Colour Photography and Film:

Sharing knowledge of analysis, preservation, and conservation of analogue and digital materials 2024

Edited by: Alice Plutino, Barbara Cattaneo and Marcello Picollo

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3rd Edition of the Conference "Colour Photography and Film: Sharing knowledge of analysis, preservation, and conservation of analogue and digital materials"

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3rd Edition of the Conference "Colour Photography and Film: Sharing knowledge of analysis, preservation, and conservation of analogue and digital materials"

Amsterdam, September 12 and 13, 2024

Organized by The Gruppo del Colore – Associazione Italiana del Colore (Color Group – Italian Color Association), in collaboration with the University of Amsterdam (UvA), Eye Filmmuseum (Eye), the Istituto di Fisica Applicata "Nello Carrara" of the Consiglio Nazionale delle Ricerche (IFAC-CNR), and the Opificio delle Pietre Dure (OPD)

Conference Program

Wednesday 11 September 2024	
UvA conservation program and studiobuilding tour Introduction and presentation AG + SBMK photoproject and tour by Katrin Pietsch, coordinator photograph conservation, Maartje Stols-Witlox, program director - Kayleigh Kunst-van der Gulik, Ariënne Boelens (SBMK photoproject Speakers)	
Thursday 12 September 2024	
SESSION 1	
Esther Ng, Yen Lin Kong	Tan Lip Seng's montaged colour transparency slides: A case study in unpacking intentionality and 'the decisive moment' in image-making, preservation and conservation
Lénia Oliveira Fernandes, Élia Roldão, Emília Tavares	Fading memories: Assessing colour slide film's cultural impact in Portugal and abroad
Melissa Gianferrari, Chiara Zironi, Paolo Barbaro, Davide Bussolari	"Infinito" by Luigi Ghirri - Restoration work and diagnostic imaging: an opportunity for further reasoning
SESSION 2	
Tessa Maillette de Buy Wenniger, Katrin Pietsch, Maarten van Bommel	Investigating solvent treatment methods on a matte pigment inkjet print
Joana Silva, Sille Petersen, Morten Ryhl-Svendsen, Jesper Stub Johnsen, Karen Brynjolf Pedersen	Evaluating the stability of colour slides: 30 years of natural ageing at the National Museums of Denmark
KEYNOTE	
Elif Rongen-Kaynakçi	**Rediscovering the colours of early cinema: a journey through Eye Filmmuseum's silent film restorations**
SESSION 3	
Giovanni Vanoglio, Laura Genovese, Angela Quattrocchi, Moreno Pilloni, Alessandro Rizzi	Your memory is our history: recovery, digitalisation and dissemination of vernacular video production
Nadezhda Stanulevich	Prokudin-Gorskii's technique of colour photography and contemporary exhibitions
SESSION 4	
Irina Ciortan, Giorgio Trumpy, Irina Sandu	The Scream (ca. 1910) through the Years: from Photographic Documentation to Digital Rejuvenation
Sille Juline Høgly Petersen, Morten Ryhl-Svendsen	Polaroids around the 80s. An investigation of the stability of instant film according to storage, handling, and exhibition.
Paulina Miasik, Sylvie Penichon	An investigation into the structure and color stability of different generations of Polaroid 20×24 materials
Rita Hofmann-Sievert, Manfred Hofmann	Light sensitivity of contemporary photographic print materials

Friday 13 September 2024	
KEYNOTE	
Monica Marchesi	**Reprinting as a game-changer**
SESSION 5	
Iryna Marholina	Reception of film colour in the Soviet postwar cinematic community: between aesthetics and technology
Enea Ahmedhodzic, Ema Muftarevic	Preserving Bosnia's Cinematic Heritage: Challenges and Achievements of the Film Centre Sarajevo in the Post-War Era and Beyond
SESSION 6	
Jan Hubička, Linda Kimrová, Melichar Konečný	Understanding colors of Dufaycolor
Alice Plutino, Lorenzo Stefani, Costanza Cucci, Andrea Casini, Marcello Picollo	Limitations and Potentials of Hyperspectral Imaging Technique Applied to Cinematographic and Photographic Film Materials
SESSION 7	
Lisa Vergelli, Francesca Frasca	Colour change tools to assess the preservation state of motion picture films
Alessandro Russo, Sergio Canazza	Color and original soundtrack restoration of experimental films by Italian artist Roberto Lucca Taroni
Lucia Becatti, Enea Ahmedhodzic, Beatrice Sarti, Alessandro Rizzi	The Role of Subjectivity in Color Film Restoration
David LeHoty, Giorgio Trumpy, Barbara Flueckiger, David Pfluger	Style Transfer in Advanced Film Digitization and Rendering Workflows
SESSION 8	
Paula Ogayar Oroz, Katrin Pietsch	Training the eye, an exploration of hand-coloured daguerreotypes and their examination
Clara Tomasini	Insensitive to red. The hand-colored daguerreotype and its sociopolitical value in the Río de la Plata.

Foreword

It is with gratitude and satisfaction that we introduce the proceedings that resulted from the third edition of the conference on *Colour Photography and Film: Sharing Knowledge of Analysis, Preservation, and Conservation of Analogue and Digital Materials*. It was organized in September 2024 by the *Gruppo del Colore – Associazione Italiana del Colore* (Color Group – Italian Color Association), in collaboration with the University of Amsterdam (UvA), Eye Filmmuseum (Eye), the *Institute of Applied Physics "Nello Carrara"* of the Italian *Nation Research Council* (IFAC-CNR), and the Doctoral School in History of Art at Sapienza University in Rome. The conference, held at the University Library in Amsterdam, welcomed more than one hundred participants representing 16 countries across five continents; over 50 of them attended the convening in person.

The papers presented over the two-day conference in eight thematic sessions covered a wide range of topics, from the history of photographic and film materials to conservation critique and ethics, from deterioration issues to new restoration treatment approaches. From a historical perspective, the objects studied ranged from colored daguerreotypes to color slides, with a particular focus on specific processes such as Dufaycolor and Polaroid. The history of early color films and the stratification of vernacular materials were also explored. The cultural impact of color in both film and photography was discussed in several papers, as were the importance of a clear strategy and unambiguous policies to ensure proper archival preservation.

Digitization as a conservation and restoration strategy was proposed for both film and photographic materials. While digitization practices have emerged as an ineluctable solution for dissemination, digital restoration and rejuvenation remain evolving fields where research is growing exponentially.

The ethical considerations underlying restoration practices in early cinema were expertly introduced on the first day by the keynote speaker, Elif Rongen-Kaynakçi, Curator of Silent Film at Eye Filmmuseum, in her talk titled *Rediscovering the Colours of Early Cinema: A Journey Through Eye Filmmuseum's Silent Film Restorations*. Although her contribution does not appear in these proceedings, we would like to express our gratitude for her generosity in participating in the conference.

We are also truly grateful to Monica Marchesi, art historian and conservator at the Stedelijk Museum, for serving as the keynote speaker on the second day of the conference. In her talk *Reprinting Photography as a Game-Changer*, Dr. Marchesi shared new considerations from her seminal long-term project on reproduction and reprinting as a conservation and exhibition strategy. This project underscores the importance of dialogue among artists, conservators, and curators when addressing the deterioration and obsolescence of photographic and film technology.

Finally, we wish to thank all the participants and speakers who submitted their contributions to be published in this volume. It was our great pleasure to include them in the proceedings.

Barbara Cattaneo, Alice Plutino, Marcello Picollo

Index

Reprinting Photography as a Game Changer

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Abstract

The reprinting of photographic artworks can take various forms: as a conservation strategy where, discoloured photographs are replaced with pristine ones, as an artistic practice that allows photographic prints to be exhibited to the public without protective glazing, and as a collaborative mode of production between the artist and the museum. This paper will look back and share experiences from the past ten years, focusing on potential gains or losses during the reprinting process. It will also reflect on how, through reprinting, the author's views on conservation have evolved: from an approach aimed mainly at preventing or slowing down change to one in which documenting or curating change becomes equally relevant.

Keywords: collaborative approach, conservation, contemporary art photography, digital component, Rineke Dijkstra, network of care, printing, photographic artwork, reprinting.

Introduction

I have chosen the title 'Reprinting Photography as a Game Changer' because my experiences with the practice of reprinting of photographic work has fundamentally changed my role as a professional and how I approach conservation. I would like to share my experiences with reprinting, and the insights I have gained along the way as a paper conservator at the Stedelijk Museum Amsterdam (SMA), The Netherlands tasked with the conservation of contemporary art photography.

First, it is important to draw a distinction between two different printing objectives: 1) Reprinting as a conservation strategy and 2) Printing and reprinting as an exhibition practice. When I speak of *reprinting as a conservation strategy*, I am referring to cases where a photographic artwork is considered too damaged or discoloured to be displayed. This process typically occurs after the damage has already taken place, and it involves substituting the damaged work with a new, pristine one. A close resemblance between the initial and the new print—such as matching the photographic image and dimensions—is often regarded necessary, and the artist's involvement in the process is also crucial.

Printing and reprinting as an exhibition practice, on the other hand, involves various artistic actions. In certain instances, artists may anticipate that their preferred display methods could damage the prints, prompting them to develop a strategy where reprinting serves both as an exhibition approach and a conservation measure. In other occasions, artists may create photographic artworks that physically exist when they are on display. At times, the photographic print is retained and becomes part of the museum's collection, while at other times, at the end of an exhibition, it may cease to exist in its material form, continuing only as a photographic image.

In earlier work, I described reprinting as an act of reduction to the essential characteristics of the work.[1] I employed the concept of reduction as defined by the French scholar Gérard Genette in his 1994 book, translated into English as *The Work of Art: Immanence and Transcendence.* According to Genette, reduction is an operation of selection and replacement. Selection implies that certain

[1] Marchesi 2017, NWO Research Program Science4Arts, Photographs and Preservation. How to save photographic works of art for the future? | NWO, 2012 – 2017.

characteristics are regarded as constituent and are therefore preserved in each version, while other elements are considered contingent and can be replaced with new ones. In this sense, reprinting can be seen as a subtractive activity, as it removes non-essential characteristics, but it's also an additive one as it introduces new features that were not initially present (Genette 1997, 82). These concepts can help us better appreciate the variations that result from the reprinting process.

Expanded practice of conservation

The goal of my earlier research was to underline how photography is not a reproducible medium but a multipliable medium, able to multiply the image but unable to replicate the material characteristics of the photograph as an object (Savedoff 2000, 174). In other words, I wanted to emphasize that reproducing a photographic artwork exactly from a material standpoint is nearly impossible, especially when a significant amount of time has passed between the initial print and the new one. However, during my later engagement with the work of Rineke Dijkstra, I came to realize that the analysis of reprinting as a conservation strategy is not just about retrospectively identifying differences between various printed versions of an artwork.[2] I learned that many decisions made during the reprinting process can only be grasped by closely observing the artist in action, rather than by studying the outcomes after the facts (Fig.1).

Figure 1: Colour matching of Kolobrzeg, Poland, July 26, 1992, at the printing studio. Image: Monica Marchesi

Based on interviews and observations of the reprinting process undertaken by Dijkstra, it became clear that, in this case, the artist remains essential to the process of reprinting photographic work, as it relies on a subjective assessment and determination of colour. She is the one who makes the selection of constituent and contingent features: identifying the elements that should be retained and those that can be replaced.

Geismar and Laurenson (2019), when studying Catherine Yass' artwork *Corridors* and its reprinting, observed: "Understanding *Corridors* in technical, material and social terms requires an expanded practice of conservation that recognizes that photographic processes are linked to particular moments in time and are embedded within particular networks of skill and expertise" (193).

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[2] Research project 'Rineke Dijkstra: Exploring the reprinting of colour photography as a preservation strategy", 2019 – 2023, with financial support of the Brook Foundation.

This said, I think is fundamental to adopt an expanded practice of conservation when dealing with reprinting. It is an activity that not only includes technical knowledge and expertise about materials but also a deeper understanding of the artist's practice and the network of professionals involved in the process. To conclude on the Rineke Dijkstra project: As a result of the reprinting, new ink jets prints entered the SMA collection as a replacement of the initial chromogenic prints. To establish the status of the two sets of prints and their use, legal arrangements were made between the artist and the museum. This contract marked a significant milestone, being the first of its kind between the SMA and an artist regarding the reprinting of photographic artworks. The contract outlined the terms of use for both types of prints, aiming to establish transparency in the expectations of both parties as well as clear communication with the audience (Marchesi 2023).

Tentative conclusions and new research

Looking back, the most valuable aspect of working with Dijkstra, was actively observing, documenting, and seeking to comprehend the decisions made by the artist during the reprinting of her artworks. As mentioned, this situation differs from the case-studies I explored in my previous research. In the works studied for my PhD research, I could only retrospectively assess similarities and potential differences between the initial and reprinted artworks.

As the process unfolded, it became evident that Dijkstra considers colour to be a fundamental element of her work. For her, any imbalance in colour or tonality is distracting and detracts from the viewer's engagement with her photographs. This emphasis on precise colour representation is so important that it justifies the meticulous and time-consuming reprinting process, deepening my understanding of the artist's intent and colour as a 'work-defining property' (Laurenson 2006). I recognized that numerous anticipated and unanticipated decisions are taken along the way. The unavailability of certain materials and techniques can significantly impact the results. Moreover, insights, opinions, and evolving tastes may shape the printing outcome as the project progresses. The specialized skills and expertise of scanning and printing operators play a crucial role in helping Dijkstra achieve successful reprinting but also bringing their own sensitivity to the task. For these reasons, I encourage colleague conservators, when they undertake the management and the supervision of the reprinting of photographic artworks and, provided that this is possible, to be involved in the process from the beginning.

Based on these insights, and acknowledging the challenges that come with a growing number of digital-based photography in our collection, I recently embarked on a new research project, 'Print on Demand. Printing digital artworks through a collaborative mode of production', financed by the Dutch Research Council (NWO) and the SMA.[3] In recent years, with the increasing digitalization, artists have become deeply engaged with - and responsive to - digital technologies. This trend is evident in the museum's acquisitions, which increasingly feature artworks with digital components. While these acquisitions may include time-based media installations or works incorporating drawings and graphic design, my research focuses specifically on photographic artworks.

As argued by Geismar and Laurenson (2019) "contemporary art photography is entangled within precarious networks of skills, labour and material, many of which are rapidly becoming obsolete" (177). The perpetuation of photographic works relies on several external dependencies, such as particular software and hardware, and the availability of printing materials and expertise. The challenge for conservators thus shifts from caring for the material artwork to maintaining the ecologies that support the work's production. As such there is a need for new internal procedures and documentation formats to make sure that the information necessary for the (re)printing is collected and kept accessible for future reiterations. Therefore, during the acquisition process, curators,

[3] Research project 'Print on Demand. Printing digital artworks through a collaborative mode of production", NWO Museum Grants Programme, March 2024 – March 2025, Museum Grants | NWO, Seventeen awards in latest round of Museum Grants | NWO

conservators, and registrars, together with the artist(s), should establish and document the 'work-defining properties' of the artwork, and the internal and external expertise needed. Additionally, the status of the printed material should be defined since reproduction challenges core values and longstanding views about authorship and material authenticity. How can the broader production network be acknowledged as part of an infrastructure that traditionally heralds single authorship? But also: Does the museum have the right to print a new work or to produce exhibition copies? And, in the latter case, are these copies supposed to enter the collection or should they be destroyed after the exhibition? What is the status of the original print? These issues highlight the urgent need for a conceptual framework and practical guidelines to support conservators in their decision-making on the (re)printing of photographic artworks.

The project studies the process of printing as a new artistic practice based on a collaborative approach between the artist(s), the museum, and the broader 'network of care' (Dekker 2015, 2018). The main research question is: How can we improve the acquisition process and long-term care for artworks which depend on digital files and a collaborative mode of production for their physical materialization?

One expected outcome of the project is the creation of a practical "roadmap" designed to assist caretakers handling similar artworks. This roadmap will be concise and user-friendly for museum professionals, outlining the essential information needed for producing prints and identifying the experts to involve during production, display, and long-term care of both digital files and printed materials. It will include actionable guidance on how to collect and document this data. Additionally, I plan to present my findings in an academic paper for a peer-reviewed open-access journal. A reflection on my research process will also be shared as a research log as part of the online academic platform *Stedelijk Studies*.[4]

As digitization continues to expand, I anticipate a rise in photographic artworks with digital components. Collecting and educational institutions should recognize that digital components will grow not only as a tool for conservation documentation but also as a part of the artwork itself. Expertise in preserving digital heritage will become increasingly important, and collecting institutions will need to hire or have permanent staff members dedicated to data preservation also for photographic artworks. As demonstrated by the Dijkstra case study, the specialized skills and embodied knowledge of scanning and printing operators play a crucial role in the quality of the printed results. When the responsibility for printing shifts from the artist to the museum, it is vital to understand that those responsible for the printing process influence the physical manifestation of the work, bringing their own expertise, creativity, and sensitivity to the task.

Acknowledgements

I would like to thank Rineke Dijkstra for generously sharing her ideas on multiple occasions, offering insight into her artistic practice throughout the project, and being so gracious during our numerous meetings. Thanks also go to colleagues of the Stedelijk Museum Amsterdam, in particular, Fabienne Chang, Soji Chou, Mechteld van Praag Sigaar, Tessa Rietveld, Femke Segers, Hripsimé Visser and Sandra Weerdenburg; to the research team at Tate, and in particular to Jacqueline Moon and Zoe Miller; to Arjan van der Raadt of the printing studio De Verbeelding; to Aldwin Izarin en Hans van der Linde of the scanning studio Drum Scan Service, to Prof. Kitty Zijlmans, Prof. Pip Laurenson, and Dr. Helen Westgeest, who supported me throughout my doctoral research, to Dr. Vivian van Saaze as my academic supervisor throughout my recent research project 'Print on Demand,' helping me refine my ideas and thoughts, and for her comments on this text. The generous support from the Dutch Research Council (NWO), the Stedelijk Museum Amsterdam, and the Brook Foundation was crucial in funding the research projects I had the privilege to initiate and participate in.

[4] https://stedelijkstudies.com/research-logs/

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Imaginary restoration: historical approach in restoring Soviet postwar film colour

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Abstract

Full colour Soviet cinema appeared during the postwar time and became possible because of the Agfa technology dismantled from German Wolfen factory and brought to the USSR together with tones of film itself. Although, means and resources for making colour movies became available, the transfer of the german technology onto the domestic film factories, however, went not without difficulties. The main problem within the cinematographic community, with the exclusion of a tough and omnipresent censorship, rooted in the low quality of the colour film, produced and processed domestically. Leading directors were obliged to shoot in colour as colour technology was even more than artistic a political evidence of the postwar country success, but the colours were unstable, and as the result in some 20-25 years archival master copies of all the colour films were disposed due to their unacceptable conditions.
By now all the archival film materials of the postwar soviet colour film heritage lack the first positive, which was crucial colour-wise. Nevertheless, as the cinematic community put all its enthusiasm in finding the ways of dealing with this new technology and actively organized different meetings and conferences on colour a lot of documents and transcripts survived to help not only understand the reception of colour film at that time, but to solve a quest of the imaginary restoration, i.e. to imagine how did colour look back then.

Keywords: Soviet; postwar; reception; colour; Agfa; postwar; restoration.

Introduction

When both film director Igor Savchenko and his cameramen Evgenii Andrikanis were sharing their experience of work on the *Old vaudeville* [*Starinnyi Vodevil'*] (1946), during one of the meetings of the section of cinematographers and artists at Moscow House of Cinema, they were remembering the problem they faced because of a wrong suit fabric. It was one of the first postwar colour films, which was shot on trophy Agfa film at a Prague film studio. Andrikanis described the situation as follows:
«The soldiers had blue baize jackets instead of blue cloth ones, and these jackets turned into black instead of remaining blue. It turned out that there was such absorption of light that darkness remained, and I had to overexpose the light in the studio. I repeat that the question of texture in colour cinema is of great importance.» (Andrikanis, 1946)
The master copy of *Old vaudeville* (1946) was destroyed in 1968 with even earlier remarks from 1951 of its unsuitability. «Due to colour balance violation, it is not suitable as a reference copy» was stated on the technical card of *Old vaudeville* in Gosfilmofond. Existing copies of the flm which are available for use are made from the interpositive, which in its turn is made from the original negative. We can see, that the frame is not overexposed at all, and the jackets are once again black. (Fig. 1) A reference copy still needs to be made, albeit through an imaginary restoration.

