photographie. 6.6 cm x 8.8 cm x 0.2 cm.

We used two types of spectroscopy: first Fourier transform infrared spectrometry in reflectance mode that allows analysis without contact with the photograph. The objective is to identify the binder in the image layer. Infrared spectra proved to be difficult to interpret. On the one hand, the image layer is so thin that the infrared reflectance includes the signal from the glass support. On the other hand, the spectra collected in reflectance mode can show distortions, which make it difficult to distinguish between gelatine and albumin as is possible when measuring by contact. We can nevertheless conclude that none of these seven plates use collodion, as it was expected for one of them. We were able to compare with IR reflectance spectra collected on contemporary interferential plates by Nick Brandreth and Filipe Alves. We know that they use a gelatine binder and an albumen one respectively. So the binder of all the plates we analysed might be gelatine and it would be in accordance with Goddé's text.

X-ray fluorescence spectroscopy was the second type of analysis performed in order to identify the chemical components of the image layer. It reveals the presence of numerous elements. This spectroscopy at this excitation energy analyses the image layer and the support glass. Silicon, potassium, calcium, titanium, chromium, iron, nickel, zinc, and arsenic are all elements in the glass used as the support of the image layer, glass which is therefore a calcium glass. The glasses differ according to the presence of arsenic or lead, unrelated to the attribution of the plates. Other elements are linked to the image layer: sulphur, iodine, mercury, bromine and of course silver. The origin of iodine and bromine found in the non-attributed plates raises questions about the fixing of those plates. As expected, iodine and bromine were also detected in the contemporary unfixed plates. Contrary to the non-attributed plates, the Goddé plates appear to be well fixed. The mercury may come from the mercury bichloride intensifier also practiced by Goddé. These first spectroscopic measurements therefore give results in accordance with the text for the two Goddé plates.

Conclusion

These first data contribute to a better documentation of the materiality of unmounted interferential plates and of course raise questions about the origin of the current state of the plates: what were the original colours like? When and why did they lose their colours? By combining the study of contemporary and historical plates, we hope to better understand the traces left by the process and its variants in the image layer and thus help to specify recommendations for their storage, consultation and exhibition.

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Léon Vidal's Photochromy: Study of the process in albums *Le Trésor Artistique de la France* at the Rijksmuseum

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Abstract

The Rijksmuseum holds two relevant albums titled *Le Trésor artistique de la France* (1878-79). They content 39 photomechanical illustrations made mostly with Léon Vidal's Photochromy process, being the best example of this technique. To better understand the materiality of the Photochromy prints, they have been examined with visible light, under microscope and UVA-Induced Visible Fluorescence. X-Ray Fluorescence analysis has been also performed. These techniques allowed us to know the structure of the prints. They consist on: baryta paper, translucent pigments layers and final image of pigmented gelatine. Each print is presented under a passe-partout. The prints were mostly in good condition although some of them suffered from mold attack. The treatment of the moldy areas is out of the scope of this paper, but it was performed as part of this research project. Another relevant aspect was the formation of a phantom images on some of the passe-partouts, which were only visible through the application of UVA-Induced Visible Fluorescence, and which could be a type of faded pigment traces. XRF analysis was performed to get information about the composition pigments used in the chromolithography layers and the inorganic components present in passe-partouts.

Keywords: Léon Vidal, Photochromy, Photomechanical, Woodburytype, Chromolithograph; Characterization, XRF, UV.

Introduction

One of the most remarkable inventions of the professor and scientist Léon Vidal was the creation of the photomechanical colour reproduction process known as Photochromy in 1872. Its limited application over time, with only a few years of use, means that the examples of this technique available to us are objects of exceptional value that require study and understanding, both historically and in terms of their physical structure and chemical composition. The aim of this work is to understand the materiality of the Photochromy process to better conserve and treat these objects. The findings will shed light on these uncommon photomechanical colour process and provide more information about appropriate treatments and long-term preservation procedures.

Léon Vidal and *Le Trésor Artistique de la France*

Léon Vidal (1833-1906) was a French scholar and inventor. Founder and editor of the journal *Le Moniteur de la Photographie,* he was also general secretary of the Sociéte de Photographie de Marseille and professor at the École Nationale Súperieure des Arts Décoratifs. He was interested early in his career in different photographic processes, such as collotype and carbon prints, and he published several manuals in which he explained his discoveries and technical advances, focusing on colour photography. These publications include: *Traité pratique au photographie du charbon* (1877), *Traité pratique de Phototypie* (1879), *Manuel pratique d'Orthochromatisme* (1891), *Photographie des Coleurs* (1897) and *Traité pratique de Photochromie* (1903). He was dissatisfied with the results for obtaining reproductions using heliochromy or the colour experiments of Ducos du Hauron and Charles Cros, and his most influential work was the creation of the Photochromy in 1872 (patent I.N.P.I nº 97.446 du 23 déc. 1872) (Arqué *et al*, 2009). This new process of photomechanical colour reproduction was explained in *Cours de Reproductions Industrielles* (1882) and he used it to reproduce various artistic objects from the Musée du Louvre, which he grouped together in a compendium known as *Le Trésor Artistique de la France*. According to some authors, such as Paul de Saint Victor (1876), this process for obtaining the colours involved "a system of infallible polychrome reproduction applied to photography and merging with it".

Léon Vidal, in his quest for natural colour reproduction, officially demonstrated his new colour process at the Paris World Fair in 1878. In the text "Le Renoveau de L' Exposition Universelle", in the newspaper *La Mosaïque* (seventh year, 1879, p. 47), we can see an illustration with an engraving of the Photochromy pavilion (Fig. 1) where Léon Vidal demonstrated the process as well as showing some examples. The following words are recorded:

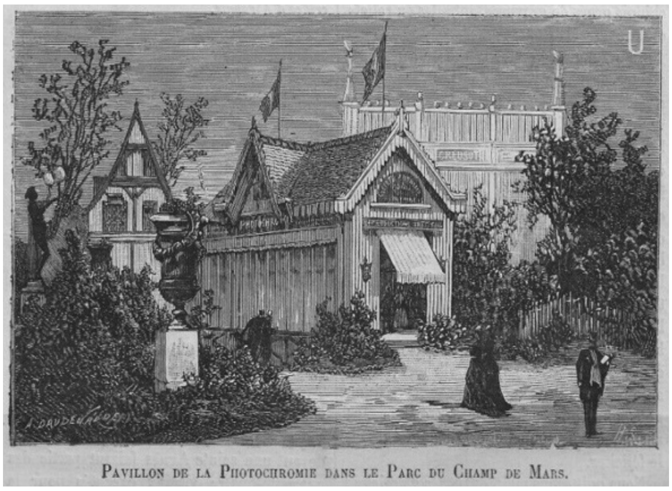


Fig. 1 - *La Mosaïque. Revue pintoresque ilustrée de tous les temps et de tous les pays* (decembre 1879, p. 48).