Fig. 1 - *Old vaudeville* [*Starinnyi Vodevil'*] (1946), positive printed from interpositive (the latter printed from the original negative), 2002

Governmental efforts and ideology of colour

The government's efforts to transfer Agfa to Soviet soil after the war was over were impressive. In the first years, the production and shipment of film to the USSR was established. In addition, requests were sent to extend the work of the factories to obtain more chemicals:

"We ask you to allow an extension of the period of operation of the Agfa factory, the workshops of the Farbenfabrik plant in Wolfen, the Bitterfeld plant of the former I.G. Farbenindustrie, the Hydrierwerke plant in Rottleben, the Stickstoffwerke plant in Piesteritz, engaged in the production of chemicals, semi-finished products and dyes for colour cinematography, until January 1, 1947, with subsequent dismantling and shipment until April 1, 1947." (Bolshakov, 1946).

The equipment of the factories, as can be seen from the text, was planned for dismantling, in the meantime future specialists were sent on business trips to Germany to learn how to work with this equipment.

Not only above-mentioned activities were undertaken to push the development of colour cinematography. The earliest to come from the side of the cinematographic community was the conference on colour, which was held in Moscow House of Cinema in September 1945. It was attended by directors such as Alexander Dovzhenko, art scholars such as Aleksei Fedorov-Davydov or animators — Mikhail Tsekhanovski. The significance of the conference was huge as it outlined the ideological colour agenda. The following principles were derived for Soviet colour:

- full coloured picture tends to reveal primitive-representative values of the western society, it deals in no way with the artistic reproduction of the reality being a naive-reproductionism instead;

- bright and motley picture expresses bourgeois tastes of postcardness and should not be used in Soviet films at all;
- it is necessary to find a way of colour dramaturgy, colour must support the content of the picture (inevitably ideological one).

These trends were surprisingly supported by cinematographers, who took on the problem of the imperfect colour realisation decided to improve colour quality on the screen by narrowing the colour spectrum (no more full coloured picture), moving away so called American lighting, solid and bright (no bright and motley picture), and finally, cameramen got used to working with coloured lighting, which inevitably supported a colour dramaturgy (as it did back in the period of tinting and toning, determining, at a minimum, the time and place of action). Thus, ideological demands for colour based on state policy became simultaneously a response to how to work with colour in far from ideal conditions. Let's take a closer look at what exactly constituted the challenges for filmmakers when working with colour film.

Difficulties in colour implementation

No matter which side of film producing one approached, there were always difficulties with colour. First of all the leading Studio was not ready to embrace the new technology. The pavilions, as well as the dressing rooms, lacked the required lighting equipment — Abram Room wrote about such problems in detail in his «systematized list of proposals, creative and technical, for organizing the filming of colour films at our Studio [Mosfilm]» (Room, 1947).

The film itself, if it was already a domestic product, and not Agfa still being produced in Germany, was of extremely questionable quality. Though questionable was not only the quality, but the entire production process. In 1949, after at least one full-length film (Michurin (1948)) had been already printed on the film produced by the Moscow Factory №3, in a counter letter following the report of Chief Engineer Bogdanov, the latter was asked to clarify such details as «on what basis will the colour film be manufactured (factory No. 3 or Agfa)», «characteristics of the selected "type" of film, in comparison with which the produced colour film will be tested », «organization of technical control of colour film production at factory No. 3 and film testing at the factory itself» (Uspenski, 1949).
Even the developing and printing processes of each new copy used to be a surprise. The issues of the temperature of the light during the printing of the positives, and the instability of colour chemicals were actively discussed during the conference on colour photography, which was held in Moscow October 23-27, 1950. And even then colour imperfections were far from their end. It was already 1965 when E.Kumakov wrote in his article about the «poor colour quality in cinema» (Kumakov, 1965). Only in the end of the 1960's the masking component to fix the layers stability was introduced into the film production.

As can be effortlessly seen from the above-mentioned documents — conference reports, transcripts, correspondence and internal studio documents — production problems were discussed and were well known to the filmmakers, especially aware of them were cameramen, who took part in the final approval of the colour while printing the master copy.

Production of colour film positive

The entire process of colour film positive production (and the role of the first positive, aka master copy, aka reference positive) is brilliantly described in the book *Colour in Cinema* (Iordanskii, Cheltsov, 1950) and can be divided into following steps:

- As colour negatives pile up during the filming process, the current printing laboratory produces the first colour film positive from these negatives (during the first years there were only two such laboratories — in Moscow and in Prague). This colour film positive, usually called a current colour positive, unlike the colour positives of mass printing intended for demonstration on movie screens, is necessary for the director of the film and the film crew to check the acting, the quality of the colour negative, the nature of the colour reproduction of the scenes, and the correspondence of the resulting colour cinematic image to the general artistic concept of the film being created.

- Usually, by the time the filming of a movie is finished, a current colour film positive is printed from all the negatives of the shot plans and episodes of the movie, which is edited in accordance with the direct instructions of the director of the movie. The process of editing the film positive consists of the director selecting the best quality positives of all individual plans, determining the length of the positive of each plan, and the final sequential arrangement of the plans in accordance with the script.
- Based on the edited current film positive, the film negative of the image and the negative of the soundtrack are edited with strict mutual synchronization to ensure precise timing of the sound and image on the movie screen, for example, the sounds of an actor's speech with the movements of his mouth when pronouncing them.
- From the finished edited colour negative, the studio's current printing laboratory, guided by the instructions of the film's director and chief cameraman, produces a reference copy of the colour positive. After viewing this reference copy on the screen and approving it, the colour negative of the cinematic image and the regular black-and-white negative of the soundtrack are sent to the printing factory for the production of the required number of rental copies of the film.

During the last stage, as Iordansky and Cheltsov write, «the colour design of the frame is finally completed in the positive copy of the film» (Iordanskii, Cheltsov, 1950). Such finishing touches were a standard part of the procedure, which many cameramen relied on when making certain decisions during the shooting. For example, cameraman Andrei Moskvin, knowing about a shortcoming of the domestic film, specifically mixed blue dye into the actors' powder so that when leveling the tone of the faces during the printing of the reference positive, the blueness would be removed not only from the faces, but from the entire frame, which was Moskvin's goal. (Butovskii, 1971) Therefore, not only the role of the now lost first positives is obvious, but also the importance of information about the shortcomings that the cameramen tried to solve during the design and, most importantly, printing of the film.

Conclusions

When it comes to restoration, original samples are priceless, but they are not always available. Then memoirs and descriptions of the filming process are of great help, as in the case of the jackets in *Old Vaudeville*, which the cameraman Anrikanis spoke about with displeasure. But even this information is not always available. And at that point historical approach, which includes not only the analysis of documents of the time, but also an understanding of the political and economical context, can serve well.

Particularly important, dealing with the postwar sources is to differentiate them by the degrees of reliability. Periodicals can be of great help in finding a particular event, but they can hardly reflect anything specific about what exactly was discussed there. Even the event itself does not always provide an opportunity to its participants to discuss the industrial or artistic issues directly. Censorship at that time manifested itself not only in opposition to Western values (as we saw in the conclusions of the conference on colour, 1945), but also, of course, in the creation of pseudo-well-being, the illusion of which is actively supported not only by newspapers and magazines, but also by many public events. The best sources in our case are transcripts of internal institutional meetings, be it a meeting of the cameramen and artists section at the Moscow House of Cinema, or Studio's artistic councils. All the industrial reports are undoubtedly useful, though not directly if talking about the particular film restoration.

Last but not least, there is the ethical question of which films deserve restoration, and whether it is worth concentrating attention on the postwar Soviet period colour-wise. But here the choice is fundamental, since, despite the deficit of sane plots, it was the postwar years that became decisive for the further development of colour cinema in the USSR for at least two decades. And such an approach to, for now, only an imaginary restoration only outlines a possible path to its further implementation.

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Prokudin-Gorskii's technique of colour photography and contemporary exhibitions

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Abstract

Analog photography has been a subject of curatorial interest for over a hundred years. Among early colour photographs are works created using techniques that have primarily been examined from aesthetic and cultural perspectives, such as those by Russian photographer Sergei Prokudin-Gorskii (1863–1944). To produce colour projections and photomechanical prints, Prokudin-Gorskii utilized the colour separation method, which involves the preliminary separation of spectral information for subsequent reproduction using light or dyes. This principle is foundational to digital projectors and colour printing.

This paper explores the potential of using Prokudin-Gorskii's historical photographs to explain the principles of additive colour synthesis. It analyses curatorial design practices used in exhibitions and catalogue productions of Prokudin-Gorskii's works. This study demonstrates how technically flawed photographs can illustrate the principles of additive colour synthesis, contributing to the history of methods and curatorial practices, and providing a foundation for future exhibition projects.

Keywords: exhibitions; projection; immersion; curatorial design practices; history of photography.

Introduction

For the past thirty years, digital projections and printing techniques have dominated artistic, historical, and scientific exhibitions. However, certain processes and phenomena still require additional explanation for modern audiences.

Analog photography has captivated curatorial interest for more than a century. A key question arises: is the history of photography adequately conveyed to exhibition visitors? This need for additional context is especially relevant for the technically complex methods of early twentieth-century colour photography. While art historians, photography scholars, and photographers have extensively explored this subject in publications and exhibitions (Lavédrine, 2013; Hannouch, 2022), certain techniques, such as those used by Sergei Prokudin-Gorskii, have often been discussed only from an aesthetic or cultural standpoint.

Prokudin-Gorskii's glass negatives and expedition albums, mostly held by the Library of Congress, were digitized in the early 2000s. Since then, curators have primarily used these photographs in exhibitions focusing on the pre-revolutionary Russian Empire. To create his colour projections and prints, Prokudin-Gorskii employed a colour separation technique. This involved exposing three black-and-white panchromatic emulsions through red, green, and blue filters (Pénichon, 2013). Using a camera capable of sequentially exposing one glass plate through these filters, he created images that were later combined using corresponding lantern projectors. A detailed explanation of Prokudin-Gorskii's technique can be found in Stanulevich (2022).

The principles of colour separation underpin modern digital projectors and colour printing. This research examines how Prokudin-Gorskii's photographs can serve as educational tools for explaining additive colour synthesis.

The study addresses the following questions:

1. Do exhibitions of Prokudin-Gorskii's photographs explain the history and technical aspects of his methods?
2. How can additive colour separation techniques be represented to audiences?

This paper proceeds in three parts: an exploration of the inspiration and materials for the study, an analysis of publications and restorations related to Prokudin-Gorskii's works, and an evaluation of curatorial practices in exhibitions and catalogue production.

The inspiration for this study stems from a project by Dutch artist Pim Zwier, who analyzed Prokudin-Gorskii's technical imperfections, such as colour deviations and phantom images. Zwier noticed, for example, a transparent boy leaning against a wooden shed in a photograph of the monument commemorating the opening of the Onezhskii Canal in 1909 (Fig. 1).

Fig. 1 - Monument dedicated to the opening of the Onezhskii Canal. 1909. Sergei Prokudin-Gorskii. Digital colour composite from digital files from glass negative. LC-DIG-prokc-20933. Library of Congress Prints and Photographs Division Washington.

Upon examining the three original black-and-white photographs, Zwier discovered that the boy only appears leaning against the shed in the green-filter image. In the blue-filter image, he is a vague blur approaching the shed, while in the red-filter image, he is a vague blur leaving the scene (Zwier, 2016). Zwier interpreted these images as resembling extremely short films, consisting of a single frame of indefinite duration. This observation led him to experiment with transforming the historical analog process into digital video. Zwier created a photo series and a short film titled Three Dimensions of Time, featuring a motionless background with transient elements.

This study evaluates Prokudin-Gorskii's flawed images as educational tools. It also examines publications by restorers who specialize in the digital reconstruction of Prokudin-Gorskii's photographs, as well as curatorial practices in displaying these images. Limitations include the availability of only one image from an exhibition at the Library of Congress.

Digitizing Prokudin-Gorskii's collection required developing specialized software to combine three black-and-white colour-separated negatives into full-colour images. The Library of Congress scanned

1,902 glass negatives at a resolution of 10,000 pixels on the long side. However, technical issues, such as subject movement, emulsion damage, or frame misalignment during exposure, resulted in flawed images (Agüera y Arcas). Also in the process of taking the original glass plate negatives were often shifted in one or more of the three dimensions, causing the scene to be skewed or distorted between frames (Wirth and Bobier, 2009). Examples of colour correction and the problem of digital restoration in general were discussed in Russian in the catalogue the exhibition catalogue at the Schusev State Mu-seum of Architecture in Moscow (Garanina and Minahin, 2003).

Among scientific articles about Prokudin-Gorskii, there are also studies of his "defective" works. For example, Erica X Eisen (2022) mentioned that during the research of Ser-gei Prokudin-Gorskii's flawed images our focus shifted away from elegant landscapes and fantastic Orthodox Church domes towards the great effort involved in staging and producing the photographs themselves.

Restorers manually aligned the layers to create full-colour digital images, a labor-intensive process. While new tools have accelerated this task, certain images remain uncorrected, preserving their original flaws. Comparing different restoration versions of the same photograph provides further learning opportunities.

Works on matching the layers are published not only on the official Library website but also on the projects for the study of Sergei Prokudin-Gorskii's legacy website ("Herit-age of S.M. Prokudin-Gorskii" website). Comparing different versions of layer-matching of the same photograph made by different restorers can also be useful in the practical study of technologies.

Flawed images have inspired creative projects, such as Zwier's Three Dimensions of Time, which explores viewer perceptions of three-colour technology. Reviews from film festivals highlight the evocative nature of these works, describing them as "gymnastics for the eyes" and "perceptive exercises between optical enigmas and fantastic visions."

A retrospective of Prokudin-Gorskii's exhibitions gives us information about exposition solutions. The exhibition practice of the early 2000-s offered matted prints from digital colour images, as is the case with classical photography or graphic works. In a number of exhibitions, the passe-partout covered non-crossing areas of the colour channels. This way only banners and explications could explain the technical details of Prokudin-Gorskii's colour images development process. Most often, they were used for biographical information about the photographer and his expeditions instead.

The first exhibition based on digitally reproduced Prokudin-Gorskii's photographs titled "The Empire that Was Russia: The Prokudin-Gorskii Photographic Record Recreated" opened on April 17, 2001, in the Library of Congress. For this exhibition, the glass plates were scanned, and through an innovative process known as digicromatography, brilliant colour images have been produced (News from the Library of Congress). Based on the picture from the William Craft Brumfield collection, I can say that the technical details of the shooting were touched on in the exhibition. At least the booth with the name of the exhibition was accompanied by a horizontal layout of a colour reproduction into three separate components - magenta, cyan and yellow, which certainly corresponds to the principles of three-color printing (Eremeeva, 2021).

The exhibition "Miracles of Photography. Recreating the photographic heritage of Sergei Prokudin-Gorsky" in the Russian Museum was designed in the aforedescribed manner (Exhibition the Russian Museum Website). This exhibition opened on April 12, 2003, and had the same name as the last exhibition of the photographer, which took place in the Nikolaevsky Hall of the Winter Palace in 1918. The Library of Congress staff prepared the banners and unusual booklet. Photographs from the exhibition's opening day and the booklet are stored at the Russian Museum's Department of the

Archival Photographs. In the booklet design, I found the decision to accompany fragments of images with a side-by-side presentation of a full-size frame interesting.

Another important exhibition called "The Splendors of Russia in Natural Colors. The Complete Prokudin-Gorsky 1905-1916" opened on November 19, 2003, at the Schusev State Museum of Architecture in Moscow. In this case, exhibition curators explored various ways to present a photograph: full-scale printing, use of a passe-partout, demonstration of copies of negatives and album sheets.

Prokudin-Gorskii's photographs were also printed without frames in the exhibition of 2016 in Lappeenranta, Finland. In this way of demonstration, fragments-strips of each colour-separated channel are not concealed from view.

The large number of catalogues of Prokudin-Gorskii's photographs has been published in Russia over the last twenty years. Similarly, to foreign publications, they rarely contain a detailed explanation of the colour theory, the basics of colour separation, etc. Nevertheless, interesting design solutions can be gleaned from them. Below is a layout of a triple negative image (Fig. 2) and a digital colour image (Fig. 3) on one book spread (Kolyvanova, 2017).

The use of three colours in the titles of publications, and exhibition catalogues is also meant to evoke viewer's association with three primary colours - red, green and blue (RGB). For example, a poster (Fig. 4) of the exhibition of Prokudin-Gorskii's photographs on October 22, 2016, to April 2, 2017, contains a photo and the title of the exhibition that were repeated in RGB colours.

Some flawed images reveal ghostly effects: subjects in motion may appear in only one colour layer or as misaligned shadows across layers. Such imperfections illustrate the challenges of early colour photography and offer insights into the additive synthesis process. I have identified approximately 80 images with notable mismatches, making them valuable for technical analysis and education.

Fig. 2 - Rafts on the Peter the Great Canal. City of Shlisselburg. 1909. Sergei Prokudin-Gorskii. Digital file from glass negative. LC-DIG-prok-00876. Library of Congress Prints and Photographs Division Washington.

Fig. 3 - Rafts on the Peter the Great Canal. City of Shlisselburg. 1909. Sergei Prokudin-Gorskii. Digital colour composite from digital files from glass negative. LC-DIG-prokc-20876. Library of Congress Prints and Photographs Division Washington.

Fig. 4. - Exhibition "Väri on valoa – Saimaalta itään värivalokuvin" poster, 2016/2017, The South Karelia Museum in Lappeenranta, Finland; photograph by the author, 2016.

Conclusions

Prokudin-Gorskii's photographs capture people, cities, and landscapes frozen in time. At the same time, colour deviations document the passage of time between exposures. Exhibition practices for Prokudin-Gorskii's works have evolved since the early 2000s. For example, the Library of Congress's 2001 exhibition The Empire that Was Russia introduced digicromatography, a technique that produced vivid colour images. Other exhibitions, such as the 2003 Miracles of Photography in the Russian Museum and the 2016 Väri on valoa in Finland, showcased innovative ways of presenting the photographs. These included side-by-side layouts of colour-separated negatives and their composite images, as well as designs that emphasized the RGB colour model.

Modern technologies offer interactive opportunities to reconstruct and demonstrate the processes of shooting, assembling, and printing early colour photographs. Flawed images, in particular, are excellent tools for explaining the recombination of light spectrum components in additive synthesis. By exploring Prokudin-Gorskii's flawed images and curatorial practices, this study contributes to the history of photographic methods and exhibition design, laying a foundation for future projects.

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Preserving Bosnia's Cinematic Heritage: Challenges and Achievements of the Film Centre Sarajevo in the Post-War Era and Beyond

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Abstract

Bosnia and Herzegovina's cinematic heritage faced severe risks due to war and neglect following the Siege of Sarajevo (1992–1995). In response, the Government of the Federation of Bosnia and Herzegovina established the Film Centre Sarajevo (FCS) in 2008 to preserve this heritage. In 2021, with support from the U.S. Ambassadors Fund and in collaboration with the University of Milan's MIPS Lab, the FCS introduced cataloging, digital archiving, and digitization techniques. This study provides a detailed case analysis of the FCS, examining the strategies employed to address preservation challenges and assessing progress in safeguarding its cinematic heritage.

Keywords: film restoration; film preservation; cinematic heritage; cultural heritage preservation

Introduction

Bosnian cinematography experienced significant growth after World War II, beginning in 1947 with the founding of the Commission for Cinematography of Bosnia and Herzegovina and Bosna Film (Peterlić, 1986). Under the management of Monci Finci, Bosna Film achieved international success, with *Hanka* becoming the first Bosnian feature film to compete at the Cannes Film Festival in 1955. Despite early achievements, financial difficulties led to a series of mergers and, ultimately, the dissolution of Bosna Film in 1975, with Sutjeska Film acquiring its assets and rights (*Katalog BH igranih filmova 1951-1992*, 2021).

Studio Film, founded in 1953 and re-established in 1967, along with Sutjeska Film, played crucial roles in supporting emerging filmmakers and expanding the scope of Bosnian cinema. Sutjeska Film gained international recognition, notably with *Do You Remember Dolly Bell* (1981), which won the Golden Lion at the Venice Film Festival (*Katalog BH igranih filmova 1951-1992*, 2021).

These companies played a crucial role in the development of Bosnia's film industry, fostering the exploration of social and cultural themes. In 1992, the Siege of Sarajevo caused devastating human and material losses, severely damaging the country's cultural heritage, including its cinematic archives. The image below (Fig 2) illustrates the destruction left after the war, highlighting the challenges of preserving film materials. After the war, preservation efforts became more challenging, as neglect led to ongoing deterioration. In response to growing concerns, the Government of the Federation of Bosnia and Herzegovina established the Film Centre Sarajevo (FCS) in 2008 to protect, preserve, and ensure the nation's film heritage is accessible to future generations (Vlada Federacije Bosne i Hercegovine, 2008).