"Modest in its proportions but particularly interesting, both for its exhibition and for the works that were produced there, the photochromy pavilion was almost next to the Creuzot building. The admirers of this colossal factory did not forget to visit the photochromic enclosure and left in awe. There they had seen the power of human work in a completely new light - a new aspect: the masterpieces of art reproduced with astonishing fidelity, by a set of means borrowed from photography, woodburytype and chromolithography; in such a way that the most delicate, the most elusive of things, art, was fixed and multiplied in all the splendour of its colouring".

Le Trésor Artistique de la France was published in Paris by the Société Anonyme des publications périodiques, under the direction of Paul Dalloz, and it was printed in the atelier Le Moniteur Universel. Distributed in instalments, the first issue of the work was announced in the specialised press on 9 March 1878. Its purpose was to reproduce faithfully in colour various artistic objects from the Musée du Louvre, specifically those on display in the Galerie d' Apollon, and they were accompanied by explanatory texts. The examples encountered in the albums consist of 39 prints, of which 8 are monochrome collotypes, one is a woodburytype and 30 are made with the process of Photochromy. Despite its initial success, the unaffordable price of the publication *Le Trésor Artistique de la France* made the project unprofitable, and production was stopped in March 1879 with its last issue (Meizel, 2012)

The Photochromy process

The Photochromy process is the sum of art and science. It is a hybrid photomechanical process produced by the combination of the photography, chromolithography technique and

Woodburytype. It is worth mentioning that in some cases, the colours were applied in sections made with the carbon transfer process (Hannavy, 2008), but Vidal himself did not recommend this process for large editions. The Photochromy process is described by Léon Vidal in his manual entitled *Cours de Reproduction Industrielles* (1882):

1. Photographic section: First, a glass negative of the object to be reproduced is taken. By contact with this negative, a positive is obtained. And by contact with this positive the negatives will be obtained. These new negatives may be made of translucent paper instead of glass. At least three negatives will be obtained but, if necessary, up to ten or even twelve different negatives should be taken (one for each monochrome colour). In each negative, the areas not intended for printing shall be covered with opaque ink applied with a brush. Thus, for example, if we take the negative that will provide the blue monochrome colour in chromolithography, we will cover the non-blue areas of the negative with opaque ink.
2. Chromolithographic section: Preparation of the lithographic stones by applying a layer of asphalt mixed with chloroform and, by contact with the negative, exposure to light and subsequent development with turpentine oil. The surface of the stones must then be chemically modified by applying gum arabic, water and a small amount of nitric acid (Arqué, 2009). This process shall be done for each negative. The lithographic stones are inked with their respective colours. The paper[10] is then placed on top and pressed. The different transparent lithographic colours are superimposed of each other (Stulik and Kaplan, 2013). Once the colour printing was finished, it is left to dry, and a layer of gelatine is applied.
3. Woodburytype section: A Woodburytype image is then superimposed, forming a final image of gelatine and ink[11]. Finally, the edges of the image smudged by the Woodburytype process were trimmed and the prints are mounted on a second cardboard support[12].

Characterization of the prints

The Photochromy prints in the albums are large format, measuring 546 x 381 mm. They are mounted on a second cardboard support and are individually framed in a passe-partout, accentuating their three-dimensional effect (Fig. 2).

Fig. 2 - L. Vidal (1878). Photochromy print. Rijksmuseum (RP-F-2001-7-1545B-8).

Fig. 3 - L.Vidal (1878). Photochromy print. Rijksmuseum (RP-F-2001-7-1545B-9). Detail.

[10] Vidal recommended Rives paper because of its quality (Vidal, 1882).
[11] The ink used to be made of gelatine mixed with carbon-based pigments (lamp or vine-black) (Stulik and Kaplan, 2013).
[12] For more information on the description of the woodburytype process, see: Stulik and Kaplan, 2013.

The final image is highly detailed, with a sense of relief and a glossy sheen over the entire surface caused by the woodburytype technique (Fig. 3).
The prints made with the Photochromy technique would consist of the following structure (Fig. 4):

- The support is paper coated with a layer of lithographic varnish and a layer of satin-finish baryta (barium sulphate or lead white).
- Next, we have different translucent colours superimposed using the chromolithography technique. In this case a first layer of flesh colour, followed by a layer of yellow, dark blue, light blue and carmine red. As many colours as needed could be used.
- After the colours layers, we have the image made of gelatine and black pigment, created using the Woodburytype technique.
- The result is a Photochromy image that combines the accuracy of the depicted object and the colour rendition of reality.

Fig. 4 – Diagram of a Photochromy print. Source: L. Vidal. *Cours de Reproduction Industrielles* (1882), adapted by the author.

As for their condition, most of the prints showed generalised dirt and traces of the metallic dust that had come off the decorative passe-partout. Some had fungal stains on their surfaces, and one had a very pronounced craquelure on the woodburytype layer.

Experimental procedures

Experimental procedures were carried out in the department of Paper and Photo Conservation and the department of Science at the Rijksmuseum, and the interpretation of data was carried out by the author. The procedures and instrumentation used in this study are described in the following lines.

Stereo-binocular Magnification

The prints were examined using a Leica MZ-9.5 stereo-binocular microscope with magnification capability of 480x. Digital images were captured with a Canon EOS 550D.

Digital Microscope

We examined the prints with a HIROX RH-2000 digital microscope with magnification capability of 10.000x. Digital images were captured with HIROX System.

Ultraviolet (UV) Induced Visible Fluorescence

The prints were also examined under UV illumination using LED Lamp (Preservation Equipment Ltd) with 368 nm (long-wave) capability with a ZWB2 filter (black glass). The prints were photographed under UV fluorescence using a Canon EOS 5D Mark III provided with Hoya HMC UV-IR Digital Multi-Coated Slim Frame Glass Filter, a Kodak 4 x 4” 85B Optical Wratten 2 Filter and a Kodak 4 x 4” #2E Pale Yellow Optical Wratten 2 Filter.

X-Ray Fluorescence (XRF) Analysis

In order to determine the elemental composition of inorganic pigments presents in the chromolithographic parts of the prints and the composition of passepartouts, we perform XRF analysis in different areas. A Bruker ARTAX XRF device was used for this research.

Results

With the Stereo-binocular Magnification we can see the details of the impressions, being able to better understand the process of making them as well as the defects of execution. We can see how an abrasion in the gelatine layer of the woodburytype allows us to see the overlapping of the chromolithography colours (Fig. 5)

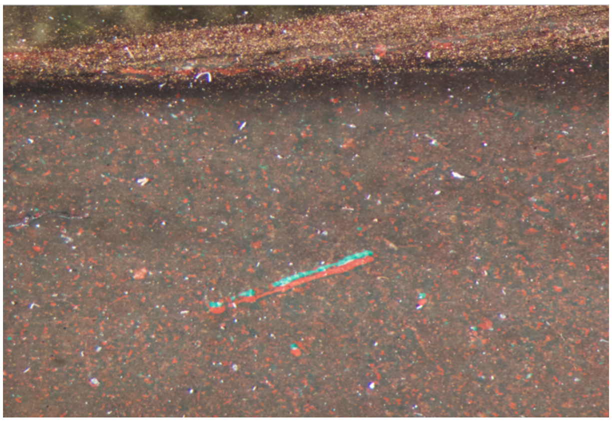


Fig. 5 - L. Vidal (1878). Photochromy print. Rijksmuseum (RP-F-2001-7-1545A-9). Leica MZ-9.5 stereo-binocular microscope.

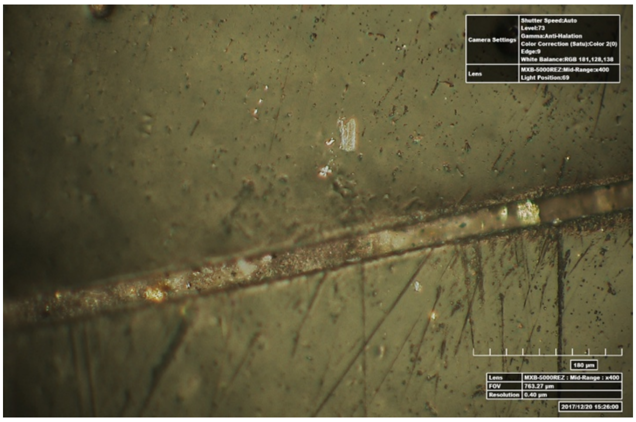


Fig. 6 - L. Vidal (1878). Photochromy print. Rijksmuseum (RP-F-2001-7-1545A-9). HIROX RH-2000 digital microscope.

The Digital Microscope allows us to look at the prints at higher magnification. Here, we see again the abrasion on the woodburytype layer and in underlying layers pigment particles from the chromolithography (Fig. 6).

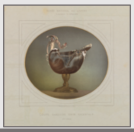
Fig. 7 - L. Vidal (1878). Photochromy print. Rijksmuseum (RP-F-2001-7-1545A-21). Visible light

Fig. 8 - L. Vidal (1878). Photochromy print. Rijksmuseum (RP-F-2001-7-1545A-21). UV light. Courtesy of Martin Jürgens

The realization of UV photographs allowed us to unveil an interesting feature. In some of the passe-partouts, the image of what it looks like phantom frames are visible under UV fluorescence (Fig. 7 and 8).

X-Ray Fluorescence analysis allowed us to qualitatively identify the inorganic components that make up the prints. These analyses were performed in six prints, both in different points of the chromolithography colours and in the passepartout presenting the phantom frames. The summary of pigments suggested based on XRF results are described below (Table 1):

Table 1: Data obtained from XRF analysis (Peaks listed roughly in order from largest to smallest)

Print	Description	Major peaks	Minor peaks	Pigments suggested
RP-F-2001-7-1545A-2 	Light silver in helmet	Sn, Ca, Pb	Fe, Zn	Iron Black, White Lead, Zn or Sn powder
	Dark silver in helmet	Sn, Ca, Pb	Ba, Fe	Iron Black, White Lead, Sn powder
	Golden dot	Cu, Zn, Pb	Sn, Ca, Fe	Yellow Lead, Lead tin Yellow, Bronze powder
	Passepartout	Fe	Ca, Pb	-
RP-F-2001-7-1545A-3 	White dot	Pb, Ba	Fe	White Lead
	Golden	Cu, Pb	Zn, Ba, Fe	Yellow Lead, Bronze powder
RP-F-2001-7-1545A-21 	Phantom frame in passe-partout	Cu, Zn	Fe, Pb, Ca	-
	Passe-partout	Fe	Cu, Pb, Ca	-
RP-F-2001-7-1545B-7 	Red bottom	Zn	Fe, Hg, Pb	Red Ochre, Red Lead/Minium, Vermilion
	Grey mirror	Zn	Fe, Ca, Pb	Zinc White, Iron Black
RP-F-2001-7-1545B-9 	Black background	Hg, Pb	Fe, Ba	Mars Black
RP-F-2001-7-1545B-10 	Golden dot	Cu, Zn, Pb	Sn	Yellow Lead, Lead tin Yellow, Bronze powder
	Silver armour	Pb, Sn, Ca	Fe, Zn	Iron Black, White Lead, Zn or Sn powder
	Dark green bottom	Pb, Hg	Fe, Ba, Cr	Chromium Oxide

Discussion

For the suggestion of pigments present in the chromolithography, the results obtained with XRF analysis have been compared with the data collected on pigment composition in the publications of B. Baade (2011) and B. H. Stuart (2007). They have also been compared with manual by Fredéric Hesse (1897). *La Chromolitographie et la Photochromolitographie.*

The silvery colour that appears in those prints, representing different parts of armour, was achieved by mixing black and white pigments. In this way, the presence of Fe can be associated with the identification of the Iron Black pigment (Fe_3O_4) and the presence of Pb with the White Lead pigment ($2PbCO_3 \cdot Pb(OH)_2$). A powdered metal, such as Zn or Sn, may have been applied to give the silver effect.

As for the gold pigment, the presence of Pb suggests the identification of Yellow Lead (PbO) or with the addition of Sn it could be Lead Tin yellow (Pb_2SnO_4). Furthermore, the occurrence of Cu, Sn and Zn suggests the presence of added bronze powder, to give the yellow that characteristic golden colour.

The Pb found in the white pigment suggests that it is probably White Lead ($2PbCO_3 \cdot Pb(OH)_2$). The rest of the elements found at this area possibly belong to the paper support.

Analyses carried out on the red colour show the presence of Fe, which can be related to the Red Ochre pigment (Fe_2O_3). Also, with lesser presence, we can find Pb, therefore we could suggest Red Lead/Minium pigment. (Pb_3O_4). However, the presence of Hg suggests that Vermilion (HgS) may also be present, but there is no indication that S is present in the composition. The strong presence of the element Zn is confusing for the identification of the red pigment. It could be due to the addition of the Zinc White pigment to lighten it. On the other hand, the publication by F. Hesse (1897) indicates that lacquers such as Carmine, Geranium, Ponceau or Madder could be used to apply the red colour. In order to identify the presence of these lacquers, another analytical techniques are needed.

Regarding to the greyish colour of the mirror zone, the element Zn has been found to be predominant, in this case it could be due to the use of Zinc White pigment (ZnO), as Pb is not very present. The appearance of Fe may once be due to the Iron Black pigment (Fe_3O_4).