FCS inherited a film collection stored in poor conditions, leading to issues such as fungal growth, shrinkage, acetate decay, and other forms of degradation. This paper analyzes the Center's efforts to preserve Bosnia's cinematic heritage, examining both the successes and challenges encountered. Supported by new expertise and funding from international collaborations, the authors of this paper applied both effective and experimental techniques to recover, classify, and catalog the films, establish a digital archive, and initiate digitization solutions to ensure their long-term preservation.

Fig 2 - Drone photograph of the Film Centre Sarajevo, 2022

Conservation Challenges and Collaborative Efforts

The post-war conditions in Bosnia and Herzegovina presented significant obstacles to preserving cinematic heritage. Years of unstable storage environments, characterized by fluctuating temperatures and high humidity, left film materials vulnerable to issues like fungal growth and acetate degradation, commonly known as "vinegar syndrome" (National Film Preservation Foundation (US), 2004).

Fig. 2 and Fig.3 illustrate the disordered storage conditions and severe degradation of film materials at the Centre, illustrating ongoing threats to long-term preservation.

The socio-political and economic instability of the post-war period further impeded conservation efforts, as there was a lack of adequate facilities, trained personnel, and financial resources, all crucial elements for effective preservation. For years, films were stored in inadequate conditions with minimal conservation efforts.

Fig. 3 - Condition of film deterioration

Fig. 4 - Condition of film materials, 2022

FCS currently holds a collection of around 80 feature films and over 500 documentaries and short films, many of which have deteriorated due to prolonged exposure to poor storage conditions (K.L., 2020).

Before the war, production companies in Sarajevo operated their own black-and-white film development laboratory, which allowed for in-house production of prints from negatives. However, for color negatives, films had to be sent to Belgrade or Zagreb for development and long-term preservation, leading to these negatives remaining in those cities. Consequently, the FCS primarily holds projection copies rather than original negatives.

Facing accessibility challenges, the Centre adopted an improvised digitization strategy before 2021. Projection copies were screened and recorded with SD cameras, enabling revenue generation through image rights sales. Additionally, select films were digitized with the help of external laboratories, preserving iconic works such as *Do You Remember Dolly Bell?* (1981), *Battle of Neretva* (1969), *Sutjeska* (1973), and *Walter Defends Sarajevo (1972)*.

In 2021, the FCS received a grant from the U.S. Ambassadors Fund for Cultural Preservation, allowing it to attempt to align its film preservation efforts with international standards. This financial support was essential for enhancing the Centre's capabilities and establishing the foundational conditions necessary for the preservation, conservation, and digitization of film heritage (U. S. Embassy in Sarajevo, 2021). Additionally, a partnership with the MIPS Lab at the University of Milan provided technical expertise in film preservation and digitization, further strengthening the Centre's initiatives. The new management initiated projects aimed at developing an archive where materials could be preserved, digitized, and made accessible to the public.

Interventions

The initial goal of the FCS was to create a suitable physical space for film materials, provide adequate workspaces for employees, and offer additional training for interested individuals. A significant issue that required attention was the lack of skilled personnel. The project facilitated enhanced physical protection for the film materials through several key improvements: the installation of new windows, roof renovations, facade upgrades, and the introduction of security cameras. Additionally, water and heating systems were installed to ensure appropriate environmental conditions. Measures were taken to improve microclimatic conditions for the films, including repurposing rooms, establishing a depot, introducing ventilation systems, and acquiring devices to remove excess moisture. A separate area was also equipped for contaminated materials.

Importantly, the building of the FCS has been restored by implementing a new thermal insulation system and new energy-saving infrastructures, such as the use of LED lamps, despite the continued use of tungsten lamps in Bosnia and Herzegovina. These steps aim to decrease the impact of the new film conservation room on the overall costs of the FCS and improve the efficiency of thermal and electrical systems (Plutino, Gaia and Ahmedhodzic, 2024).

Furthermore, the project enhanced the premises for ongoing operations by cleaning and adjusting the existing rewinding table, acquiring film cleaning equipment, purchasing office furniture, and obtaining computers, scanners, and other essential tools.

Methodology

The methodology employed by the FCS involved a systematic approach to the preservation and organization of film materials. Initially, efforts were focused on cleaning all film boxes and relocating them to the newly prepared spaces. Each box was opened, and an inventory was created, assigning a unique identifier to every film reel. This inventory is maintained in a digital format for efficient management.

As part of the cataloging process, the physical, chemical, and microbiological conditions of the films were assessed. Just as it is important to separate different types of material, if possible, it is also important to separate films that are deteriorating from those in good condition. Therefore, it would be advisable to create environments where these already deteriorating materials can be confined (Micarelli, 2018). Materials contaminated by fungi were separated from intact ones, and temperature and humidity levels were monitored as much as possible. After completing the categorization, cleaning began on selected documentary films and archival materials in preparation for scanning.

For the film material collection of the FCS, preservation efforts are guided by the legal standards set for the preservation of monuments, which recommend general storage conditions: an optimal humidity level of 50% to 60% and an air temperature between 16°C and 22°C (Komisija za očuvanje nacionalnih spomenika, 2021). However, these parameters differ from internationally recommended standards. The Image Permanence Institute (IPI) suggests "frozen" conditions (0°C) as the best practice for maximizing film longevity, particularly for degrading acetate and nitrate films, followed by "cold" (4°C) as an acceptable alternative. Relative humidity (RH) should be kept between 30% and 50%, with lower RH values (closer to 30%) preferred to minimize deterioration rates. These conditions are critical for maintaining film stability and extending its life (Reilly, 1993). It is important for acetate films that the environment remains stable, cool, and dry, with no significant fluctuations in temperature and relative humidity (Micarelli, 2018).

During cataloging, we considered several key factors, such as title, film category, conservation status, support type, and the film's condition. The title, typically found on the box label, facilitated historical research, uncovering many titles once believed lost. Conservation status visually identifies primary issues affecting the film, with specific categorization used to prevent contamination if microorganisms are present. Materials are assigned a unique identifier, allowing systematic tracking and management.

The authors of this article utilized technology and digital archiving methods, essential in preserving Bosnia's cinematic heritage. The Centre acquired a Cintel BlackMagic[5] scanner, which, despite budget constraints, enabled high-quality digitization of 16mm and 35mm film reels. This scanner offers reliable image quality and direct audio capture, supporting conservation and restoration work.

The first essential step to achieving a high-quality acquisition is the calibration of the equipment. Every device used for capturing, displaying, or reproducing images (such as scanners, monitors, projectors, or printers) can be calibrated, meaning adjusted to ensure a match between the digitally reproduced values and the real ones (Plutino, 2020).

The images from the scanner are acquired using DaVinci Resolve[6], as it is the software associated with the scanner. During scanning, each frame captured by the scanner's sensor is saved with embedded metadata as a 16-bit linear image sequence in Cintel Raw Image (CRI) format. The advantage of DaVinci Resolve is that it integrates editing, compositing, motion graphics, color correction, recording, and audio processing into a single software solution.

Generally, when digitizing an archival film, an original copy is saved for preservation purposes. At the end of the process, each frame will be an uncompressed file with a Digital Picture Exchange (DPX) extension, linked to the next frame to maintain the sequence order, and will contain the maximum amount of image information (Dagna, 2014).

For the preservation of FCS scans, we have chosen to archive them in both the original CRI and in DPX format. In particular, DPX format has several features specifically designed for restoration purposes:

- The ability to encode the specific sensitometric characteristics (gamma) of the scanned film emulsion.
- The incorporation of calibration data to ensure that the color space of the scanned film appears consistent across all display devices used in the workflow, including the restoration workstations' monitors, printed films at the end of the process, the digital file, and more.
- The DPX format also allows for the creation and storage of file information (such as the film name, an archive tape number, and the operator's name), known as metadata, within the file itself, for project management purposes.

The FCS utilizes the OWC Mercury Pro LTO-8[7] model for tape-based backup and archiving, essential for protecting and preserving large volumes of data. Each LTO-8 tape offers a native storage capacity of up to 12 TB, expandable to 30 TB with compression. The integrated IBM LTO-8 drive reads and

[5] Cintel BlackMagic, https://www.blackmagicdesign.com/it/products/cintel (visited on 12/11/2024)
[6] DaVinci Resolve, https://www.blackmagicdesign.com/it/products/davinciresolve (visited on 12/11/2024)
[7] OWC Mercury Pro LTO-8, https://www.owc.com/solutions/archive-pro (visited on 12/11/2024)

writes on both LTO-8 and LTO-7 tapes, providing flexibility in media usage. Digitized materials are securely stored on LTO (Linear Tape-Open) tapes, ensuring long-term preservation, though this technology requires periodic updates (Ahmedhodzic, 2021). These efforts, coupled with detailed metadata creation for each film, are vital for archive management and enhance accessibility for research and education.
The next step after scanning, if the project requires it, is the actual digital restoration, which is the digital equivalent of film repair—except that only the elements of the film selected through technical evaluation are scanned. As such, this process can take several months, requiring skill and expertise from the operators (Enticknap, 2013).
The limitations in staff and funding have led us to make a decision regarding the next step, specifically to focus, where possible, solely on color correction of the scanned material, without undertaking full digital restoration. Unfortunately, film restoration programs are costly and not easily sustainable for the FCS. However, thanks to collaborations with European archives and film libraries, along with European funding, it was possible to restore the film *Slike iz života udarnika* (1972). Part of this project, such as the scanning of the reference positive, was conducted at the FCS's new lab, contributing to the enhancement, promotion, and preservation of Bosnia's cinematic heritage. The priority of the first phase of rebuilding the center's archive has been to catalog and initiate the digitization process—marking a technological advancement within the Federation of Bosnia and Herzegovina, as FCS is the first to possess a laboratory of this kind.

Results

Significant progress has been achieved in the preservation of Bosnia's cinematic heritage through systematic conservation and cataloging efforts, initiated in 2021 and continuing through 2023. These actions have not only improved the stability of preservation conditions but also led to the rediscovery of films once thought lost. By cataloging over 5,000 reels by both type and condition, the archive can now precisely assess and address the specific needs of each film, enhancing conservation practices and ensuring their longevity.

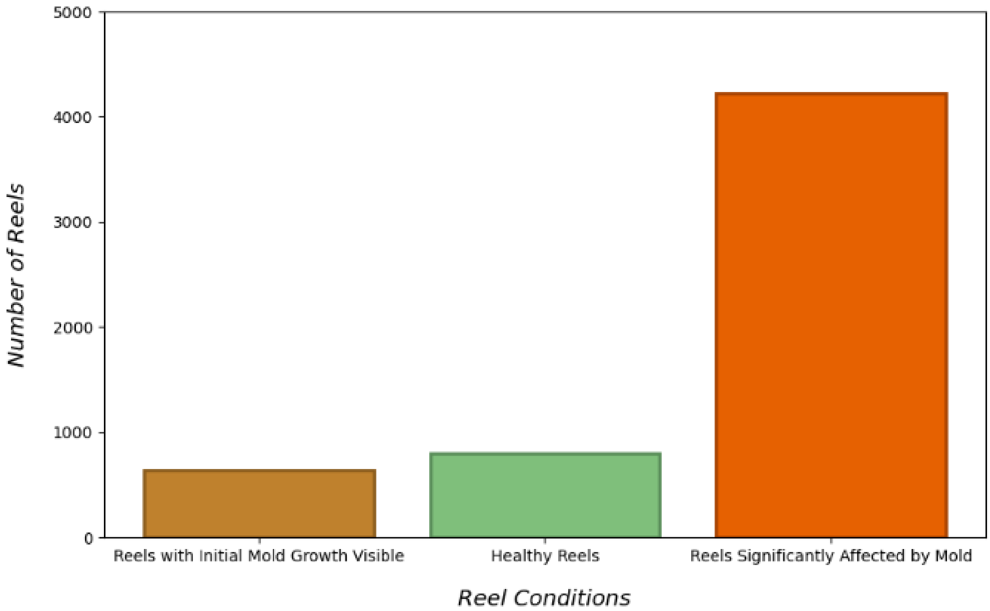

Fig. 5 - Condition of films affected by microbiological agents

The results of this thorough examination, presented in Fig.4, illustrate the condition of film reels impacted by microbiological agents, such as mold. Among the reels inspected, **638** displayed initial signs of mold growth, **802** were classified as healthy with no microbial damage, while a significant number—**4,217 reels**—were found to be severely affected by mold. This condition breakdown

emphasizes the urgent requirement for focused conservation efforts to halt further degradation and maintain the integrity of the healthier reels.
Fig.5 illustrates the classification of film reels within the archive, showcasing a diverse array of material types. The collection is primarily composed of feature films **1843 reels** and documentaries **1550 reels**, complemented by substantial quantities of archive footage and audio tracks. This comprehensive cataloging process has enabled the identification of additional valuable items previously unaccounted for in the catalog, including feature films like *Brown Eye*, *Evil Eye* (1968) and archival material that was previously unknown. These findings underscore the importance of systematic archival efforts in uncovering hidden cultural assets and expanding the archive's documented heritage.

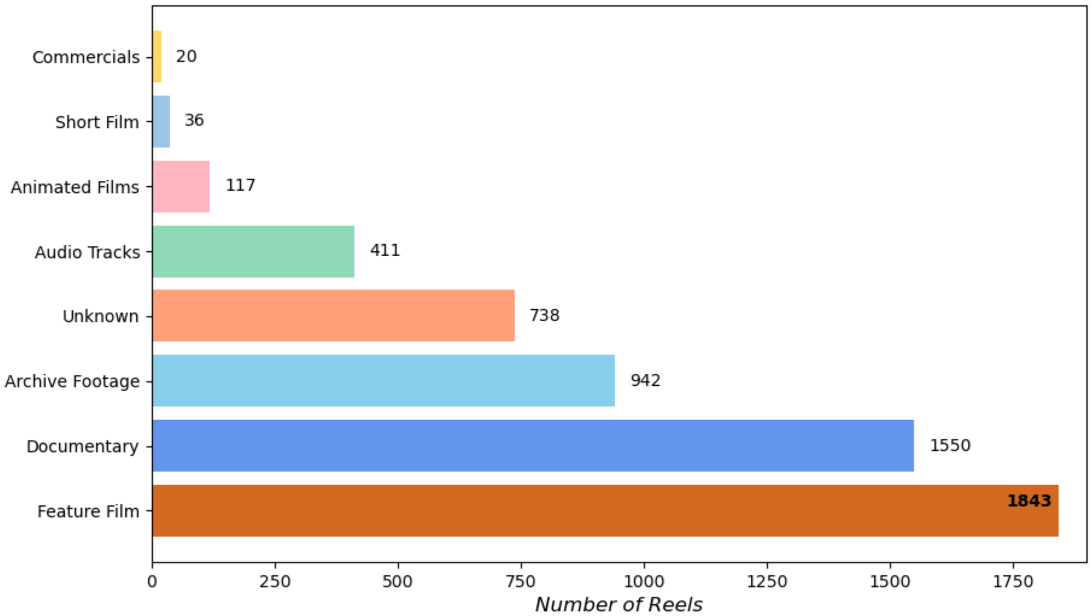

Fig. 6 - Classification of film reels by type

The cataloging process also provided valuable insights into the current status of the documentary collection, consisting of **514 titles in total**, as compared to the current catalog available at the FCS. Of these, **23 documentaries** have been digitized in high-quality 4K/2K format by the authors between 2022 and 2023, ensuring their preservation. The majority of the footage—**355 documentaries**—is only available in a lower-resolution format, primarily used for professional television recordings at the time. With the advent of new technology at the Center, the quality of this format is now questionable for sustainable preservation. Additionally, **136 documentaries** lack any form of digital preservation, underscoring the critical need not only to digitize these items but also to locate their **original film reels** for preservation. Through extensive cataloging efforts, we managed to recover **66 previously lost titles**. However, many of these are in **fragile condition**, requiring **considerable restoration and cleaning** efforts before they can be safely digitized.
Unfortunately, our assessment also confirmed that **72 titles** are **missing entirely** from the collection, representing a substantial loss to Bosnia's cinematic heritage. These findings emphasize the crucial role of systematic cataloging and conservation. Such efforts are fundamental in both recovering and preserving Bosnia's cinematic legacy.

Conclusions

The FCS has made significant strides in the preservation of Bosnia and Herzegovina's cinematic heritage through a concerted effort in cataloging, conservation, and digitization. Initiated in 2021, these efforts have not only improved storage stability but have also led to the rediscovery of films previously thought lost, thus playing a crucial role in safeguarding Bosnia's cultural memory. Cataloging over 5,000 reels by type and condition has allowed the archive to address specific preservation needs, especially in tackling mold and other forms of degradation affecting the collection. The inspection of reels underscored the need for targeted conservation, with a significant portion showing microbial damage, emphasizing the urgency of ongoing restoration work.

Through this detailed cataloging process, the FCS gained valuable insights into the state of its documentary collection. Although a fraction of the titles has been digitized in high-resolution formats, the majority remain in a lower-quality format, highlighting the ongoing need for updated digital preservation efforts. Additionally, the recovery of previously lost reels was a major achievement, though many of these require extensive restoration due to poor condition, while others remain unaccounted for, representing a loss to Bosnia's cinematic heritage.

The FCS has successfully implemented both traditional and modern conservation techniques, such as the partial restoration of its facilities, the establishment of stable environmental controls, and the setup of a digitization lab. The creation of preservation copies on LTO tapes, though requiring periodic updates, demonstrates a commitment to long-term archiving solutions. Despite resource constraints, the Center's adaptive approach has enabled it to operate effectively, setting a potential model for other archives facing similar challenges.

In summary, while the FCS's efforts have brought Bosnia's cinematic heritage a step closer to preservation, the challenges of restoring and digitizing fragile materials highlight an ongoing need for resources, expertise, and institutional support. The work achieved thus far underscores the significance of these cultural assets and reinforces the importance of continued efforts to protect Bosnia's cinematic heritage for future generations.

Challenges and Future Perspectives

This section discusses the ongoing challenges faced by the Film Centre Sarajevo (FCS) and explores future strategies to strengthen Bosnia's film preservation efforts within a complex political and economic environment.

The FCS has made notable progress in preserving Bosnia's cinematic heritage, yet it faces enduring challenges that limit its operational capacity. The political and economic instability in Bosnia and Herzegovina continues to impact cultural institutions, with heritage preservation often overlooked as a national priority. This context, coupled with a shortage of specialized staff, constrains the FCS's workflow and reduces the scope of its projects. Moreover, there is an urgent need for enhanced IT infrastructure, including improved data storage, server capabilities, and security measures, to support long-term preservation efforts effectively.

Addressing these challenges requires increased investment in both digital and physical infrastructure, as well as initiatives to standardize preservation practices across all Bosnian institutions handling film heritage. Establishing a unified framework for preservation would not only ensure consistent standards but also encourage inter-institutional collaboration, enhancing the resilience and reach of preservation efforts nationwide.

The recent suspension (2024) of operations due to unresolved administrative issues has further hindered the FCS's progress, placing current and future projects at risk. This disruption affects ongoing collaborations and limits training opportunities, emphasizing the need for strategic support to secure the Center's achievements and maintain its momentum.

Ultimately, the work of the FCS highlights the importance of cultural preservation in safeguarding a nation's identity and history. Its journey in conserving Bosnia's cinematic legacy serves as both a roadmap and an inspiration for similar institutions, demonstrating the resilience necessary to protect cultural memory despite significant obstacles. Moving forward, sustained support—both domestically and internationally—will be crucial for ensuring the future of Bosnia's film heritage. The rediscovery and restoration of Bosnia's cinematic treasures not only honor the country's cultural past but also inspire future generations to value and protect these irreplaceable assets.

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The Role of Subjectivity in Color Film Restoration

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Abstract

Digital color correction is a fundamental step in film restoration, essential to "repair" the effects of time, degradation, and digital scanning challenges. Achieving the original intent relies on multiple factors, including the availability of a reference, the vision of the director of photography, the colorist's expertise, the technology used, and other influential elements. This study examines the impact of subjectivity in digital color restoration by analyzing three scenes from the film *Slike iz života udarnika* (1972). Six distinct color-corrected versions, each produced by a different European institution using identical source material, were analyzed and compared through a set of quantitative metrics.
The analysis involved measuring luminance, RGB channel values, multi-resolution contrast (MRC), and ΔE76 color difference, using the original negative, a projection print scan, and the official restored version as benchmarks. The findings underscore the influence of subjective interpretation in color restoration and highlight the potential of quantitative metrics to better understand and document variations in the restoration process.