The black background colour of one of the prints shows the element Fe in its composition, which could therefore be Iron Black pigment (Fe_3O_4). However, the presence of Hg and Pb is more pronounced, but could not be related to any black pigment, and may correspond to other underlying pigment layers.

As for the dark green colour present in the background of one of the prints, the presence of Cr has been found to be consistent with this colour, which could be the Chromium oxide pigment. (Cr_2O_3). Again, we find a higher presence of the elements Pb and Hg, which cannot be related to any green pigment.

XRF analysis was performed on two passepartout, one of them containing an example of a phantom frame. The results show the presence of common elements in cardboard supports, such as Ca, Fe and Pb, which come from the manufacturing process. The high presence of the elements Cu and Zn in the phantom frame area is significant. The purpose of these phantom frames is unknown but, given their decorative character and arrangement, they could be a type of pigment that has faded in the light and can now only be observed with UV fluorescence.

Conclusions

This study has provided more information on this complex photomechanical process. Knowledge of the material conformation of these prints is essential to be able to carry out the appropriate conservation treatment. The results of the experimental procedures showed the structure and composition of the colour layers in these prints. However, it should be noted that the superposition of these colours in the prints can lead to confusion when obtaining the inorganic elements with XRF. For a more detailed identification of the pigments in the photochromy, it would be necessary to compare the results with Raman spectroscopy. FTIR analysis would also allow the identification of the organic elements present in the prints. There are signs that on top of the woodburytype layer there might be some type of varnish of an organic nature. For future research, it would also be appropriate to evaluate the stability of the pigments used for the chromolithography. On the other hand, the discovery of phantom frames in some of the passepartouts has been significant. It is paradoxical that it was only found in some of the passepartouts and that it can only be seen with UV Fluorescence. It is ruled out that it is a kind of watermark, so it could be the application of a pigment. No other similar case has been found so far.

Acknowledgments

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The Colour in Nicola and Elvira Notari's Italian silent movies

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Abstract
The period around the 1920s was a highly prolific one for the Italian production company, Dora-Film. Nicola Notari was born in Naples and was a photographer and film producer. In the early 1900s, Elvira Coda moved from Salerno to Naples, where she met Nicola, marrying him a few years later.
Together, Elvira and Nicola founded Dora-Film, which was one of the first film production houses in Naples. Elvira Coda Notari was among the first women filmmakers in the history of cinema. She was also the female pioneer of Italian film, a forerunner in the Italian dramatic comedy and neorealist genres. Elvira became the scenarist and director of highly successful silent movies based on Neapolitan dramas. She began her career by helping Nicola Notari to colourize the photographs, and later the frames, for their own film productions.
Following developments in France spearheaded by Méliès, Chomon, and the brothers Charles and Émile Pathé, colour films were now being made in Italy too: copies of black and white films were coloured manually, frame by frame. These films represent a key milestone in the history of Italian cinematographic heritage.
This aim of this paper is to outline the extraordinary contribution of Elvira and Nicola Notari and their company Dora-Film to the silent movie era. Our brief review will focus on the excellent restoration of "'A santanotte", one of the first colorized movie productions to emerge from Italian color movie culture, as well as on other films produced by Dora-Film in Naples in the early 1900s. Thanks to her personal interpretation and the application of hand colouring techniques, Elvira endowed Italian cinema with a female expressive perspective.

Keywords: Italian colourization silent movie, Elvira Coda Notari, Nicola Notari, early Italian female filmmakers, Dora-Film, historical Cinematographic Heritage.

Introduction

The use of colour during the silent era began with experimentation on early films by pioneer filmmakers Georges Méliès and Segundo Chomon. Pathé Film and other makers of silent movies copied their colourization techniques.
Nicola Notari, an Italian painter and photographer, opened a laboratory at his home where he experimented with photo colourization, and later, with the assistance of his wife Elvira, the application of chemical pigment to embellish silent movies.
At this stage in the development of colour movies, colour played a key part in the narrative structure of a movie, completing images and offering viewers a further code interpreting the content and spatial-temporal location of the scenes (Poli, 2021).
The application of colour to images evokes concepts of space and time; colour can guide viewers' interpretation of shifts in time between past, present, and future: for example, colour may be added or omitted to signal a flash-back, yielding different nuances. The colourization of images also impacts their emotional expressivity when the colour bears symbolic value and/or "meaning"

Cinema in Naples

As cinema began to enjoy great success around the world, interest in photography and figurative painting was waning. People were curious and enthusiastic about the new form of entertainment invented in France. On 30 March 1896 at the Margherita Salon in Napoli, a selection of the

Lumière brothers' films was projected, and in 1897 the first cinema theatre opened with a program of popular films and a box office. Cinema had made its debut in Italy by the early 1900s, although it still very much a fairground attraction.
Naples was among the first cities to offer entertainment in public venues by organizing film screenings in cafés such as the Margherita Salon or the Salon Parisian.
Thanks to the establishment of cinema theatres in a number of cities around the world, film found its ideal space and increased in popularity.

Fig. 1 – The staff of Partenope Films with Roberto Troncone on right (Bruno G., 1995)

In parallel, many periodicals about the cinema were being published in Naples, including for example, La Lanterna, Lux, L'arte muta, and others. In this city, there was great cultural dynamism surrounding the world of cinema. The three early cinematographic companies that led the sector in Naples were: Dora-Film, Partenope Films, and Lombardo Film, later known as Titanus Film. Roberto Troncone of Partenope Film created the first documentary in Naples when he filmed the eruption of Vesuvius, selling his production to many venues around the world (Bruno, 1995).

Elvira Coda and Nicola Notari

Nicola Notari and Elvira Coda, from Naples and Salerno respectively, were both born in 1875 and were twenty years old when the Lumière brothers invented le cinematograph. Like many other young artists, they were fascinated by the technique and the art of filmmaking.
In 1902, Nicola met Elvira in Napoli, while queueing up to see two shows in a funfair booth, both of which were novelties for the period: the exhibition of an "artificial" wax model of the human anatomy and a short film about the Pope. (Amabile, 2022, pp.3-10)
Nicola Notari was a painter and photographer, and set up a laboratory at his home, where he experimented with colourizing his own photographs, initially with the help of his sister Olga. Later, with the input of his wife Elvira, he began to make his own movies and to colourize sequences of frames in motion pictures. Nicola and Elvira shared a strong interest in this new form of artistic entertainment based on the generation of moving images, a technique that made it possible to endlessly replicating people and streets on a screen: a dizzy spectacle, as Flavia Amabile described it, that amazed and astonished viewers to the point of inducing a "tangled web of sensations" (Amabile, 2022, p. 11).
Nicola was more interested in the technical dimension of filmmaking, while Elvira had already foreseen that cinema would become a form of entertainment for an increasingly demanding public. Indeed, Flavia Amabile emphasizes this aspect, reporting in her book an alleged dialogue between the two at the Salon Margherita where a film screening had been organized.

It seems that Elvira told Nicola "It is not enough to be able to create a beautiful image, the audience and the ability to seduce it is important too" (Amabile, 2022, p.22)

Fig. 2 – Elvira Coda and Nicola Notari (Bruno G., 1995)

Some months later Elvira and Nicola got married. They had two children and founded the production company Dora Film. Elvira was the first female movie director and producer in Italy and a tireless, intuitive, farsighted entrepreneur.
She also headed up a School in the Art of Cinema, where she trained actors, although she usually used non-professional actors.
Her son Edoardo Notari acted in several silent movies, often interpreting the role of Gennariello.
Dora Film produced silent movies from 1906 until 1930. Its productions played a key role in highlighting the social issues featured in popular forms of dramatic entertainment, with themes inspired by Neapolitan literature, songs, and popular theatre. Elvira made about sixty feature films and over a hundred documentaries and shorts. Dora Film's extraordinary body of work consisted of black and white films as well as colour movies produced using various colourization techniques and effects. Colour was added via a variety of methods.

The Dora-Film and the first techniques for colourizing silent movies
In 1906, Elvira and Nicola Notari founded Dora-Film in Naples. The first Italian manufacturing firm that specialized in film was Alberini & Santoni of Rome, founded in 1904 by Filoteo Alberini and Dante Santoni.
The company's advertising messages of Dora Film emphasized that they were a leading colourization studio (Fig. 4).

Fig. 3,4 – Women at work of manual colourization on reels. The advertising messages: they were a leading colourization (Bruno G. 1995).

The involvement of female workers in manufacturing the company's films contributed to the emancipation of women at that time (Fig. 3). Silent movies were enhanced by colouring the individual frames of scen es that demanded a special atmosphere. The women also worked on editing the reels (Bruno, 1995). The success of Dora-Film's colorized silent movies shows how effectively the passionate events and the spirit of Neapolitan popular culture may be conveyed on film.

Fig. 5,6 – Dora Films silent movies coloured*: L'Italia s'è desta, 1927 and Napoli sirena della canzone 1929* (https://emutofu.com)

The first, early twentieth-century, films to feature colour were colourized manually using brushes, following the technique invented and applied by Georges Méliès and Segundo Chommon, which was later also used by the French company Pathé Film (Mannoni and Malthête, 2008).
It soon became possible to perform this technique more industrially thanks to a more sophisticated system using stencils. In France, the colourisation of film in cellulose nitrate was labelled *Pathécolor* or *Pathécrome* and involved the frame by frame application of pochoir masks (Montanaro, 2005).
As mentioned earlier, Elvira first helped her husband to colourize photographs and later to colour the frames of films. By this time, Nicola had extended the laboratory and equipped Elvira with a watchmaker's eyepiece, brushes, and aniline so that she could manually colour copies of films, frame by frame. (Amabile, 2022, pp. 60-62).
The masking technique made it possible to colour lengthier reels of film. Manual colourization with a brush or pochoir/stencil was executed via a subtractive process. The result was the enhancement of the silent movie thus treated. even though the cellulose nitrate film became less transparent. Colourization was not economic however: it could only be applied to very short silent movies. Nevertheless, the effect was impressive. (Poli, 2021).
The colourization of the 1922 film *'A santanotte*, one of three silent movies that have survived the ravages of time, is monochromatic: in other words, colour was applied to selected sequences using the immersion technique. Parts of the movie are uniformly pigmented thanks to chemical treatment of the cellulose nitrate film: the lighter areas of the image acquire the lighter shade of the chosen colour, while the darker parts are slightly more pigmented (Fig. 7).
Elvira seems to have intentionally chosen different colours for the different sequences. More specifically, for the outdoor sequences she picked cool colours (light blue, deep blue or green), while for the indoor sequences she used warmer colours, ranging from yellow to orange.

The role of colour in the silent movies
Some of the silent movies supports were tinted with different techniques of colorization using subtractive method with chemical pigments by imbibition in a monochromatic aniline solution or by paintbrushes and stencil for a partial colour's effect (Yumibe, 2012).
The partial or the total coloration of scenes attribute to the colour some differnt roles. The use of uniform colouring method of some shots into a sequence of films has two roles. The first is realistic and the second symbolic, for example: the blue colouring was used for the night, green for the landscape and the colour the yellow or orange for indoor sequence, the use of red colour,

more rare, was employed for the fires, the disasters and the revolutions with the weapons, the colour appears as a symbolic element.

Therefore fundamental is the role of colour in the narrative dimension, which aims to offer to the viewer another code to understand the narration, the scene location and the orientation in the dimensions of space-time. Another role of colour is the evocative dimension in space-time terms as colour guides the viewer in understanding the passage of time between past, present and future, for example in the flash-back the crossing time transition usually is underlined with a passage of different colour or white. Another role of colour in the early film is a perceptual function with an emotional code for a dimension more expressive.

Restoration and preservation of silent movie and the conservation with the digitalization.

Many silent movies have Eastman Kodak nitrate support composed by nitrate cellulose, a plastic roll of 35mm treated with nitric acid. The cellulose nitrate is a fiber with serious problems of conservation. The deterioration is caused by light, pollution and high temperatures. The cellulose nitrate did not allow the conservation of many silent movies because the time consuming the support, and many movies made before 1950 were losted. (Edmondson and Schou, 1984)

The process of digitalization of scanning high-resolution images and higher specific computer is the modality to guarantee the restoration and the preservation of their memory.

The Restoration of *'A santanotte*

The restoration of the Dora Film *'A santanotte* was carried by the Cineteca Nazionale - Centro Sperimentale di Cinematografia in Roma, based on a duplicate negative copy with contemporary Italian captions and a nitrate negative copy stored at George Eastman House in Rochester, NY.

This process was part of the project "Not only divas. Pioneers of Italian cinema" funded by the Film Dipartimento of the Ministero Italiano della Cultura in collaboration with the George Eastman House.

Fig. 7, – Same frames of *'A santanotte* 1922 *restored in 2007* (https://www.youtube.com/watch?v=__uVTu4xTSg&t=36s)

In 2007, a duplicate negative copy of the film '*A santanotte* – originally intended for distribution in the United States - was discovered at the George Eastman Museum. The extensive handwritten information on the tails of the nitrate copy made it possible to reconstruct both part of the text of the missing captions and the colours, in the absence of an original positive colour copy to refer to. The surviving Italian negative and an additional American copy were used to restore the full movie. The restoration was materially executed by the laboratory "L'immagine Ritrovata" in 2008. Via the silent movie '*A santanotte*, Elvira brought to the cinema Neapolitan dramas based on popular songs and plays. Its restoration represents a valuable addition to Italy's cinematographic heritage.