Keywords: Color grading; Color correction; Film restoration; Chromogenic films; Color films

Introduction

Color film restoration is a complex, multidisciplinary process focused on returning old films to their original appearance through digitization and color correction. Reconstructing the original appearance would be easier with access to more comprehensive information. This includes specifics about the film itself, such as storage conditions, dye fading, or tone shading, as well as details from the original shoot, like lighting, camera settings, and filters. Factors like scanner settings, characteristic curves, standards, gamuts, devices, and dynamic range become crucial, each playing a role in affecting color accuracy. in a digital environment, the color correction allows independent adjustments of each color component (red, green, blue, and their complements yellow, cyan, and magenta) within individual elements of a single frame, offering a level of control beyond that of analog restoration (Fossati 2018). Due to that, an "infinite" gamut of colors can be possible, so with limited clues about the original appearance, the operators restore the film based on historical research, their experience, and subjectivity. The decisions made during the restoration process are indeed often influenced by the personal preferences and biases of the restorers, even being experts in the field.
This work aims to analyze the impact of subjectivity on the outcome of color restoration, even when starting from the same digitalized negative source. The purpose of this study is not to rank different restorations but to examine how individual interpretations can lead to varied results and to gain insight into these differences.

Matherial and methods

For this work, we selected three scenes from the Yugoslav film *Slike iz života udarnika* (*Life of a Shock Force Worker)*, directed by Bato Čengić in 1972.
The film follows the life and experiences of a coal miner worker within the rigid socio-political context of the post-war socialist Yugoslavia. This film is part of the so called *Yugoslav Black Wave*, a movement in the history of cinema which is unique both for its political implications as a bold critique of the state socialism of Yugoslavia in the 1960s, and for its aesthetic form, which displays

a visual freedom unmatched even within the context of experimental European cinema of that decade (Kirn, Sekulić, & Testen, 2011).
The rights to this film are held by *Filmski Centar Sarajevo*, which kindly granted us permission to use these scenes. This film was chosen specifically because it underwent a restoration in 2023, overseen by the original director of photography (DoP), Karpo Aćimović Godina. The restoration was made possible through a collaborative film restoration grant as part of the *A Season of Classic Films* program, and the restored version was presented at the 80th Venice International Film Festival in 2023.
To explore the subjective differences in color correction, we contacted 6 European institutions specializing in film restoration and conservation. Each laboratory received a brief description of the film, the three scenes from the negative film, and the equivalent three scenes from a non-restored positive copy to be used as reference (all the information about the film reels are summarized in Tab. 1). These laboratories were asked to focus exclusively on the color correction of three provided negative scenes, without making any further edits or restorations, and to maintain the original resolution, color space, format, and bit depth. As previously mentioned, individual contributions will remain anonymous, as the objective of this study is not to establish a ranking but to examine differences among the versions resulting from subjective interpretation.

Tab. 1 - Details regarding the copies from which the three scenes were selected

	Negative	**Positive**
Base	Acetate	Acetate
Format	35 mm	35 mm
Scanner	ARRISCAN XT scanner	Cintel Scanner
Color Space	REC 709 Gamma 2.4	REC 709 Gamma 2.4
File Type	TIFF	MP4

For the analysis proposed in this article, we used the metrics from the Image Quality Cockpit (Barricelli *et al.*, 2020), including mean luminance (L channel of CIE Lab color space), mean of R, G and B channels, and multi-resolution contrast (MRC). The mean luminance and mean RGB values represent the average intensity across the entire scene, providing a general measure of brightness and color balance. The MRC is the mean value of the average local contrast calculated on different scales of the frame, being the local contrast the difference between the L channel of one pixel and its 8 surrounding pixels.
The ΔE_{76} color difference metric (Robertson, 1977) was then used to compare variations between each result, the original negative, the positive reference, and the DoP version. This approach differs slightly from the Cockpit metric, which typically assesses quality by comparing two consecutive frames from the same video (e.g., to detect flickering). For this work, however, differences across the various restored versions are more relevant.
As each metric considers standing images, all values were calculated on a chosen single frame.
For frame analysis, scenes were separated and analyzed individually before being compared using ΔE values. For each evaluation, the negative, the positive, and the DoP version were used as references. However, it is important to note that the negative and positive films are aged and lack accurate color correction, while the DoP version differs from the various restored versions in that it underwent the complete restoration process. In contrast, the six versions analyzed here were subjected only to color restoration. In addition, the DoP version is different from the others for another important factor: the work method. While the laboratories in this experiment all worked on the negative film, using the positive copy as a reference, the DoP chose to work directly on the positive copy, considering it the closest representation of the original 1972 cinema release. Once he achieved

the desired color correction, he then applied it to the negative with minor adjustments. (Ahmedhodzic, 2022).

Results and Discussions

Scene 01

The results of the color correction of the first scene performed by the six laboratories are presented in Fig. 1 along with the negative, positive and DoP versions. This scene posed significant challenges for color correction due to its indoor filming conditions. The differences in color correction are most easily observed by examining the cushion and carpet, as well as the view of the sky through the window. The latter provides a clear illustration of the variations in color interpretation, ranging from blue to white to pinkish hues.

Based on a visual inspection of the images, Laboratory 5 achieved the closest match to the positive copy, while Laboratory 3 remained more consistent with the negative. In comparison to the DoP version, however, Laboratory 1 appears to be the closest.

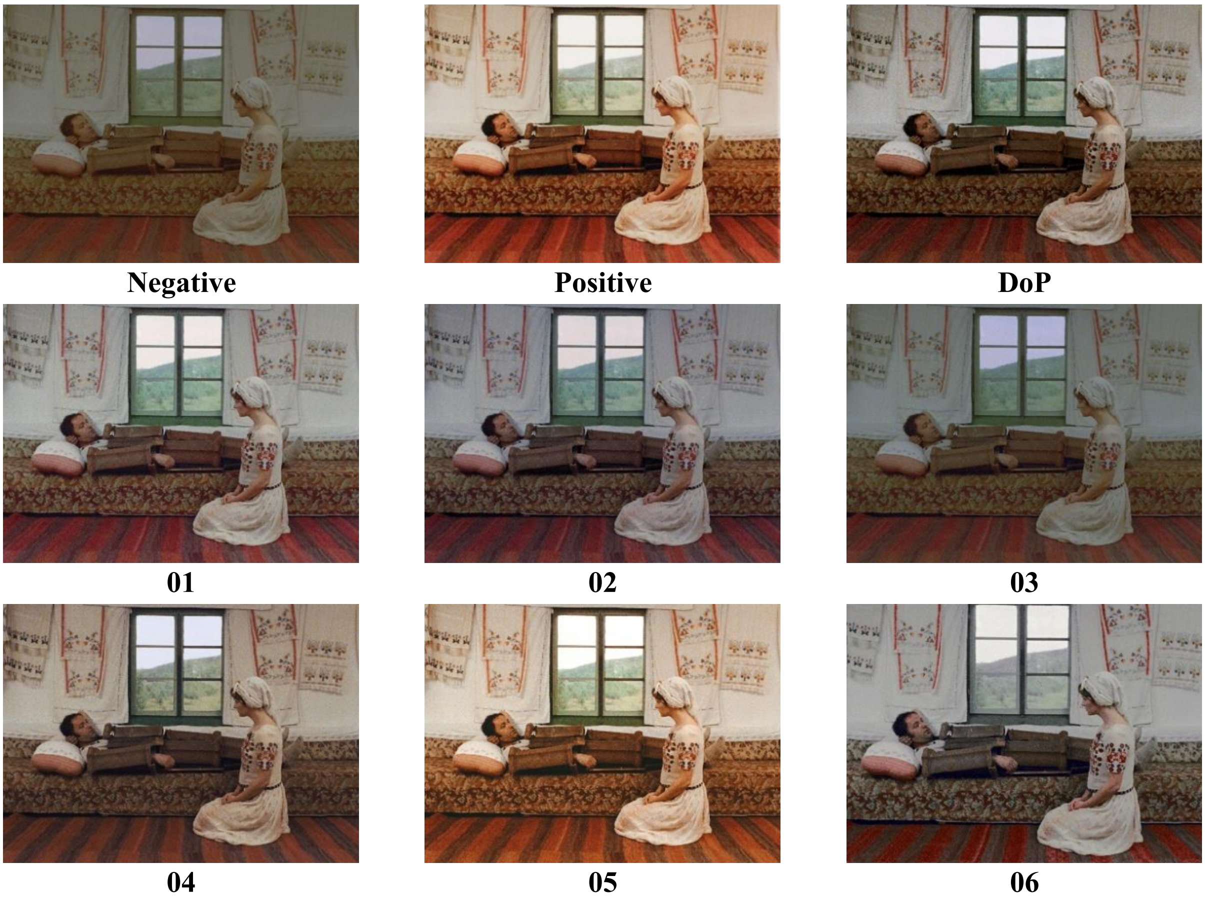


Fig. 1 – References and results of the color correction obtained from each laboratory for the first scene.

Table 2 summarizes the metrics calculated using the Image Quality Cockpit framework.

In particular, for the mean luminance, laboratories 5 and 3 exhibit the closest values respectively to the positive and negative copy, which is consistent with observations from the visual inspection.

For the RGB mean values, laboratory 5 most closely matches the positive reference in the red and green channels, while laboratory 2 aligns more closely in the blue channel. The red channel, besides showing the highest values among all channels, presents the greatest variation in mean values across all versions, probably caused by the warm tonality of the positive print and the lack of information about the original lighting conditions. Laboratory 5 presents the widest range of mean values, with the red over 160 digits and the blue just above 100 digits. As for the visual comparison, for the original negative, the closest match is achieved by Laboratory 3. It is important to note that Laboratory 3 lowered the red channel, raised the blue channel, while leaving the green channel largely unchanged. The MRC metric (Table 2) further highlights the similarity between laboratory 3 and the original negative, laboratory 4 and the DoP version, and laboratory 5 and the positive reference. Overall, this scene shows the most variability in MRC values (a range of 1.22) compared to the other two scenes, likely due to the lack of information regarding the original lighting conditions.

Tab. 2 - Results obtained from Cockpit on the first scene

ID	R	G	B	L	MRC
Positive	163.25	123.61	97.94	54.84	2.03
Negative	102.63	86.62	69.47	37.86	1.12
DoP	**117.27**	**99.23**	**86.55**	**42.84**	**2.39**
1	127.70	111.17	104.22	47.82	1.98
2	109.23	97.17	96.85	41.85	1.83
3	96.04	86.87	79.55	37.42	1.29
4	**122.63**	**102.51**	**90.26**	**44.22**	**2.12**
5	164.34	129.87	103.61	56.44	2.51
6	122.18	110.54	105.56	46.89	2.00

Scene 02

Fig. 2 shows the color correction outcomes of the second scene as performed by the six laboratories alongside the original negative, positive and DoP versions. From a visual comparison, the version of laboratory 4 has a warmer tone, while the other corrections display a similar color balance, with differences mainly in contrast and luminance. In particular, laboratory 3 appears to be the darkest, while number 5 the lightest.

Fig. 2 - References and results of the color correction obtained from each laboratory for the second scene.

For an easy comparison, one could look at the woman in red, whose colors change in every rendition, or at the standing woman, where differences are also noticeable.
When aligning each corrected version to each of the references, number 1 would be the most similar to the DoP version, number 5 to the positive and number 3 to the negative. This observation aligns closely with the visual assessment conducted on the first frame, suggesting a consistent approach in the methodologies used by these three laboratories.

The mean luminance levels (Table 3) are lower than those in the first scene but follow a similar pattern: Laboratory 5 is closest to the positive reference, while Laboratory 3 aligns most closely with the negative. In this scene, the DoP version matches almost perfectly with Laboratory 4, with a luminance difference of only 0.009 units, and is also quite similar to Laboratory 1, with a mean luminance difference of 0.15. In the mean RGB values (Table 3), a similar pattern is observed in the red and green channels, while the blue channel shows a slight variation: the negative and DoP versions are much more similar, and Laboratory 3 does not have the lowest value. Laboratory 4 is the only one with a significantly higher mean red channel value than the other channels, explaining the noticeable red cast upon visual inspection. The MRC results (Table 3) are comparable to those from the luminance analysis. Laboratory 5 is closest to the positive reference, while Laboratories 4 and 1 are closest to the DoP version. Laboratory 3, although the farthest from both the positive and DoP versions, is the closest to the negative.

Tab. 3 - Results obtained from Cockpit on the second scene

ID	R	G	B	L	MRC
Positive	98.88	97.39	100.57	39.78	3.10
Negative	58.60	69.67	80.55	28.43	1.70
DoP	**87.56**	**87.19**	**84.13**	**35.60**	**2.92**
1	**84.92**	**87.51**	**92.07**	**35.76**	**2.77**
2	73.07	71.06	73.21	29.12	2.58
3	64.18	68.72	79.14	28.28	2.06
4	**93.21**	**86.40**	**81.81**	**35.59**	**3.04**
5	97.55	95.88	100.98	39.26	3.21
6	78.92	76.86	78.34	31.68	2.67

Scene 03

Fig. 3 presents a visual comparison of the color-corrected versions of the third scene produced by the six laboratories, alongside the original negative, positive, and DoP versions. All results for this scene differ significantly from the negative input and from each other. In a visual comparison, Laboratory 2's version stands out as the most distinct, with a completely different tone. Laboratory 1 emphasized the trees with a much more saturated green than the other versions, while Laboratory 5 removed most of the green. These differences are easily noticeable in elements such as the grass, trees, house, and the workers dressed in blue.
Among the versions, Laboratory 5 is the closest visual match to the positive reference. Identifying a corresponding version for the DoP reference is more challenging: Laboratories 1 and 6 are quite similar, but the green of the grass and trees does not match exactly, and Laboratory 4 shows a slight color difference in the house.
No visual correspondence was identified for the negative reference, which displays a blue hue that has been nearly eliminated in every version. Even Laboratory 3, which closely matched the negative in the other two scenes, does not align with the negative in this scene.

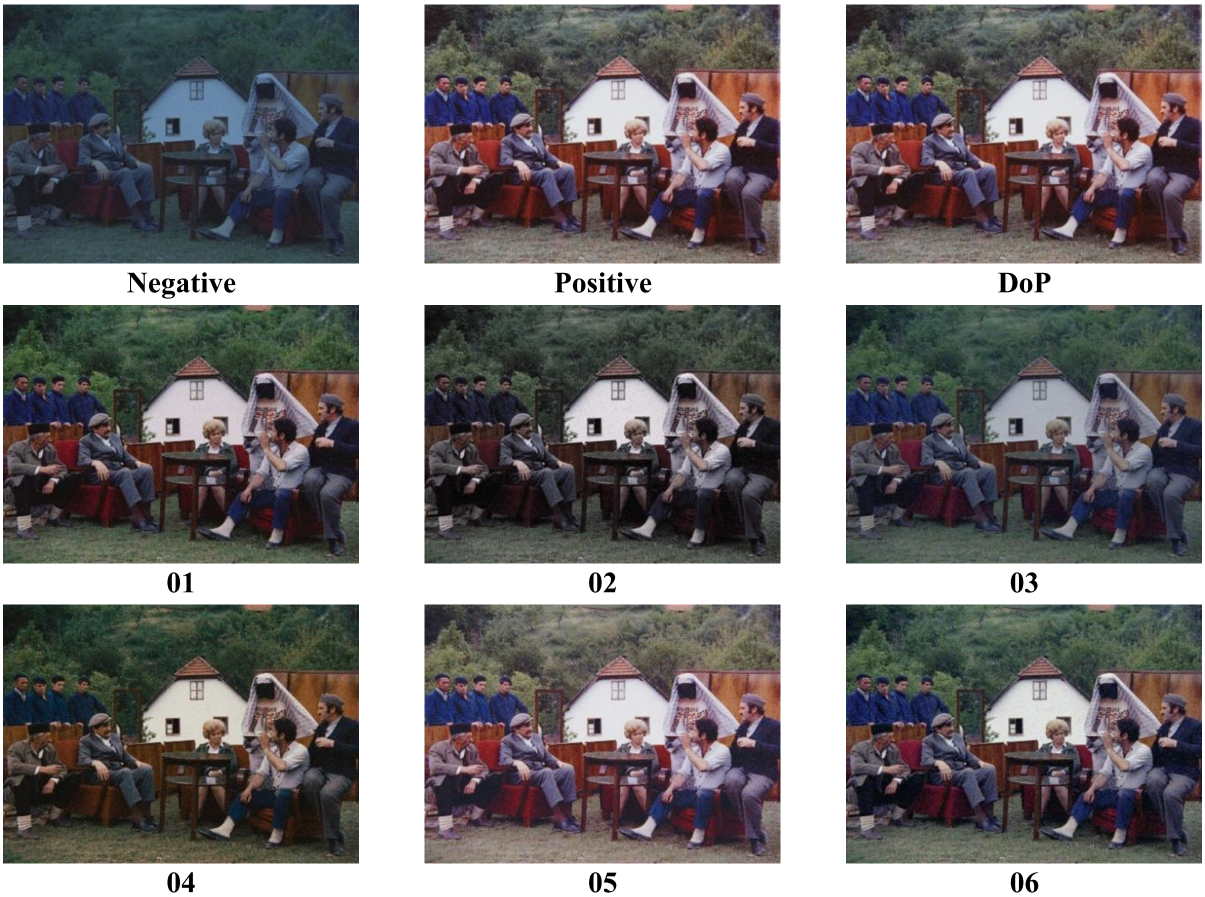


Fig. 3 - References and results of the color correction obtained from each laboratory for the third scene.

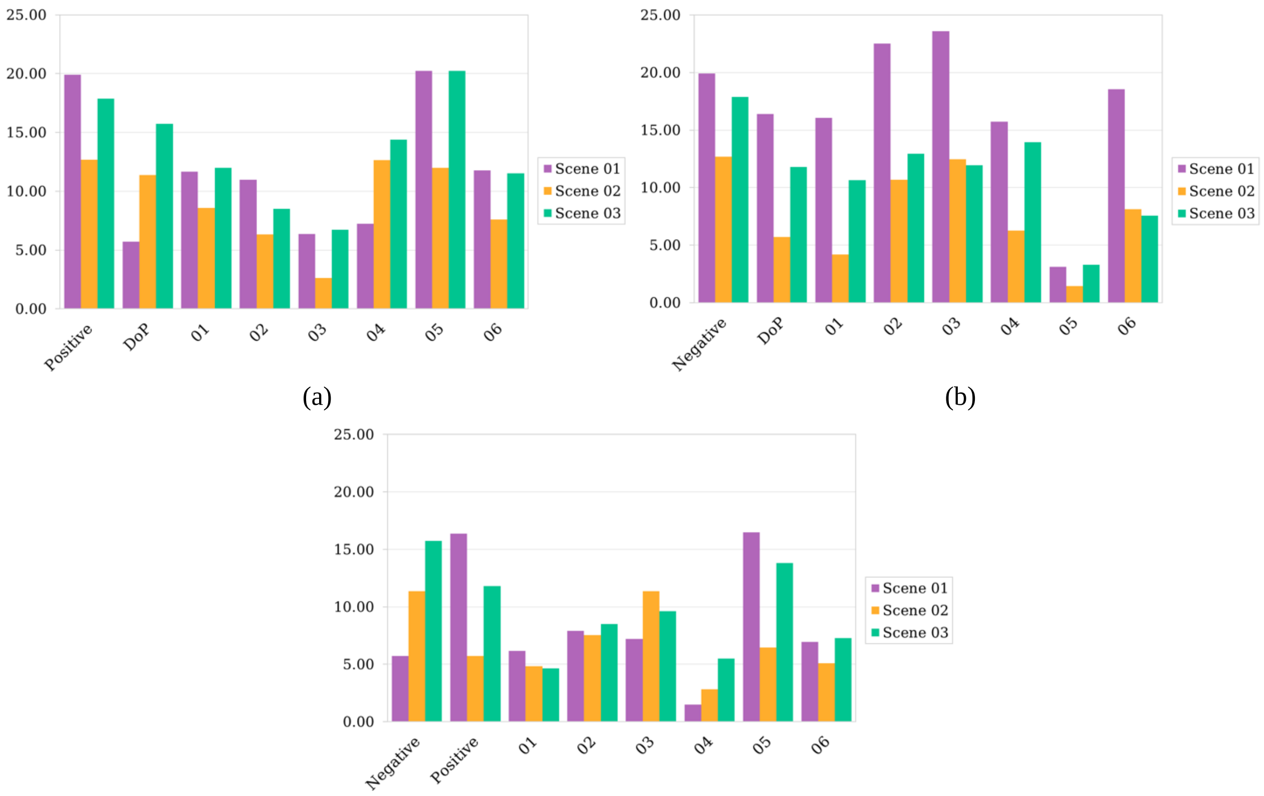
The luminance of the scene (Table 4) remains low overall. The version with values closest to the positive reference is, once again, Laboratory 5, while Laboratory 2 is closest to the negative, followed by Laboratory 4.
The MRC values (Table 4) are very low for the negative version, while all other versions have an index above 2 units, which explains the lack of a visual match with the negative. Apart from Laboratory 3, the MRC remains relatively consistent across the different versions.