Conclusions

In sum, thanks to these first experiments at the beginning of the twentieth century, Italian cinema began to branch out into new forms of entertainment that offered a novel way of representing feelings and emotions.

Initial attempts to colourize film, albeit timid, fed into the growing success of cinema, which offered fertile ground for the development of further novel solutions. Bringing to light the valuable filmic output of Elvira and Nicola Notari's Dora-Film implies recognizing and restoring a part of Italy's cinematographic heritage that was hitherto believed to be lost.

Digitization techniques have played a key part in ensuring the high quality restoration of the film and the preservation of its memory.

Finally, digital media will also play a role in fostering greater knowledge and dissemination of leading movies in the Italian historical cultural repertoire, prompting further studies on Italian silent cinema.

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An Overview of Critical LED Lamp Properties Related to the Fading of Photographic Prints in Image Permanence Testing

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Abstract

Although the use of LED lighting is now widespread in museums, galleries, and archives, to date no confirmed image permanence standards for LED lamp exposure of photographic and graphic arts prints have been published. This paper comprises an overview of the considerations involved in the selection and classification of LED lamps for use in an image permanence test method standard that is currently under development by ISO Technical Committee 42. Relevant lighting parameters of colour rendering indices, relative spectral irradiance, and correlated color temperature will be discussed. The advantages and disadvantages of different methodologies for the measurement and classification of these parameters will be assessed. The effects of these parameters on the fading and color changes in photographic prints under LED lamps will be compared with fluorescent and tungsten-halogen lamps. The paper will conclude with a summary of ongoing research and the next steps in the development of the LED lamp image permanence standard test method.

Keywords: image permanence, light stability, lightfastness, LED, lighting, inkjet, color rendering index, relative spectral irradiance, correlated color temperature

Introduction

ISO/TC42 (Photography) WG5 has published many image permanence test method standards. Relevant standards that include light exposure include ISO 18950 for general light exposure under museum conditions, ISO 18930 for accelerated outdoor exposure simulations, and the ISO 18937 series for indoor light exposures. We have chosen to separate ISO 18937 into three parts, with ISO 18937-1 containing an introduction and the requirements that are common to all parts, ISO 18937-2 for testing with a xenon arc lamp, and, currently in development, ISO 18937-3 for indoor exposure of analog and digital images to LED lighting. It is noted that there are still no published standards for exposure of any types of printed materials or other objects to LED lighting, so ISO 18937-3 is very likely to be the first.

The new LED exposure test method covers two use cases: home – office – commercial display; and museum – gallery – archival applications. For each use case it has been agreed that technical parameters of several types will be specified: correlated colour temperature (CCT), relative spectral irradiance (RSI), and metrics for colour fidelity from two colour rendering indices (CRI). The remainder of this paper will be devoted to the description of the history of these classes of parameters and their application to LED exposure of images.

Materials and Methods

A total of 18 consumer blue-pump LED lamps were purchased in 2020 and 2021 at retail outlets in the United States to serve as a representative sample of consumer LED lighting in North America. Ten of these lamps had a CCT of approximately 5000 K, and eight of them had a CCT around 3000 K. None of these lamps have the colour rendering indices high enough to be deemed suitable for museum and gallery use. In addition, one violet-pump LED lamp with high colour rendering index that is currently in use by several major museums was obtained online.

The authors had hoped to visit several museums and conferences to obtain more of the high-CRI LED lamps, but COVID-19 travel restrictions limited those visits.
The spectra from 250 to 850 nm, CCT, CRI, and other properties of the lamps were measured in the Wilhelm Imaging Research lab with an Allied Scientific Pro SRI-2000-UV Spectroradiometer. Additional analysis was performed to calculate accurate values of the IES TM-30 colour fidelity and colour gamut indices.

How Do LED Lamps Create "White" Light?
The bandwidth of an LED emission peak is typically only 10 to 40 nm wide, so it covers a very small portion of the visible spectrum and emits a colour characteristic of that spectral range. There are currently three ways in which LEDs are used to create light that appears to be white:

1) The most common method is to use a blue or violet LED chip as a "pump" that emits light that is partially absorbed by phosphors that then emit the green – yellow – orange – red parts of the visible spectrum via the process of fluorescence. This approach is depicted in Figure 1. The use of violet rather than blue pumps can often improve the colour rendition in the cyan region of the spectrum, but it requires more expensive LEDs.
2) Red, green, and blue monochromatic LEDs may be used with colour-mixing optics or electronic controls to create white light. The primary drawback of this approach is that there can be large spikes corresponding to the peak wavelengths with very little or no spectral irradiance between them.
3) A hybrid approach can be used in which multiple discrete monochromatic LEDs are combined with phosphors in the same lamp. Red is often the second LED to be added in order to improve the colour rendering of the red portion of the spectrum. The use of green LEDs is addressed below.

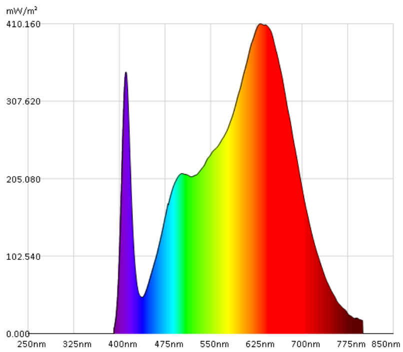

Figure 1: Example of an LED lamp relative spectral irradiance. This lamp has a violet pump peak at approximately 410 nm that excites several phosphors to create the rest of the visible spectrum.

An important innovation in the lighting market has been the development of tunable LED lamps that can change their CCT from "warm" to "cool" lighting. The simplest method to implement tunability is to manufacture a strip of lighting elements with both low CCT and high CCT pump-phosphor LEDs. Colour temperatures below the minimum and maximum CCT can be approximated by controlling the percentage of low CCT and high CCT elements that are activated. It has been discovered recently that the colour accuracy at intermediate CCT levels of these tunable systems can be improved by the addition of a green LED, as this keeps the output closer to the blackbody locus on a chromaticity diagram (McGrath, 2021).
A recent development for the museum and gallery use case is LED lamps which employ a filter that clips off the blue or violet peak of a pump-phosphor LED lamp (Yamagiwa, 2021). The goal of this development is to approximate the visible spectrum of tungsten-halogen Illuminant A and its nearly perfect colour rendition, but with greatly reduced UV and IR content. The

result should be reductions in both the surface temperatures and the photodegradation processes of analog and digital images.

Correlated Colour Temperature (CCT)

The correlated colour temperature may be defined as the colour of light emitted at a particular temperature by an idealized opaque, non-reflective, perfectly-emitting blackbody. For real light sources, the closest point along the Planckian locus is taken as the CCT. For most consumers of lighting, it corresponds to their perceptions of "warm" or "cool" light.

For the home – office – commercial use case, ISO 18937-3 uses a CCT of 5000 ± 250 K as the representative value. For the museum, gallery, and archive use case, the preferred CCT range will be 3000 ± 300 K, as this corresponds to the traditional tungsten-halogen lamps that were once the dominant light source in museums, galleries, and archives.

Relative Spectral Irradiance (RSI)

The relative spectral irradiance (or spectral power distribution) of the light source strongly influences the photodegradation of photographic and print materials during display. In general, since photon energy increases as the wavelength decreases, shorter wavelengths of light in the RSI are associated with increased photodegradation. However, it should be noted that each colorant or material also has its own action spectrum that describes its propensity to participate in photodegradation reactions as a function of wavelength. The interaction of the RSI and these action spectra determine the types and rates of change for the image and its supports (Saunders, 2020).

As an illustration of this effect, consider the changes in RSI for a tunable LED lamp as the CCT is changed in Figure 2. At 5000 K, a daylight or cool lamp setting, the peak emission due to the blue LED pump is quite high, but the height and area under this peak is reduced significantly as the CCT decreases. Since that peak is the dominant feature of the short-wavelength end of the lamp spectrum, it is expected that for many imaging materials and colorants that the area under this peak will correlate with some photodegradation processes.

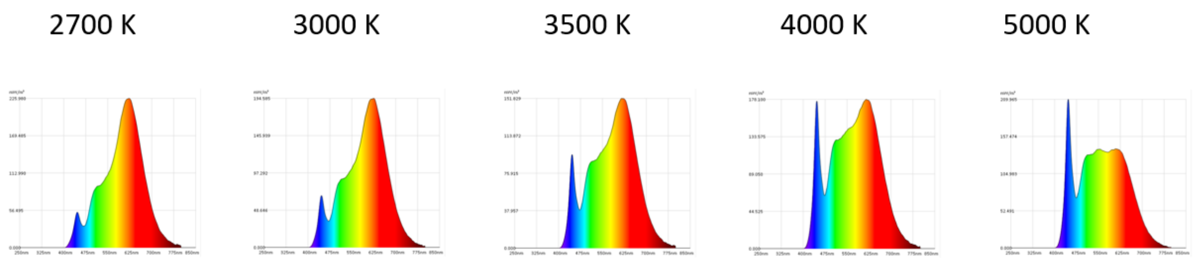

Figure 2: Changes in relative spectral irradiance corresponding to changes in correlated colour temperature for a tunable LED lamp.

As there are many types of LED lamps available, an LED exposure test method standard can only be meaningful if the relative spectral irradiance of the lamps can be classified and specified in some fashion. Otherwise, the use of LED lamps with greatly different RSI would give test results that could not be considered comparable.

One issue of concern is that there are no widely-accepted definitions of blue and violet light in terms of wavelengths, so the industry terms "blue-pump" and "violet-pump" LED lamps are unclear. For this reason, attempts were made to define classes of LED lamps for this standard. However, after decisions were made to use subsets of the "blue-pump" LED lamps to represent both use cases and to not use any "violet-pump" LEDs in the initial version of the standard, it was decided that we should instead use the CIE terminology "blue excited phosphor type LEDs".

Colour Rendering Index (CRI) Metrics

The International Commission on Illumination (CIE) defines a colour rendering index as the effect of an illuminant on the colour appearance of objects by conscious or subconscious comparison with their colour appearance under a reference illuminant (CIE, 1995). The reference should be a light source that represents all visible wavelengths well, such as a blackbody. Colour quality or accuracy metrics are generally defined so that a value of 100 corresponds to perfect color accuracy.

The first commonly accepted, and most widely used, colour metric is the CIE Ra value (CIE, 1995). This method specifies a set of 14 “test colour samples” for use in CRI measurements (Figure 3), but the CIE Ra value is calculated using only the first eight of the test colour samples.

Figure 3: CIE test colour samples for use in CRI measurements (CIE, 1995)

Tungsten filament incandescent lighting generates a continuous spectrum of light that represents all wavelengths strongly, so the colour rendering is excellent. However, that is not always the case for other light sources. Table 1 shows representative values of Ra for many common lighting technologies (Wikipedia, 2022)

Table 1: Representative values of colour rendering index Ra and correlated colour temperature for common light sources. Non-LED data from (Wikipedia, 2022).

Light Source	CCT (K)	CRI (CIE Ra)
Coated mercury vapor	3600	49
Tri-phosphor warm white fluorescent	2940	73
“Standard” LED lamp	2700-5000	83
Tri-phosphor cool white fluorescent	4080	89
High CRI LED lamp (Blue LED with R+G phosphors)	2700-5000	95
Ultra High CRI LED Lamp (Violet LED with R+G+B phosphors)	2700-5000	98
Tungsten incandescent or halogen bulb	3200	100

The reasons that some LED lamps do not render colour well can be inferred from the RSI in Figure 2. There is a “cyan gap” with low irradiance between the blue LED pump peak and the output from the green phosphor, and the irradiance in the red region is not high enough. These two problems cause particular issues with the rendering of test colour patches 9 and 12, respectively. The use of violet LED pumps, blue phosphors, and additional red LEDs are typical for the ultra-high CRI LED lamps.

Although CIE Ra is widely used and cited in packaging and advertisements, several aspects of the measurement and calculation methods have been criticized (CREE Lighting, 2019). The most obvious is the selection of test colour samples. Only the first eight patches in Figure 3, all of which are low in chroma, are used to calculate Ra. Consequently, Ra values can be