Tab. 4 - Results obtained from Cockpit on the third scene

ID	R	G	B	L	MRC
Positive	105.34	89.24	91.47	39.02	2.54
Negative	50.77	62.93	74.97	25.84	1.25
DoP	**80.10**	**80.31**	**71.13**	**33.38**	**2.91**
1	**76.04**	**73.45**	**69.89**	**30.88**	**2.57**
2	69.24	67.26	67.42	27.86	2.63
3	68.30	71.96	76.82	30.11	2.03
4	71.81	67.74	58.55	28.28	2.53
5	112.92	96.62	99.38	42.21	2.81
6	82.74	81.21	82.99	34.27	2.79

The difference in color

As a final measure, we analyzed the mean color differences (ΔE) across all three scenes between the various versions with the original negative, the positive reference, and the DoP version. Fig. 4 presents these results, showing the extent to which each scene and each version aligns with or diverges from the references.



(c)

Fig. 4 – Color Difference ΔE of the various version with the original negative (a), positive copy (b) and DoP version (c)

When comparing the results with the original negative (Fig. 4a), a clear pattern emerges: the second scene generally exhibits the least change, except in the DoP version, where the first scene remains the most similar to the negative. Laboratory 5 shows ΔE values similar to the positive reference, confirming their resemblance, while Laboratory 3 consistently has the lowest ΔE values across all three scenes, indicating the closest alignment with the negative. Laboratory 4 is the only one that produced results following the same behaviour as the DoP version: the first scene remains closest to the reference, while the third shows the most deviation. This is clearly evident in the visual comparison, where the third scene appears completely different from the negative.

The color difference analysis with the positive copy (Fig. 4b) reveals a different pattern. In this case, the first scene consistently shows the highest ΔE values, except in Laboratory 5, where the ΔE for the first scene is slightly lower than for the third scene. The second scene generally has the lowest ΔE values, except in Laboratories 3 and 6, where the ΔE values are higher. Laboratory 5 here achieves the overall smallest ΔE values of 1.4 for scene 2, just above the threshold for human perception of noticeable difference. This result aligns with the visual comparison, which also highlighted the close resemblance between scene 2 and the positive copy.

The comparison with the DoP version (Fig. 4c) shows varying ΔE results: the highest ΔE values occur in the first scene for two cases (Laboratories 1 and 5), in the second scene for one case (Laboratory 3), and in the third scene for three cases (Laboratories 2, 4, and 6). The ΔE variations are inconsistent, with Laboratory 5 showing a range of 10 between its highest and lowest ΔE values, while Laboratory 2 has a range of less than 1. Laboratory 5 still exhibits the highest ΔE differences in the first and third scenes, while Laboratory 3 has the highest ΔE difference in the second scene. These inconsistencies, with no clear pattern, are likely due to the fact that the DoP version was unknown to the subjects, making it impossible for them to approximate its appearance.

Conclusions

This study explored the impact of subjectivity in the color restoration process, using a specific case study involving six color-corrected versions of a Yugoslav film from 1972, restored by different European institutions. The analysis highlighted how, even when starting from the same digitized negative, individual interpretations by restorers resulted in significantly different outcomes. Differences in luminance values, RGB channels, and multi-resolution contrast (MRC), as well as variations in ΔE with respect to the references (original negative, positive print, and DoP version), demonstrated that each laboratory adopted distinct approaches, likely influenced by subjective preferences and technical choices, proving that subjectivity plays a crucial role in the final outcome of any color restoration.

This study highlights the need for additional quantitative metrics to improve the assessment of restoration quality within the scientific community. Implementing these metrics during the restoration process would provide restorers with a deeper understanding of their impact on the original material and enable the recording of detailed data alongside each restored version. This approach would give future restorers and researchers clearer insights into the adjustments made to the original film, ensuring a transparent and traceable record of the restoration process over time. Such practices could support a more objective evaluation while respecting the artistic and historical integrity of film restoration.

Aknowledgements

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Polaroids around the 80s - an investigation of the stability of instant integral film according to storage, handling, and exhibition.

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Keywords: Polaroid, instant film, integral film, artificially ageing, micro fading, stability.

Introduction

This project investigated the stability of color integral instant film from Polaroid in the years 1978-1986. The project was carried out as a part of a master thesis during 2020-2021 at The Royal Danish Academy – Conservation, supervised by associate professor Morten Ryhl-Svendsen.

Polaroid as an instant film was invented in 1947 by Edward Land for Polaroid Corporation. An instant film is a photo unit containing both the negative, the positive, and the chemicals used to develop the image right after the exposure. Polaroid was for many years the sole manufacturer of instant films, and its name became synonymous with instant photography and is still used as a synonym in daily speech.

When Polaroid came up with their first commercial instant color film, the peel-apart film Polaroid Polacolor, in 1963 it was said "This process is, without doubt, the most outstanding advance to be made during this century in photography, and must be considered one of the major steps in the advance of photographic science" (Haist, 1979, p. 403) because it was changing the way that it, until then, has been possible to make traditional photographs. Suddenly it was possible to take a picture and have the developed photograph as a finished positive image within minutes, delivered in a ready-to-use product. It was a breakthrough to the common photography at that time and it gained ground both among the amateur photographers and artists for an artistical expression or as a part of the documentary of artistical performances or happenings and as documentary photography, like snapshots, staff photos, etc. Instant photographs are present in both cultural heritage- and fine art museums, private collections, and historical archives.

This project was narrowed down to instant integral film from Polaroid and focused specifically on the type of films called SX-70, Time-Zero and 600 film produced in the years 1978-1987 despite some of the other types of film probably are structured in a similar way. The film is structured with a transparent polyester layer in the front and a black opaque layer on the back side. In between those two layers there are between 13-17 layers consisting of negative layers, dye layers, and other functional layers. This sandwich is held together with an airtight foil on all four sides. The development of the image in an integral film is an internal dye diffusion process which is carried out when the film is ejected through the built-in rollers in the camera and the chemicals from the chemical pod are disposed to the layers of the film (Pénichon, 2013, p. 254).

Figure 7 Front and back side of test material from Lot 2. On the left side one can see the square image area framed by the classic white foil around the edge. On the right side one can see the black polyester above the production code and the chemical pod.

The first integral film, SX-70, from Polaroid was launched in 1973 and after at least one undisclosed improvement in 1976 the SX-70, in 1980, was replaced with the SX-70 Time-Zero Color film, which was altered to a much faster development time. One of the differences between the original SX-70 film from 1973 and the Time- Zero film from 1980 is the placement of the polymeric acid layer and the timing layer. In the original film the two layers were placed right under the clear polyester layer and in the Time-Zero film, the same two layers are located below the negative layers and above the black polyester back material. In all Time-Zero films and all later integral films from Polaroid, there is an antireflection layer coated on the clear polyester layer through which the image is viewed. The Time-Zero film also has a thinner image receiving layer and a new clearing layer right under the image receiving layer. The clearing layer decolorizes the opacifying dyes immediately adjacent to the image-receiving layer without decolorizing the opacifying dyes within the pigmented reagent layer (*Fig. 2*) (Sturge, Walworth and Shepp, 1989).

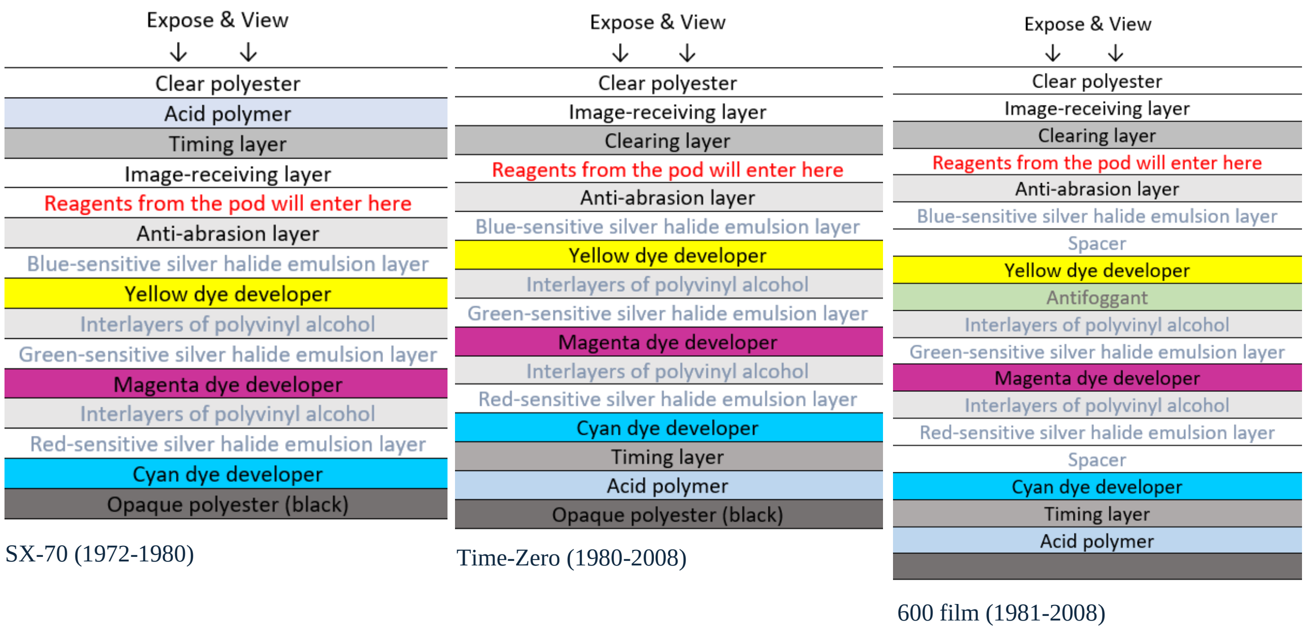


Figure 8 The layer structure in SX-70, Time-Zero, and 600 Film (Pénichon, 2013, p. 259).

In 1981 the Polaroid launched its 600 films. They had the exact same format as SX-70 film but were ISO 640. Both the original SX-70 and SX-70 Time-Zero were rated as ISO 150. Besides the high-speed emulsion, the 600 Film design includes new pigmented spacer layer behind the blue-sensitive and red-sensitive emulsion layers and an antifoggant layer underneath the yellow dye developer. The dye developers in the 600 Film are the same as in the Time-Zero film (Sturge et al., 1989, p. 204-206).

The main objective of this study was to investigate the long-time stability of various Polaroid integral films from the late 1970s and 1980s. Some questions that led to this project included whether all integral films from Polaroid were constructed in the same way over the years, or if there were significant differences, and whether this impacts their stability. Additionally, does the trapped chemical components, along with unstable dye compounds, lead to image fading and material degradation.

Another consideration was how museums and collections handle instant film from a preservation point of view. Integral photographs are unique, possessing a special expression that cannot be replicated through digitalization, so the prints should be handled, stored, and displayed with care. Generally, there is a limited amount only of literature and research available on this topic.

Test material

The test material in the project was based on historic, already exposed color integral images which partly defined the time span of the project's focus, as it was depending on accessible material.
The test material consists of three different Lots; Lot 1 and 2 were bought from two different sellers on eBay (from USA and UK) and Lot 3 was donated from a private person in Denmark. These undocumented proveniences make it impossible to know how the photographs were stored over time and when exactly they were exposed.

The images on the test material were all different from each other. Some of them were light and different colors, others were dark and more simple colors. Some were exposed indoors and others outside in daylight.

Using various guidelines (Polaroid References, 1998; Willox, 2019; Anon, S.A.), it was possible to read the batch code on the backside of the units and sort the lots into production years. From that, the film and production code were identified, and it was possible to select the test material according to year of production and film type.

The amount of uniform test material was very limited and consisted of one to three polaroids for each experiment *(Table 1)*.

Table 1 Overview of the three different Lots, production codes, year, film type, and quantities of samples for each experiment.

	Productions code	Year	Prototype Code	Possible film type	Quantity of samples
Lot 1	02**5**43018002	1985	?	Time-Zero ell. 600	3
Lot 2	07057**8**14161 17127**9**13102	1978/ 1979	?	SX-70	2
Lot 3	08**4**470210<u>16</u>	1984	-	Time-Zero ell. 600	2
	12**6**430570<u>54</u>	1986	2	Time-Zero	1
	06**7**430540<u>56</u>	1987	2	Time-zero	1

Experimental work

Batches of samples were exposed to artificial aging, under light or dark conditions, respectively, and at varying relative humidities. Some samples of each lot were left unaged for comparison (reference materials). The light fading should quantify the light sensitivity of the material, and indicate if there were differences between the lots, film types, and production year. Light fading was carried out both by exposing entire photos in a light chamber, and by testing the light fastness of selected areas of photos by the micro fading technique. Dark Fading would indicate the material's dark storage stability, at three different levels of relative humidity (ISO 18909:2006(E)).

Light fading was conducted in a light chamber by exposure to about 100,000 lux with a light spectrum mimicking daylight through window glass: a normal indoor exhibition condition in many lesser-controlled environments (Atlas Weather-O-Meter 3000+ with Xenon Arc lamp) (Atlas Material Testing Solution, 2014). An integral film from Lot 1 were partially covered with aluminum foil which was moved every second day over eight days to be able to stepwise follow the color change over the first week. A Blue Wool (BW) standard card was included in the test in order to categorize the obtained light dosages.

Dark fading was conducted over six weeks, at 75°C, and at 30%, 50%, and 69% RH. Relative humidity was controlled by saturated salt solutions, with the three salts and test sample lots enclosed in individual desiccator jars placed inside the oven. Salt solutions were magnesium chloride, sodium bromide, and sodium chloride. Conditions were monitored inside each jar by Tinytag dataloggers.

The changes in the test material were tested four times during the experimental periods, by measuring the color change of test material measured every seventh day for the light fading experiment and every seventh or fourteenth day for the dark fading experiment (CIELAB color space by Konica Minolta Spectrophotometer CM-2600d).

The Micro fading tester was a manually operated "0/45 contactless" based upon the original design of Paul Whitmore and the used software program was Spec32. The data are presented with values for ΔE, L*, a*, and *b. Both from every single of the 10 measurements and in total. The Micro-fader had been calibrated with Blue wool standards 1-4. Materials with a lightfastness higher than Blue wool 4 were considered as light-stable.
The micro fading was conducted on test material that has not been part of the light and dark fading experiments. An integral film from each of the three lots was selected based on image containing colors the closest possible to pure cyan (C), magenta (M), yellow (Y) and black, where black is a mixture of C, M and Y. These colors were measured individually, three times on each color, on each test material. A BW standard was measured too and the results from the integral film were related to the position of the nearest BW wedge or as an interval between two.

To analyze the impact of artificial fading the samples underwent visual observation, observation under microscope magnification, cross section, color measurements, and FT-IR were conducted.

In addition to the laboratory tests, a short survey was conducted among institutions which hold color instant images in their collections. However, in this presentation the focus will be on the micro fading, the two artificial aging experiments and the following visual observations, observation under microscope magnification and color measurements.

Results and discussion

By visual observations it was clear that the strongest changes happened on the frontside during dark fading at the highest humidity. Here the image partially turned yellow and there were also changes in the color of the foil – primarily at the top of the photographs. There might have been some discoloration happening during the light fading too, however, at the same time it might have faded away due to large light dosage.

Primarily the chemical pods on the backside of the Polaroids were affected by aging, but the un-aged reference material showed that there were already some differences in the color of the chemical pods before the tests were carried out. The color of the pods was getting darker after the dark fading experiment. This might be due to changes in the material or the remaining chemicals.

When observing the test material under magnification (8X to 35X) a clear pattern was revealed in the sign of deterioration. Six out of nine film from the light fading experiment had some chemical formations like snowflake formations (*Fig 3A, 3C*). It occurred always in the upper half of the image and was never visible where the image was protected from light by covering with foil. For Lot 2, seven out of eight images had obtained one or more cracks in the emulsion (*Fig 3B*).

Two of the test materials from the light fading experiment and five from the dark fading experiment at 75% have clear dots that look like dye clusters. The dots were the same color as the surrounding areas and they were either placed close together or more from each other, but never a mix between those two patterns (*Fig 3C*).

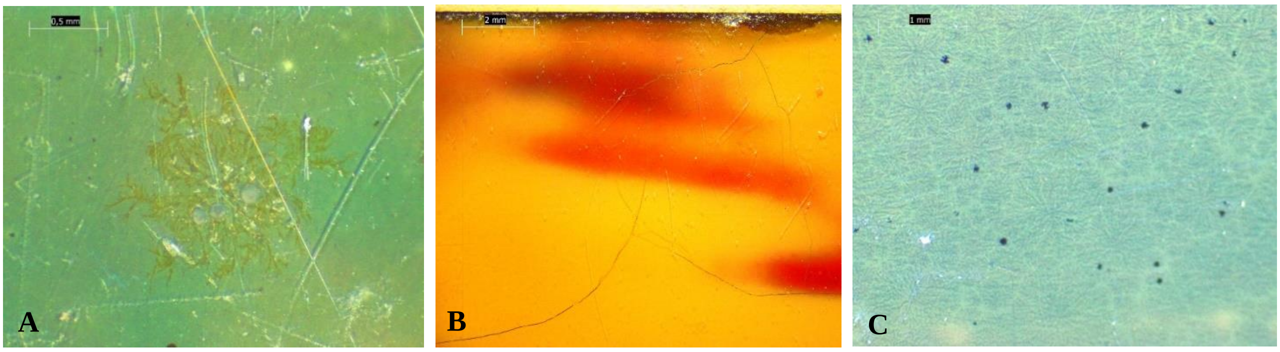


Figure 9 Examples of the signs of degradation under microscope after artificial ageing. A: Snowflake formations. B: Cracks in the emulsion. C: Dye clusters and some kind of snowflake formations.
Fotos: Sille Juline Høgly Petersen.

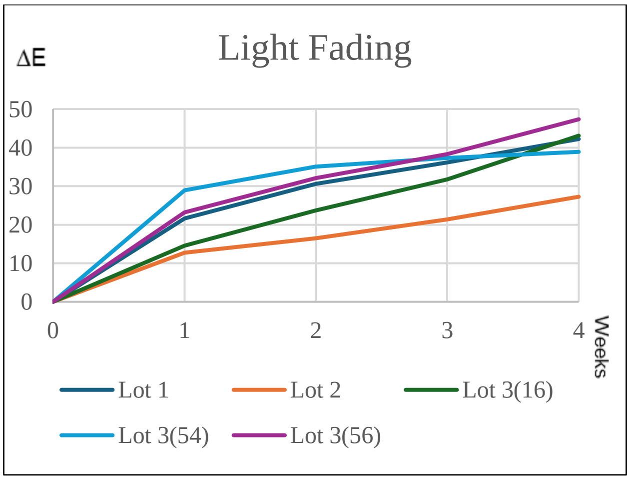
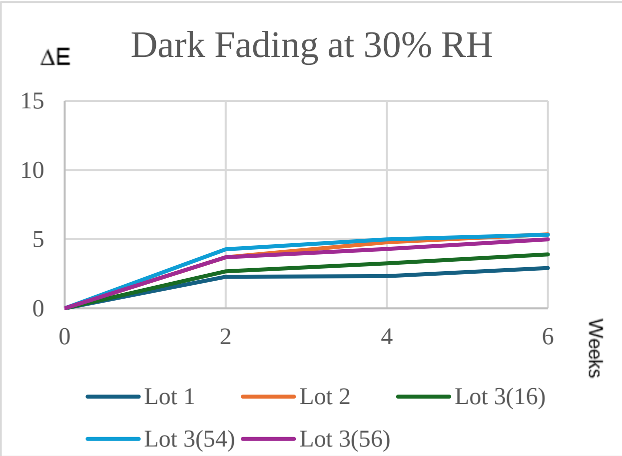
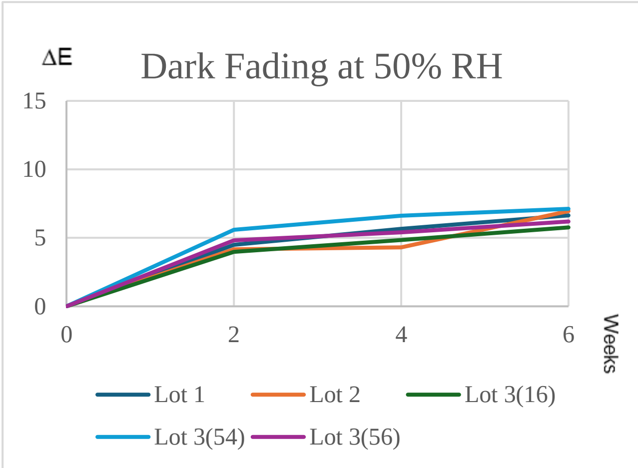


Figure 4 The color change expressed as delta E, as measured before, during, and after the light fading

The color changes in the test material from the light fading were measured before the experiment and then once a week for four weeks. The test material from the dark fading was also measured before the experiment and then every second week for six weeks. By comparing the color measurements, it could be observed that, in general Lot 3(54) from 1987 was more affected than the others during dark fading and during the first two weeks of light fading. Furthermore, it seemed that the degradation rate slowed down after respectively one and two weeks of aging in light and dark (*Fig. 4 and 5*). *Fig. 6* and *7* gives an impression of the fading the first eight days in light and darker areas in the same photography. The light area (the skyes) fades faster than the dark area (the road), and the degradation of the dyes in the light area also starts to slow during the first eight days.





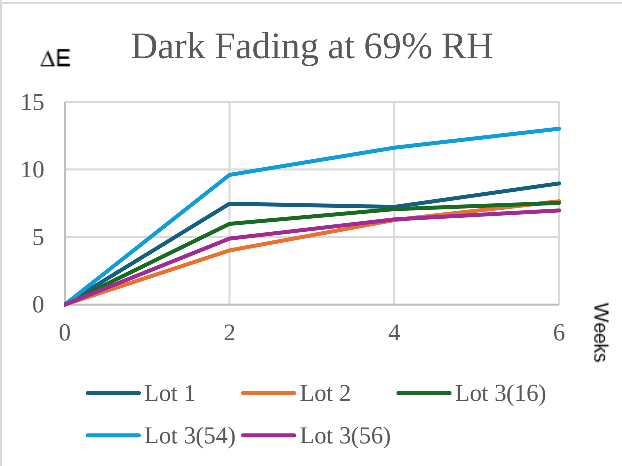


Figure 5 The color change expressed as delta E, as measured before, during, and after dark fading experiments at 30%, 50% and 69% RH.

Figure 6 The fading over the first eight days. The test material is from Lot1.
Photo: Morten Ryhl-Svendsen.

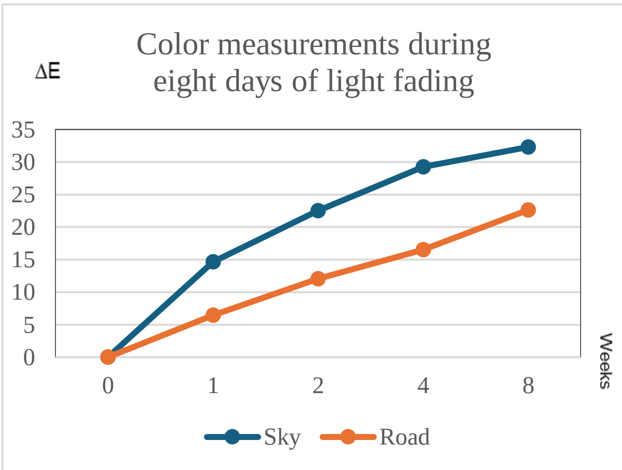


Figure 7 Color change (delta E) of the test material while light fading over eight days. The test material was measured in the area of the motif with the light sky and the darker area with the road.

The results from micro fading showed that light-sensitivity of cyan-colored areas in the different lots varied between BW 1 to 3. Polaroids from Lot 2 (1978/79) seemed to be the most light-stable, while Polaroids from Lot 3 (1987) were less stable (*Table 2*). When comparing the micro-fading results to the average color change observed at the end of the light-aging experiment, an overall agreement in the predicted lightfastness was observed.

Table 2 The light sensitivity for each color is expressed in levels of the Blue Wool standard.

Lot no.	*Specific test material*	*Cyan*	*Magenta*	*Yellow*	*Black*
Lot 1	1.8	BW2	BW2	BW3	BW2
Lot 2	2.2	BW2-3	BW3-4	BW2-3	BW2-3
Lot 3(16)	3.2	BW1-2	BW2	BW3	BW1-2
Lot 3(54)	3.15	BW2	BW2	BW2	BW(1-)2
Lot 3(56)	3.16	BW2	BW2(-3)	BW2(-3)	BW1-2

Wrapping up the results it was found that the SX-70 from 1978/79 (Lot 2) was the film type with the best light stability, but also the only one that tends to crack in the emulsion. The cracks occur in seven of eight test films. Dye clusters occur in two (Lot 2 and 3(56)) of nine films from Light Fading and in five out of nine films (Lot 1, Lot 3(16), and Lot 3(54)) from dark fading at 69% RH. At least one test film from each lot had visible yellowing in the image after dark fading at 69% RH. The chemical pods on the backside of all lots beside Lot 2 turn darker during dark fading especially at 69% RH. Lot 3(54) has the highest color changes (*Fig. 4*) after dark fading experiment, where the others lots do not fade in same order across the experimental conditions. The results from micro fading indicate that the light sensitivity depends on the color present in the motive, but also that there might have been changes in the dyes over the years.

Conclusions

In conclusion, this study of Polaroid color integral instant films from 1978 to 1986 provided insights into the stability and deterioration of these materials over time. Polaroid integral color film is a well-designed composite photographic object and even though there have been improvements over the years, the main idea about a fast and simple product has been intact and has shown its worth. However, it is a complex material where small improvements constantly influence the way it fades, deteriorates, and reacts to the surrounding climate. Despite a limited amount of test material and a several unknown factors especially in the history of the material, some interesting tendences were revealed.

There was a difference in the construction of the three film types SX-70, Time-zero and 600-film, and it seems that there are three important changes: Around 1976 the original integral film, SX-70, became improved with better functional layers. In 1980 there was the big shift from the SX-70 film to the new Time-Zero film, during which important layers including their location were optimized.

The visual signs of deterioration occurring under the light- and dark-fading experiments were observable fading, yellowing, cracks, deformation, and de-attached foil around the edges. On a microscope level the signs of deterioration were formation of colored dots, unknown visual formations, air pockets, and smaller cracks. After comparing the micro-fading test to the color change results from the artificial aging tests it was concluded that the light stability predicted by the micro-fading test is reliable and comparable to the conducted light-aging test, and is an useful tool for establishing safe exhibition conditions with regard to light dosage.

Although there are differences from film to film, and film-type to film-type, general attention with regard to preservation of the instant integral color films is needed. More knowledge about integral films, their deterioration patterns, and response to environmental impact (especially light and high relative humidity) is needed according to make the best possible circumstances for the conservators and collection managers to take care of instant integral color films in their collections.

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Tan Lip Seng's montaged colour transparency slides: A case study in unpacking intentionality and 'the decisive moment' in image-making, preservation and conservation

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Abstract

This project integrates research from curatorial and conservation disciplines in examining the concepts, materials and techniques of the Singaporean photographer Tan Lip Seng in his montaged colour transparency slides. The aim is to deepen knowledge on the development of photography innovations in 1960s to 80s Singapore and to strengthen the preservation of his works, which currently reside in the collection of the National Museum of Singapore and National Gallery of Singapore.

Tan (b.1942-) was renowned globally for his consummate skills in the colour derivation photomontage technique, which involved developing various films in the darkroom, retouching and then overlaying them to achieve a manipulation of colour and aesthetic effects. He often emphasized the importance of capturing "the decisive moment', a concept influenced by French documentary photographer Henri Cartier Bresson.

The paper first contextualises Tan's creations based on his professional career as well as his involvement in camera clubs and photo salons. It analyses how Tan has interpreted and pushed the boundaries of 'the decisive moment' in his works, and contributed to articulating a new pictorial language in Singapore's modern photography history after the Second World War. The investigation into his material and technique showed how these montaged colour transparency slides realised his artistic vision, while providing insights into their current condition and types of degradation, with the aim of formulating a strategy to address the conservation challenges. Artist interviews, literature research and scientific analysis using ATR-FTIR, SEM and EDS constituted the primary methods of investigation at the present phase of characterising the works and their condition.

Keywords: Montage slides, Kodachrome reversal film, Diazotype, Kodalith film, Artist interview

Introduction

The photographic oeuvre of Singaporean photographer Tan Lip Seng offers rich grounds of research and discovery on the conceptual and technical innovations in salon colour photography in the latter half of 20th century Singapore. Of special interest to this study is Tan's montaged colour transparency slides produced from the 1960s to 80s which garnered immense local and global recognition for their mastery and virtuosity. [2] Integral to Tan's photographic approach was the principle of 'the decisive moment', propounded by Henri Cartier-Bresson whom he was greatly inspired by.

This study combined curatorial and conservation lines of enquiry to establish key artistic intentions and practices in Tan's creative process. Such insights are instrumental in building up the knowledge of Singapore's art history and to inform decision making in the long-term preservation of his works in the national collection.

The curatorial perspective highlights how Tan applied the concept of 'the decisive moment' in his photographic processes, with a focus on Tan's methodologies from the planning of the shot, the setting up of the scene, and finally to his post-production workflows that developed into his unique personal style. Tan's culturally significant contributions to a unique photographic language would also be contextualised against the prevailing visual and graphic styles of Singapoure during the 1960s to 1980s.

Efforts from conservation and conservation science investigate Tan's engagements with materiality. Not only do his one-of-a-kind colour slides retain the tangible marks of the artist's hand and encapsulate his thought processes, they illuminate artistic practice prior to the advent of digital cameras and editing softwares. Object examination and scientific analysis with ATR-FTIR, SEM and EDS were carried out to assess and characterise the various films Tan used in his montaged works. These findings will be used to inform and formulate preservation and display strategies in the next phase of the project.

The research has been approached through literature research, documented artist interviews, visual examination and analysis of slides within the National Collection and slides donated by the photographer. These methods helped to build on past knowledge by integrating new tacit and technical knowledge of Tan's artistic practices in photography in the 1960 to 1980s. The artist interviews also illuminated aspects of Tan's works which are important and which will help establish the acceptable parameters to conserve, display and/ or reproduce the works in future.

Tan Lip Seng's artistic background and practice

The medical field, camera club and the photo salon as sites of creative encounters

Tan's photographic practice in the 1960s to 1980s developed in tandem with his profession as a medical photographer in the University of Singapore's Departments of Clinical Medicine and Pediatrics, a job he held till retirement in 2006, as well as his active involvement in one of Singapore's most established camera clubs, the Photographic Society of Singapore (PSS).

Both contexts proved to be immensely advantageous to the development of his creative oeuvre, especially in terms of experimentations in photo montaging. On one hand, Tan had the opportunity to encounter the Kodalith ortho film and diazotype film in the course of his professional work for the creation of titles, charts, diagrams and visual aids for 35-mm projection slide presentations, developing familiarity and proficiency in harnessing the material's unique properties. On the other hand, PSS was an essential incubator where Tan had benefited immensely from the generous exchange of knowledge and ideas from senior photographers such as Wu Peng Seng and Lee Lim [4]. The Society's active involvement in local and international photo salons, a vibrant platform in the circulation and exchange of photographic creations across the world and in establishing benchmarks of excellence, offered great opportunities for Tan to distinguish himself [5][6].

Contribution to a distinctive photographic language

Besides enabling the transnational flows of ideas, PSS and other camera clubs of its day were also vital in creating spaces for image makers to reflect on, engage with, and re-imagine the unfurling of modern life in 1950s to 1980s Singapore. The sweeping changes in landscapes and social norms brought about by economic restructuring and urban planning were great sources of visual inspiration for numerous photographers like Tan. Collectively, their photographic creations contributed to articulating the rise of pictorial photography in 1950s to 80s Singapore, which sought to establish the medium as an art form. Drawing references from local expressions and subject matters, the movement was pluralistic and democratic in its approach without privileging a singular style but instead encompassing a myriad of aesthetic outcomes premised on beauty (Toh, 2023). It was within this context that Tan's colour montaging slides contributed to the broadening of a distinctive visual and graphic language for photography.

Figure 1. "Under Construction" (1970) by Tan Lip Seng. Collection of National Gallery Singapore. Image courtesy of National Heritage Board, Singapore. The depiction of construction work was a recurring subject matter among

Singaporean photographers who sought to document a landscape in flux during the 1950s-80s.

The trajectory of Tan's development in colour derivation montaging was also connected to his strong affinity with the Photographic Society of America (PSA). His exposure to colour slide montaging in the 1967 PSA journal and encountering similar works from America when serving as a jury in photo salons, encouraged him to switch from a more ordinary, straight-forward approach to a more visually abstracted and technically sophisticated style (Lim, 1972, Poh, 2022) [8]. Tan's presentation on his photo montaging techniques in the 60th PSA International Conference in 1998 also established his authority in the field on a global scale.

Given that photographs and photographic techniques like retouching, cropping and montaging were increasingly integrated into graphic design in the mid-20th century, it is also essential to consider Tan's photographic innovations in light of the graphic arts. The flattened, high-contrast graphic styles of Tan's images were also adopted by other designers to retain the photographic narrativity of events captured while heightening its visual impact. This fluidity between photography and the graphic arts was a consequence of a rising demand for advertising, branding and packaging as Singapore's economy pivoted from import substitution to export orientation. Vocational arts institutes which introduced graphic design as a formal field of study in the mid-1960s also included photography training for their students, bringing both disciplines closer. (Zhuang, 2012).

Tan's application of Cartier-Bresson's "the Decisive Moment" in his colour slide montages

While documenting Singapore's nation building from the 1950s to 1980s, photographers like Tan found deep resonance in French photographer Cartier-Bresson's approach towards documentary realism based on humanism and candidness. Cartier-Bresson, one of the founders of Magnum Photos agency, has been widely regarded as a pioneering figure in modern photojournalism and street photography. In particular, his principle of the 'decisive moment', which he defined as "…the simultaneous recognition, in a fraction of a second, of the significance of an event as well as of a precise organization of forms which give that event its proper expression" (Bresson, 2014) inspired and influenced Tan, who continues to tag contemporary images shared on his website with the 'decisive moment' label.

Both Tan and Cartier-Bresson embraced the importance of composition, in how the photographer's eye is constantly calibrating perspectives and lines of vision. The latter had also alluded to spontaneity and reflexivity, with composition "having its own inevitability" when photographers tap on their gut feel to stall, track progress of a subject, and wait for the missing element of the picture to present itself in the opportune moment.

This concept of timing and perspective can be seen in Tan's 'The Only Girl in White' (Fig. 2), which depicted a performer turning to speak to another at the Singapore Youth Festival opening ceremony. Shot from an elevated angle, the crowd creates diagonals leading to the main subject, who was also positioned along the axis of the rules of the thirds.

Figure 2. "The Only Girl in White" (1978) by Tan Lip Seng features the joint use of precise timing and colour contrast to heighten the climatic moment captured. Collection of the National Museum of Singapore, National Heritage Board.

This was demonstrated as well in 'A Strange Face' (Fig. 3), which captured the brief seconds of a boy bending to pass an item to his mother during Muslim prayers during Hari Raya Puasa. The rows of devotees portrayed by Tan's camera, positioned slightly at a slightly lower angle, create leading lines for the eye that converged onto the main subject matter.

Figure 3. In "A Strange Face" (1980), Tan Lip Seng anticipated and captured the unfolding of the moment when the boy bent down to interact with his mother. He also made use of colour derivation montaging to alter the colours of the devotees' headscarves to create visual contrast. Collection of the National Museum of Singapore, National Heritage Board.

Tan had however gone a further step to utilise colour montaging to strengthen visual focus in his composition. By modifying the head scarfs of the devotees in "A Strange Face" from white to cyan, he made use of complementary colours as an interplay with the yellow in the boy's attire. Similarly, he had also altered the colours of the performers' costumes from white to magenta in "The Only Girl in White", enabling the main subject to stand out visually. In addition to working on these intricate manipulations under a magnifier, the precision required in exposure and composition of the original photos added another layer of sophistication given how colour slide photography had little room for modifications in post-processing.

Secondly, both Tan and Cartier-Bresson shared an emphasis on the interrelation of colours in a two-dimensional planar space. Both were cognisant of colour as a perceptual phenomenon, and how their interplay created depth, rhythm and movement. Moreover Tan had also honed an uncanny sense for the interaction amongst colours, often modulating the variance of warm, cool, complementary tones and hues to great effect to convey emotions. Through montaging, he had overcome restrictions imposed by physical reality before the camera, and attained a freedom of expression through controlling the application and appearance of colour.

However, a key difference between how the two photographers approached capturing "the decisive moment" lay in their contrasting perceptions of the role and function of photography. Cartier-Bresson viewed photographic images as an indexical record of reality and was inclined more towards using the camera as a tool for recording reality. In contrast, Tan's photographic intentions were oriented more towards unlocking the medium's creative potential. He favoured images laden with symbolisms and external referents, staged scenes at times to overcome limitations in subject matters, and developed darkroom manipulations to heighten photographic moments. This was also evident in most of his image titles which were descriptive and at times abstract in nature.

The making of Tan's montaged colour slides — Materials and methods

Types of films used

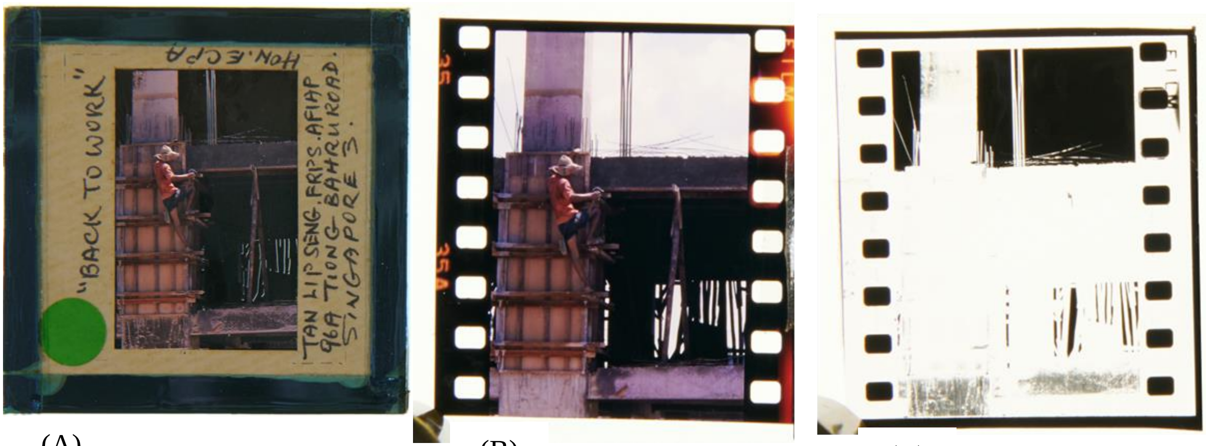
Tan used four types of films to make his montaged slides. They are the Kodachrome reversal film which gives a colour positive image, the Kodalith ortho film 6556 (Type 3) which gives a black and white negative image, the Kodak fine-grain positive film which gives a black and white negative image and the Technifax diazotype film ('K' series) which gives a one-colour positive image. These four films are used in three combinations: Kodachrome reversal film with Kodalith film, Kodachrome reversal film with fine grain positive film and Kodachrome reversal film with diazotype film. Thus, the Kodachrome film is the staple with which Tan montaged one of the other three graphic arts films with to create the final image.

In terms of film processing, the Kodachrome reversal film had to be sent to the lab due to its complicated processing chemistry. On the other hand, Tan was able to process the graphic arts films independently in the darkroom. This independence over the processing, together with the montage techniques enabled him to exercise a certain degree of control over the artistic process to create the striking and vibrant images of the 'decisive moment' he was known for in the 1960s and 1970s.

To gain insights into Tan's artistic practice and the characteristics of the films, slides donated by the artist for research were dis-assembled and studied. The findings from an example each from two montage combinations, firstly the Kodachrome reversal film with Kodalith film and secondly the Kodachrome reversal film with diazotype film, is highlighted here. As the Kodachrome is already better understood within the field, emphasis is given to the graphic arts films in this article. The intent is to use the information, together with findings from the condition assessment, to formulate the most appropriate treatment and display measures.