deceptively high. The addition of test colour samples 9-14 in the calculation can result in significant decreases in the CRI index. The use of only low-chroma patches also penalizes brighter light sources that increase chroma, which is often seen as desirable. Since the test colour patches used for Ra are not very representative, the value can often be extremely sensitive to the exact location of the blue emission peak in LED lamps (Ohno, 2004).
The calculation method for Ra uses CIE 1964 U*V*W* colour space, which is not uniform in the red region of the spectrum and is not perceptual, so errors in all directions are equally weighted. The chromatic adaptation transform does not work well for a CCT above 8000 K or below 3000 K (Ohno, 2004), and the method is restricted to white light sources. The reference illuminant for CIE Ra is discontinuous, with a step change at 5000 K CCT. Below that value of CCT the reference illuminant is the theoretical Planckian blackbody radiation spectrum. Above 5000 K CCT the reference illuminant is outdoor daylight (CREE Lighting, 2019).
To mitigate these problems with the CIE Ra, the Illuminating Engineering Society of North America (IES) formed a task group to build upon previous colour fidelity and gamut area research to develop new metrics. This resulted in the creation of IES TM-30-15 (and subsequent -18 and -20 updates) (United States Department of Energy, 2016). This system utilizes 99 colour patches that were statistically selected from spectral reflectance measurements for paints, textiles, inks, and skin tones. Calculations are performed in the perceptually-uniform CIECAM02 space. The reference illuminant for TM-30 is the same as that for CIE 13:3 above CCT of 5500 K and below 4500 K, but is a linear blend of those two spectra between 4500 K and 5500 K to avoid the step change present for CIE 13:3 Ra (CIE 2017).
The colour fidelity index R_f is analogous to the CIE Ra. There are also hue fidelity indices for 16 hue bins and for a series of skin tones. In addition to all of the fidelity indices, there is also a gamut index, R_g, that compares the gamut size to the reference illuminant. Even more hue-specific information can be depicted with colour vector graphics that use arrows to show hue shifts and local gamut expansions or contractions. The colour fidelity index R_f has now been accepted by CIE and the method was published in CIE 224:2017 (CIE, 2017). Initial psychophysical experiments indicate that R_f correlates better with perceived colour differences than Ra (Royer, 2018).

Specifications for CCT, RSI, and CRI for the Two Use Cases
The spectral data measurements from the 18 LED lamp survey introduced in the Materials and Methods section have been used to analyze the RSI characteristics and CRI performance. The CRI statistics are detailed in Table 2 and Figure 4. As expected (Royer, 2015), the CIE Ra values are generally a bit higher than the TM-30 R_f values at high CRI levels. The early working drafts of this test method standard included minimum values of the colour rendering index fidelity metrics, but it was decided during the October 2022 meeting (NOTE: Following the 2nd Colour Photography and Film Conference presentations in Florence, Italy) that minimum values of these colour fidelity metrics would not be specified because many users of the standard would not have sufficient data in this regard. Instead, only the RSI profile and CCT will be used as LED lamp specifications for testing.

Table 2: LED lamp colour rendering statistics from measurements with Allied Scientific Pro SRI-2000-UV Spectroradiometer; data for 420 nm violet LED taken from the manufacturer (Nichia, 2022)

LED CCT (K)	LED Pump Peak Wavelength (nm)	CIE 13:3 Ra		IES TM-30 R_f	
		Average	STDEV	Average	STDEV
2600 - 3200	440 – 480 blue	92.5	3.3	91.8	2.6
3055	411 violet	95.2	-----	91.5	-----
4700 – 5300	440 – 480 blue	91.2	4.9	90.1	3.6

4985	420 violet	99.0	-----	97.2	-----

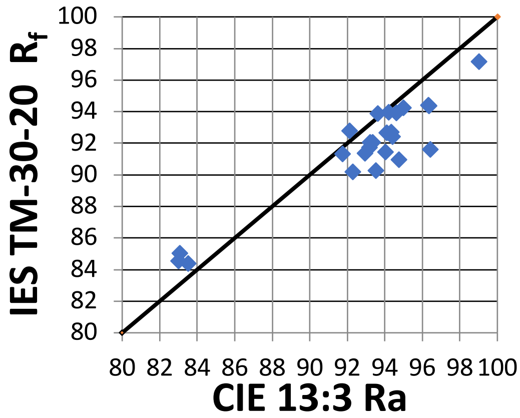

Figure 4: Correlation between CIE Ra and IES TM-30 Rf from LED lamp survey and spectral measurements

Relative spectral irradiance has the greatest effects on image photodegradation in the ultraviolet, violet, and blue regions of the spectrum. Above 600 nm, radiation does not have sufficient energy to cause any reactions that degrade colorants or binders, so it is not critical to specify the RSI in passbands above that wavelength.
The relative spectral irradiance limits for blue excited phosphor type LEDs in Table 3 correspond to the lamp survey averages plus or minus two to three standard deviations. For the critical region between 400 and 550 nm that is expected to drive most image degradation, 30 nm passbands are used to define the lamp requirements. It should also be mentioned that the passband edges were intentionally chosen to avoid the 444 – 453 nm range of the blue LED pump peaks for most lamps that were measured. Note that these limits for LEDs in the ultraviolet wavelength range are one or two orders of magnitude lower than spectra typical for fluorescent, xenon arc, and tungsten halogen lamps.

Spectral Passband Wavelength (nm)	Home – Office – Commercial Blue excited phosphor type LEDs CCT 5000 K	Museum – Gallery – Archive Blue excited phosphor type LEDs CCT 3000 K
300 – 399	0.0 - 0.2	0.0 - 0.2
400 - 429	0.0 - 1.7	0.0 - 1.0
430 - 459	10.2 – 15.8	3.0 – 6.5
460 - 489	5.5 – 10.5	2.2 – 6.5
490 - 519	8.6 – 11.9	5.0 – 9.0
520 - 549	10.6 – 14.2	8.0 – 11.0
550 - 599	15.0 – 28.0	17.0 – 28.0
600 – 800	No requirement; will add with values above to equal 100%	No requirement; will add with values above to equal 100%

Table 3: ISO 18937-3 proposed relative spectral irradiance requirements per passband as percentage of total irradiance in 300 – 800 nm range.

Plans for Round Robin Test to Investigate Effects of LED Lamp Parameters on Image Photodegradation

It is common for ISO/TC42 WG5 to employ round robin testing to evaluate new test method standards (Klemann, 2014). For this standard a two-phase approach has been proposed. In the first phase two ink-colour print material combinations will be tested at a variety of conditions in order to determine the optimum settings for the test. More research on the effects of wavelength bands on the fade of colorants will also be conducted (Hofmann, 2022). These ranges of LED test chamber settings will be used:

- Chamber air temperature 21 – 27 °C
- Black panel temperature 25 – 35 °C
- Relative humidity 40 – 60 %
- Illuminance level at specimen plane 20 – 80 klx

In phase two of the round robin tests, more materials and test chambers will be used to determine the reproducibility of the types and rates of photodegradation caused by the test conditions. The following variables and embodiments have been proposed for phase two:

- LED Lamps: CCT of 3000 K and 5000 K; multiple LED pump wavelengths
- Imaging Technologies: UV curable inkjet, aqueous inkjet, silver halide photography, dye sublimation, thermal transfer
- Imaging Materials: Photographic film, microporous inkjet paper, coated paper, plastic films and sheets

Many white LED lamps with extremely high CRI are now in use in museums, galleries and archives. Since there is little or no UV irradiance from these lamps, it has been postulated that their use will reduce the fading rates of photographs and other colored objects on display. Some, but not all, of the data obtained to date has indicated that fading under LED lamp illumination will be slower than has been observed for halogen and fluorescent light sources (Luo, 2019; Hofmann, 2022). The round robin test results are expected to provide some perspective in this regard.

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