Montage- Kodachrome with Kodalith

"Back to work" (Fig. 4A) is a montaged slide composed of one Kodachrome film and one Kodalith film. Fig. 4B and 4C showed both films respectively after the slide is dis-assembled and photo-documented in transmitted light. The Kodachrome slide is a chromogenic process and comprised of a positive image in cyan, magenta and yellow (CMY) colours captured using the camera and processed using the K14 chemistry. The Kodalith image is a negative black and white silver image made by contact-printing with the original Kodachrome transparency and then processed typical of films with the silver halide chemistry.



(A) (B) (C)

Figure 4. Photographs of: (A) "Back to work" (1960s-70s); montaged colour transparency slide by Tan Lip Seng (Heritage Conservation Centre collection); (B, C) "Back to work" with Kodachrome and Kodalith films disassembled respectively.

Further manipulations by the artist included using the Kodak Farmer's reducer to reduce or eliminate some of the black image areas on the Kodalith film. So, given the instance of "Back to work", the white silhouette of the man as shown on the Kodachrome image on Fig. 4B would have produced a corresponding black silhouette of the man on the Kodalith image on Fig. 4C. Clearly, Tan has removed it with Farmer's reducer to ensure that the figure of the man stood out in striking contrast in the final montage image.

In addition, irregular black paint was observed on almost all the black Kodalith images in Tan's works. During the artist interview, Tan explained that it is common that holes as tiny as 'pinholes' developed in the film after processing. To ensure that the image will still appear as black in those areas in transmitted light, he used the Kodak opaque black ink to touch up the holes (See Fig 5).

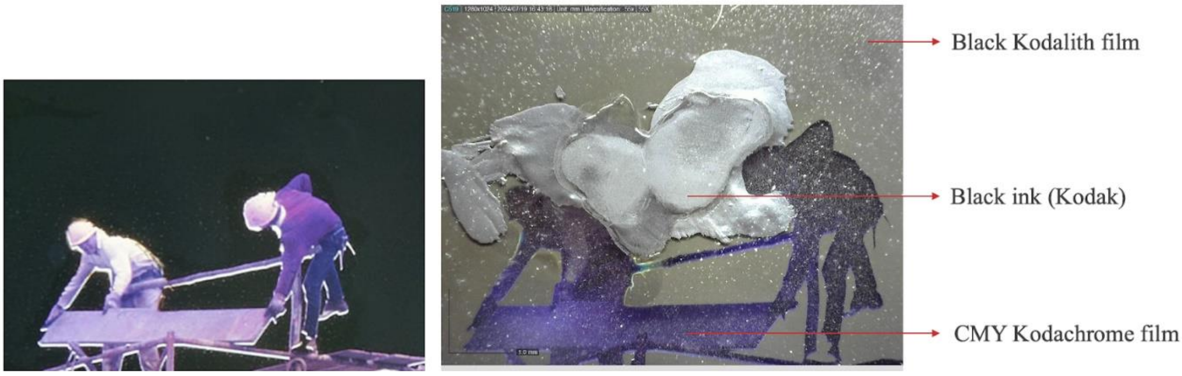


Figure 5. Detail of "Under Construction" (1970) by Tan Lip Seng, Collection of National Gallery Singapore, Image courtesy of National Heritage Board, Singapore; Detail of image in transmitted light (left) and the same detail (55X) taken with the Dino-Lite under raking light. Note the Kodak black ink (photo-documented as white blobs due to angle of light) which was hand-applied by the artist to cover the holes so that the image area appears as black in transmitted light.

In an article published in the Photographic Society of Singapore (PSS) journal in 1989, an unnamed photographer indicated that the holes were influenced by exposure. *"An under-exposed lith film tends to have many pinholes. Over exposure, no doubt, reduces the number of pinholes but it is more difficult to remove the [black image] areas which you have to get rid of [with farmer's reducer]"* (PSS Journal, 1989). The issue of how the holes came about will be a separate investigation not further covered in this article.

Tan also commonly used a montage technique termed as the "Bas relief" effect. The effect, created by montaging two films slightly out of registration, caused certain elements of the image to stand out. In "One Fine Day (Fort Canning)" where the Kodachrome and the Kodalith films were montaged, the tree silhouette and foliage in the image was dramatically enhanced visually by this technique (See Fig. 6).

Figure 6. View of "One Fine Day (in Fort Canning)" (1968) by Tan Lip Seng in transmitted light. Collection of the National Museum of Singapore, National Heritage Board. Note the dramatised white silhouettes of tree and foliage created by the bas-relief effect.

Montage- Kodachrome with Diazotype

Tan also montaged the diazotype film [6] with the Kodachrome film to great effect. Diazotype images are created based on the photosensitivity of diazonium cat-ions and the synthesis of azo dyes in the presence of an alkaline agent. Diazotype films were sold in a great variety of colours on acetate films and they were available in two density series from the Technifax Corporation: the "K" series which gives maximum density or the "P" series which gives pastel colours. The 1967 Photographic Society of America journal recommended their members to get the "K" series and to experiment with development times to get different colour saturation.

One of Tan's donated works, "Blessing candles", a montaged slide composing of one Kodachrome film and one blue diazotype film is dis-assembled for study (Fig. 7). To make the diazo image, Tan would first make a Kodalith film with a negative image of the Kodachrome image according to the process previously described. Subsequently, the Kodalith image film was in turn used to make a contact positive with the diazotype film. Upon completion, both films were mounted together to create the final image.

(A) (B) (C)

Figure 7. Photographs of: (A) "Blessing candles" (1960s-70s); montaged colour transparency slide by Tan Lip Seng (Heritage Conservation Centre collection); (B, C) "Blessing candles" with Kodachrome and Diazotype films disassembled respectively.

Under magnification, the diazo dyes have diffused edges which might be caused by the development process (Fig. 8). In developing the diazotype, Tan hung the film in a transparent jar with a few ml of liquid ammonia at the bottom. The film is removed when a satisfactory point of colour saturation is attained. The developing time required usually depends on the concentration of ammonia and the capacity of the jar used. Typically, it took him 10-15 minutes.
In an article published by the US patent office about the development process for diazotypes, "diazo diffusion" can occur in the relatively slower development process of using "aqua- ammonia". This might explain the diffuse appearance of the diazotype media here and could be a characteristic for identification.

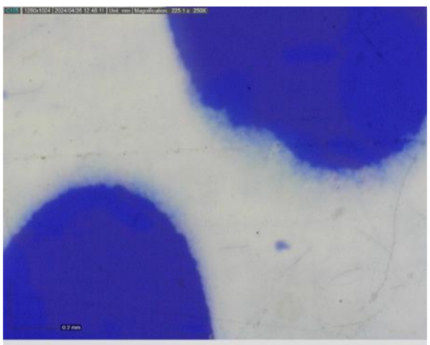


Figure 8. "Blessing candles" blue diazotype- View of detail (225X) in transmitted light. Artist- Tan Lip Seng, Heritage conservation centre collection. Note the diffused edges caused probably by the development process.

Analysis of the films

Results

Three film types, namely the fine-grain positive (Fig. 11C), Kodalith (Fig. 4C) and diazotype (Fig. 7C) are analysed. Fig. 9 shows the FTIR spectra and digital micrographs of cross-sections obtained from these three types.

The cross-section of fine-grain positive shows a top coating with black image-forming media and horizontal cracks in the substrate (Fig. 9B). No distinct coating is observed at the bottom. FTIR spectroscopy of the top coating (Blue, Fig. 9A) identifies gelatine (i.e. protein), as evident from successive amide I-III peaks at 1630 cm-1, 1565 cm-1 and 1460 cm-1, whilst the bottom side (Red; Fig. 9A) shows the presence of triphenyl phosphate (TPP) with characteristic peaks as follows: C=C stretching (1587 cm-1 and 1464 cm-1), P=O stretching (1286 cm-1), C-H plane deformations (1183 cm-1 and 1159 cm-1), and P-O stretching (1007 cm-1 and 959 cm-1).

TPP is a known plasticiser used in the production of photography films. We have noticed that over time, TPP also exudes on the protein coating, confirming that TPP molecules migrate outwards in both directions to the surface. Other than TPP peaks, ATR-FTIR spectroscopy performed on bottom side (non-image, clear areas) shows a strong, broad peak at 1019 cm-1, along with peaks at 1739, 1629 cm-1 (data not shown), which matches well to a cellulose film (Rumi et al 2024). Considering that loss of acetate is possible from the heavily cracked polymer, the polymeric film is originally likely a deacetylated cellulose acetate (Junlong Song 2012).
Kodalith and diazotype samples both show a thick substrate sandwiched between two uniformly thin coatings (Figs. 9D and 9F). To analyse the center substrate, the film surface is lightly scratched prior to ATR-FTIR analysis. FTIR spectrum of Kodalith centre shows cellulose acetate (green; Fig. 9C), as evidenced by the carbonyl stretching (1737 cm−1), the methyl bending (1366 cm−1) and the ether groups stretching of (1032 cm−1). This substrate is coated with gelatine at both sides of the film (blue and red; Fig. 9C). For diazotype, FTIR analysis detects cellulose acetate throughout the layers (Fig. 9E). Cellulose acetate in both Kodalith and diazotype is plasticised with TPP, as evidenced by the small TPP marked peaks (green; Fig. 9C and Fig. 9E). Unlike fine-grain positive, migration of TPP plasticiser to the surface is not significant for Kodalith and diazotype films, probably because of the presence of coatings on both sides.
The EDS mapping of SEM images obtained for cross-sections of film samples (Fig. 10) is performed to investigate the distribution of phosphorus (P) that could possibly originate from TPP plasticiser and silver (Ag), the photoactive compound respectively. Note that the fine-grain positive sample (Fig. 10A) shows cracks along the cross-section that are consistent with the observation from the image obtained with a digital microscope (Fig. 9B).

Phosphorus (P) is distributed across the substrate and coatings in all three samples (blue mapping, Fig. 10), confirming the presence of TPP plasticiser. Silver (Ag), associated with image-forming, is detected in the fine-grain positive and Kodalith samples (red mapping, Figs. 10A and B), but absent in the diazotype sample (Fig. 10C). Note that the distribution of silver (Ag) corresponds to the image media in the top coating and its concentration is much lower in the fine-grain positive media compared to the Kodalith media. SEM-EDS also detected iron (Fe) along with silver (Ag) in the black media of the fine-grain positive (data not shown). The nature of iron and its exact purpose is uncertain at this point.

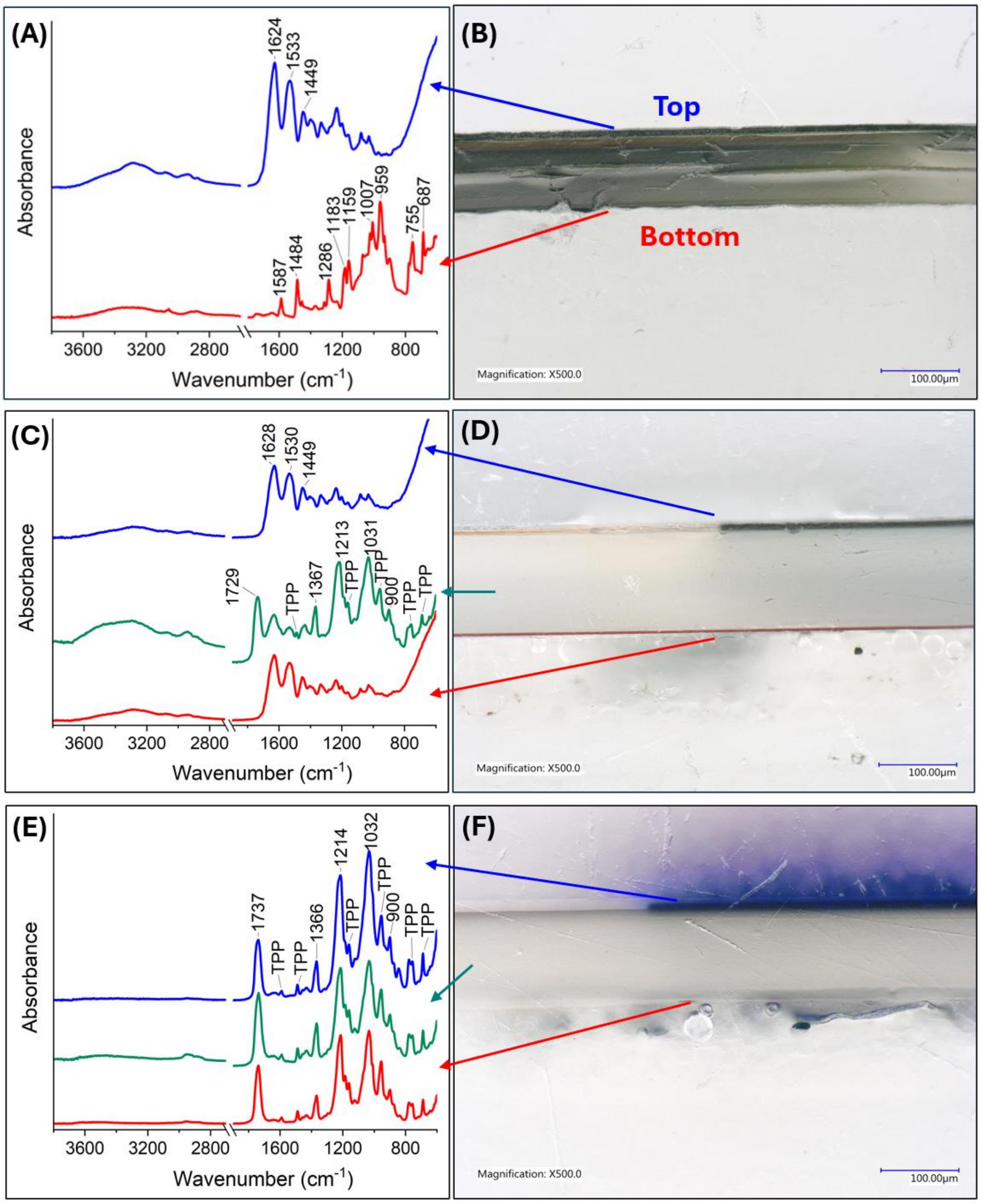
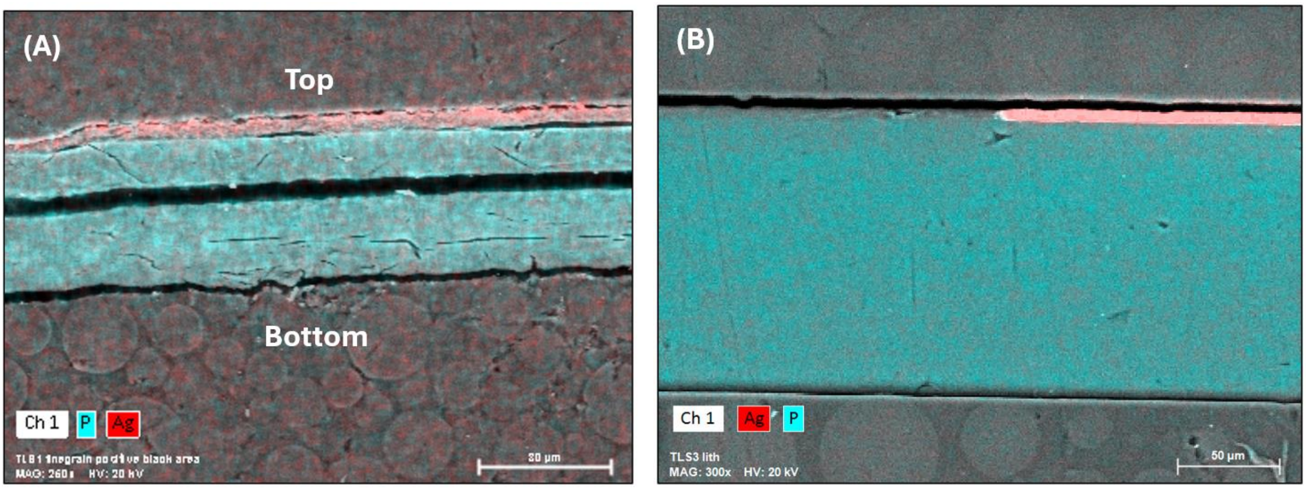


Figure 9. Photographic colour slides analysed by ATR-FTIR spectroscopy (left) and digital microscopy imaging of cross-sections: (A, B) FIne-grain positive (TLS1); (C, D) Kodalith (TLS3); and (E, F) Diazotype (TLS4). The arrows ("Top" blue, "Centre" green and "Bottom" red) indicate location of analysis with ATR-FTIR. The assignments "Top" and "Bottom" indicate the image and non-image side of the films respectively.



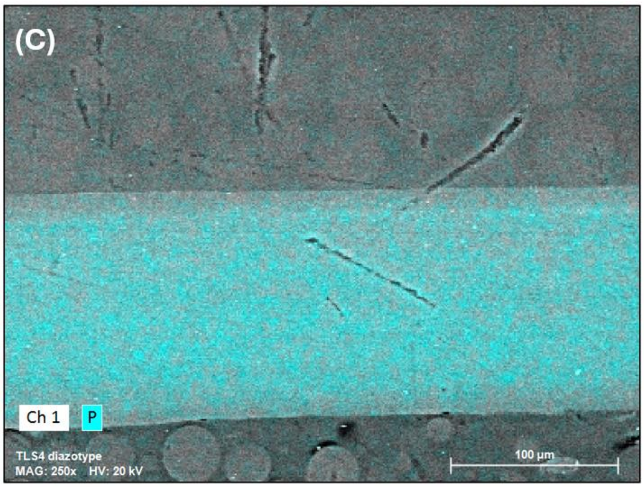


Figure 10. Film cross-section analysis by SEM and EDS mapping for Silver (Ag) in "red" and Phosphorus (P) in "blue": (A) Fine-grain positive (TLS1); (B) Kodalith (TLS3); and (C) Diazotype (TLS4). The assignments "Top" and "Bottom" indicate the image and non-image side of the films respectively.

Methodology: Film cross-sections preparation and analysis

A fragment sample (about the size of 3 x 2 mm) is cut from each film type (TLS1 Kodak fine-grain positive (Fine-grain positive), TLS3 Kodalith Ortho and TLS4 Diazotype (Diazotype) and embedded in Clarocit acrylic resin. The cured resin is grinded and polished to reveal the cross-section of the sample. The grinding and polishing are performed dry, using micromesh of successive grit sizes 2400, 3600, 4000, 6000 to 8000, until the desired cross-section is achieved. A Keyence VHX-6000 digital microscope coupled to a VH-ZST dual objective zoom lens is used. Optical images of cross-sections are acquired at 500x magnification using high brightness LED lamp in reflected, full ring mode. A Bruker Alpha II Fourier Transform Infrared (FTIR) spectrometer coupled to attenuated total reflectance (ATR) sampling module with diamond crystal is used for recording IR spectra of both sides of investigated films (image-side; Top, and non-image-side; Bottom). The FTIR spectrum is obtained using 32 scans and 4 cm-1 resolution, over a range of 4000 to 600 cm-1 for both background and sample. The film sample is clamped to the crystal with a 3-ply paper to avoid causing indentation on the sample. Hitachi SU5000 scanning electron microscope (SEM) with a Bruker energy dispersive X-ray spectroscopy (EDS) detector is used to measure the distribution of phosphorus (P) and silver (Ag) over the film cross-sections fixed in resin for 3 to 17 min. Partial vacuum is set at low pressure of 50 - 60 Pa. SEM-EDS analysis is performed at 20 kV voltage and about 10 mm working distance for optimal throughput. Prepared cross-section samples are mounted on carbon tapes prior analysis. Bruker's Esprit 2.0 software is used to perform elemental mapping over the area of interest.

Condition assessment findings

In all the montaged slide works, the films are adhered together and then to the slide mount with pressure-sensitive tape. This package is then sandwiched between two cover glasses and sealed with black paper or foil with an unknown adhesive. (Fig. 11)

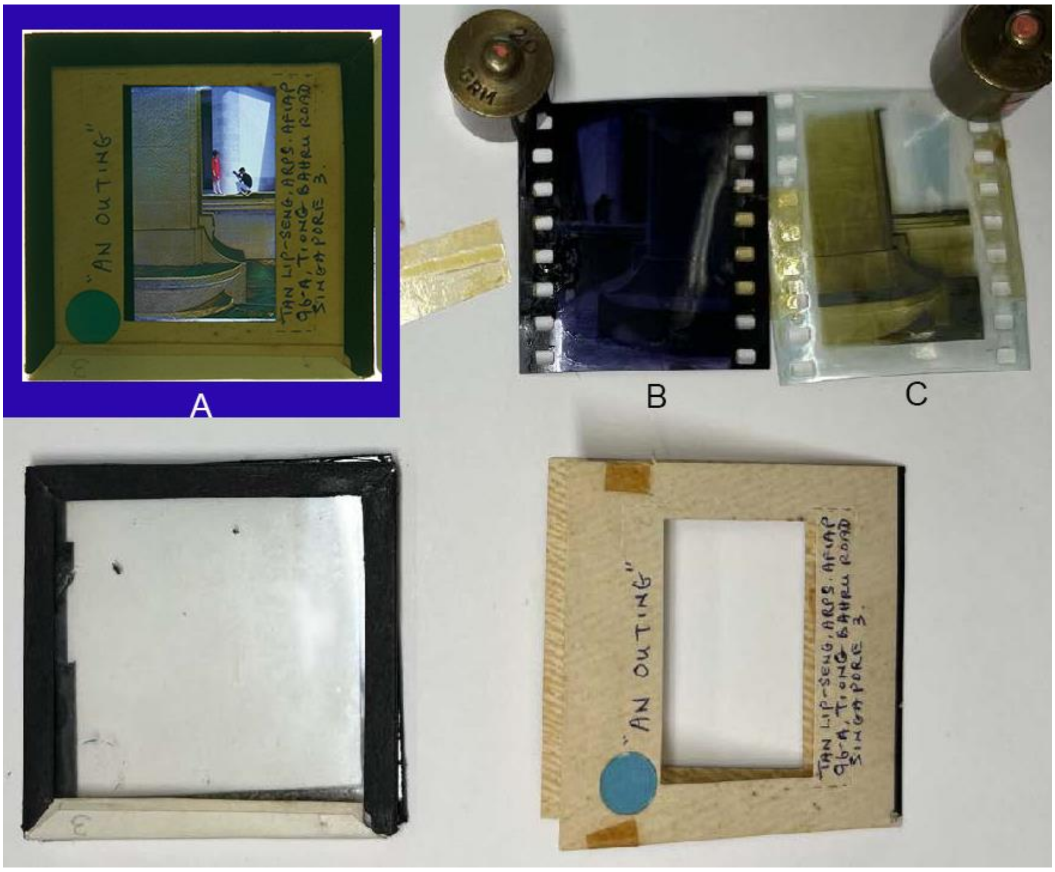


Figure 11. "An Outing" (1960-70s) dis-assembled. This montaged slide (A) consists of the Kodachrome image film (B) with a fine- grain positive image film (C). Artist- Tan Lip Seng, Heritage Conservation Centre collection. Note how the slide is assembled by the artist with the montaged films, cardboard mount, pressure-sensitive tape and cover glasses.

For the survey of the thirteen slides in the national collection, the slides were not taken apart for examination and documentation. Instead, they were studied using a stereo microscope and a Dino-Lite microscope in different lighting conditions. In summary, the findings showed that seven out of thirteen montaged slides have mould. In addition, glass deterioration is observed on twelve out of thirteen slides.

Additional findings from the condition assessment of the study slides, produced in the same period, indicated that there might be similar conditions in the collection slides. The observed conditions are issues of pressure-sensitive tape on the films and the possibility of acetate film deterioration, observed through the detection of triphenyl phosphate by ATR-FTIR on the surface of the film [8], the retrieval of the blue dyes in the anti-halation layer [7] (Fig. 10) and the AD-test results. The yellow deterioration on the image area of the fine-grain positive film (Fig. 11C) is of unknown cause and would merit further investigation, especially if the same condition is found on the slides in the national collection.

In addition, since the slides have not been stored in cold storage either before or after it came into the museum collection, there might have been some dye fading over these 40 to 50 years as well.

Conclusion

Through masterful use of timing and intuition that reflected an expanded understanding of conveying "the decisive moment" in photography, Tan had opened a chapter in Singapore's photography history with his montaged colour transparency slides. As seen in his striking image compositions, he captured opportune photographic moments and further enhanced the impact of his compositions through an emotive and perceptual use of colours that at times radically flattened pictorial space, via an array of films. This study had surfaced new possible themes and narratives in presenting Tan's work in future exhibitions. It also laid the groundwork for further studies into the practices of other significant Singaporean photographers active in photo salons in the 1960s to 1980s who created montaged colour photography slides to examine influences that Tan might have exerted or drawn on for his practice.

Research has shed light on Tan's artistic practice, in particular the characteristics of the films he used and his material and technique in altering and montaging the films to create the final image. For instance, information on the montage technique such as the 'Bas-relief' effect reveals the intentionality of the films being put together a certain way which has important implications for future treatments. Material analysis elucidated the compositions of the three understudied films. Firstly, the fine-grain positive film consists of a deacetylated cellulose acetate film support with a gelatine coating containing silver and iron image particles. Also, FTIR showed that the triphenyl phosphate plasticiser has migrated to the surface. Next, the Kodalith film is composed of a highly concentrated silver media in a gelatin coating on a plasticised cellulose acetate substrate, with a gelatine coating on the underside of the film. The Diazotype is composed of dyes in a plasticised cellulose acetate coating on a cellulose acetate substrate, with a plasticised cellulose acetate coating on the underside of film.

In summary, both the survey findings and analysis revealed the current condition of the slides, as well as the risks and challenges involved in preserving these works for the future. Conservation plans are being formulated to look into these areas: Digitalisation of the slide images, treatment of mould, glass deterioration and tape issues, re-assembly and housing of the montaged slides and investigation of the light and dark sensitivity of the diazotype film.

Notes

[1] The National Collection refers to a public collection of over 250,000 heritage objects and artworks across eight national museums and heritage institutions in Singapore, and is governed by the National Heritage Board which lays out the board's statutory duties in relation to acquisition, safeguarding and disposal.
As of 2024, there are 13 colour montage slides of Tan's in Singapore's National Collection, 6 of which have been classified as high value.
[2] Off to an early head start, Tan developed a talent for photography since the age of 12 and at 19, joined PSS in 1959 as one of its youngest members where he honed his skills through weekly Sunday photo shoots.
[3] A typical format of a photo salon involves images being submitted according to categories ranging from travel to portraiture and would be assessed by a panel of judges. Winners of each category are awarded medals or certificates and have their works exhibited. In addition, photo society members can also choose to apply for distinctions which are offered in tiers, according to a portfolio of works submitted. Upon assessment, if they are successful, they would receive titles that are internationally recognized within the photo salon circuit, with the highest rank typically being that of fellowship.

[4] In 1970, Tan became the Fellow of the Royal Photographic Society (FRPS), making history as being the first to attain the title based on his colour transparencies.
[5] One key resource Tan encountered was published within the 1967 Photographic Society of America Journal. It examined the increasing repurposing of graphic arts materials and techniques like Diazochrome film among colour slide photographers. See Macleod, C. & Kinnear, C. (1967). Diazochrome Derivations. Photographic Society of America Journal, 33 (10), 25-26.
[6] According to a journal written by Joe Coffman, President of the Technifax Corporation, the diazotype process originated from Germany and the Netherlands in the 1920s and 30s, and were frequently called "whiteprints" or "diazo prints". They were used widely in graphic arts and for making professional and educational presentations in the 1970s and 80s, due to its low cost, speed and simplicity.
[7] The retrieval of the blue colour dye in the anti-halation layer is triggered by the release of acetic acid in the degradation of acetate film. (www.filmcare.org)
[8] Triphenyl phosphate and Phthalate are two common plasticizers used in the manufacture of acetate film bases. Their exudation can occur on both the base and emulsion sides of the film and is associated with advanced stages of acetate decay. (www.filmcare.org)

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Limitations and Potentials of Hyperspectral Imaging Technique Applied to Cinematographic and Photographic Film Materials

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Abstract

This research explores the possibility of applying transmittance imaging spectroscopy to analyze cinematographic and photographic film materials to assess its potential and limitations. Reflectance or transmittance hyperspectral imaging (HSI) is an advanced technique that enables the capture of hundreds of images in contiguous narrow spectral bands, usually in the visible and the near-infrared regions. In the cultural heritage domain, the HSI data can be used to analyze the materials and their distributions on a work of art.

The processing of HSI-data is usually based on multivariate techniques, and it is strongly dependent on the analysed type of target. When analyzing cinematographic and photographic films, the final goal is the identification of the spectra of three main constituent spectra of the chromogenic film's dyes (Cyan, Magenta, and Yellow) starting from the HSI data. However blending of dyes absorptions makes it a challenging task.

In this work, we have tested the hyperspectral system on different cinematographic and photographic film negatives. Results and outcomes have been evaluated in order to assess the applicability of hyperspectral imaging techniques to film materials and to evaluate the most appropriate multivariate technique to identify film dyes.

Keywords: hyperspectral imaging; photography; cinema; motion picture film; film dyes.

Introduction

Hyperspectral Imaging (HSI) is an advanced imaging technique that exploits a wide range of wavelengths of the electromagnetic spectrum across visible and infrared regions. HSI records the complete spectrum for every pixel of an imaged area, allowing for materials identification and mapping. This makes HSI a powerful tool for identifying and distinguishing different materials based on their spectral signatures. Today HSI is well-established in various fields, including remote sensing, medical imaging, industrial quality control, etc.. In the last decade, its use in cultural heritage conservation has increasingly gained attention, particularly for the analysis and preservation of different types of historical artifacts such as paintings, manuscripts, and, more recently, photographs (Picollo, et al., 2020), (Cucci, et al., 2016). In photography, HSI allows for non-invasive examination of materials, helping conservators detect pigments, dyes, and chemical compositions used in photographs, as well as degradation patterns. For example, in a pilot study on historical photographic negatives, HSI has proven to be promising for revealing subtle differences in emulsions and layers, aiding in the accurate restoration of these delicate materials (Cucci, et al., 2023).

Despite its potentialities, applying HSI to photographic materials presents several challenges. Photographic negatives and prints, especially those produced before the advent of modern techniques, have complex compositions and are often sensitive to light exposure and environmental conditions (Gschwind, et al., 2017). Chromogenic film materials spectra are smooth and poorly structured in the investigated range, thus posing a particular challenge for hyperspectral imaging (HSI) analysis. These films are composed of three primary colors—cyan, magenta, and yellow—making it difficult to differentiate between the layers. Furthermore, due to a lack of reference databases the spectral properties of early photographic materials are often unknown, and, as they degrade over time, their spectral responses can change, making it difficult to distinguish between original features and those

altered by degradation. In the literature, there are only a few research papers (Gschwind, et al., 2017), (Trumpy & Flueckiger, 2018) (Cucci, et al., 2023) that specifically focus on the application of HSI to photographic analysis, and unlike other fields, applied research on these materials is still at the beginning. Furthermore, many HSI instruments do not offer the necessary spatial resolution to effectively analyze small-gauge films like 35mm, 16mm, or 8mm.
In this work, we compare different strategies applied to decompose the transmittance data and to match and validate the results.

Materials and Methods

Hyperspectral Imaging System

For this study, an adapted version of the HSI scanner developed by IFAC–CNR laboratories was used (Cucci, et al., 2013) (Cucci, et al., 2023). The scanner was equipped with an Opto-Engineering TC23024 telecentric lens and a Prism-Grating transmission spectrograph (Specim InSpectorIM) connected to a Hamamatsu digital camera (CCA ORCA–ERG). A mechanical component controlled the film movement, and a 150W tungsten–quartz halogen lamp illuminated a diffusing screen in contact with the film materials. The system operated within the 400–900 nm spectral range, with a spectral resolution of 1.2 nm, and a spatial resolution of 37 microns, equivalent to 27 points per millimeter or 700 PPI.

Cinematographic and Photographic Material

The study involved three samples, including:

1. A transmissive IT 8.7/1 Type 3 (35mm) for use with films such as Astia 100F, Velvia 100/100F, Provia 400X, and Sensia100, with spectral data available in the 380–780 nm range at 3 nm intervals (coloraid.de, 2023).
2. An ARRI AQUA test leader printed on Kodak Color Digital Intermediate Film 2254 (negative) using ARRILASER technology (Eastman Kodak Company, 2022).
3. Two strips of Kodak Vision 3 500T.

Sample name	#Acquisitions	HSI-cube dimension (width x height x bands)	#Frames
IT8 Target	1	897 x 672 x 399	1
ARRI AQUA	4	6351 x 672 x 399	12 x 4
Kodak Vision 3	1	6163 x 672 x 399	6

Table 3 Dimensionality of the acquisition sample. For each sample, we report the number of HSI acquisitions made per film, the dimensions of the data cube, and the number of frames in each acquired film sequence.

Hyperspectral Data Analysis

HSI data analysis is typically based on multivariate methods such as Principal Component Analysis (PCA) and spectral unmixing. These techniques were used even in the present study with the final aim of separating the single contributions of chromogenic films from the HSI transmittance data, which blend the absorption of cyan, magenta, and yellow dyes. Chromogenic films are optically homogeneous, so their absorbance can be modeled as a linear system in which the total absorbance results from the sum of the individual dye layers' absorbances (Otha, 1973), (Gschwind, et al., 2017). This work applied the N-FINDR algorithm for spectral unmixing. This method extracts endmember spectra by iteratively constructing a simplex of pixel spectra, identifying those that maximize simplex volume (Winter, 1999). Dimensionality reduction using PCA preceded this step.

Validation

For validation, on the IT8 Target, spectral matching was performed using its reference provided by the producer. This allowed for a comparison between the extracted eigenvalues representing cyan, magenta, and yellow dyes, and the manufacturer-provided reference spectra for the most saturated patches on the IT8 target.

For the ARRI AQUA test leader, point-wise transmittance spectral measurements have been performed on uniform Cyan, Magenta and Yellow frames. This process was used to validate the accuracy of the spectral unmixing.

Results

Transmissive IT8 Target

The PCA was applied to the hyperspectral data cube, extracting three main principal components (PC). The retained variance was 73.68%, 15.33%, and 6.12% for PC.

The PCs identified distinct regions corresponding to the cyan, magenta, and yellow dyes present in the IT8 target. Spectral unmixing with the N-FINDR method extracted 10 endmembers, of which three were manually selected due to their high abundance in the target's cyan, magenta, and yellow patches. Spectral matching confirmed the accuracy of these results by comparing the extracted spectra with manufacturer-provided reference data.

ARRI AQUA Film

The acquisition of the 35mm ARRI AQUA test leader (negative film) has been divided into four scannings. Three acquisitions of 12 frames (672×6351 pixels) and one acquisition of 10 frames (672 × 5184 pixels). Some specific frames have been cropped to elaborate the data cubes (around 4 GB

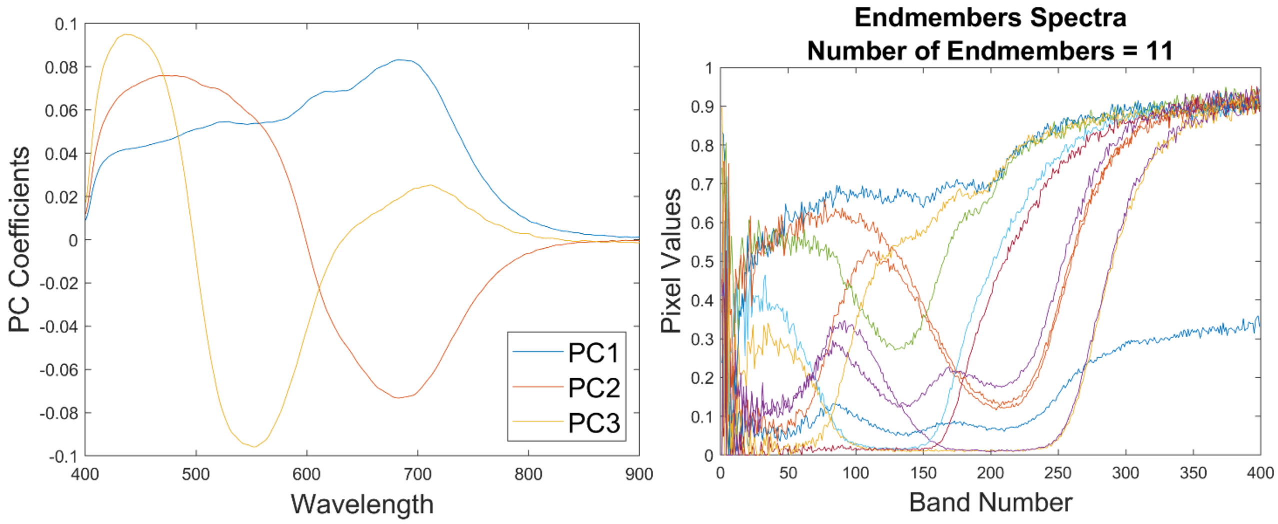

Fig – 10 On the left, the display of PC coefficients. On the right, the endmembers of the hyperspectral data.

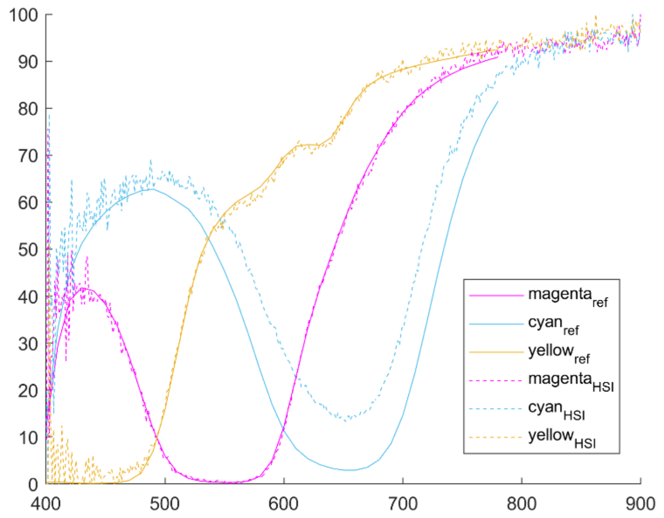

Fig –2 Comparison among the spectra of the eivenvalues 6, 9 and 10 and the reference spectra of the manufacturer..

each). More specifically, two single frames (Frame 3 - LAD and Frame 4 - CC) and a group of three frames (Frames 27, 28 and 29 - CMY) have been analyzed.
PCA extracted three principal components for each frame. Endmember extraction using N-FINDR resulted in five and eight endmembers for different frame groups.
Spectral matching with pointwise spectrophotometer data confirmed the presence of cyan, magenta, and yellow dyes in specific frames, although separation between pigments was less distinct in some cases due to high dye mixing.

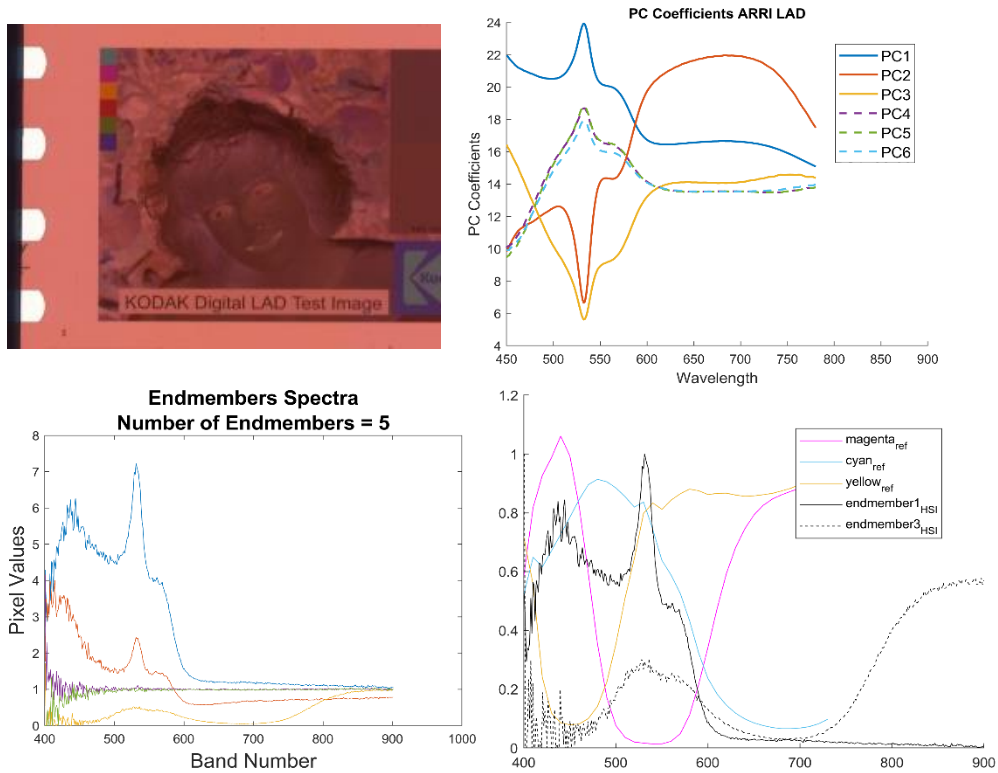

Fig –3 On the top left, the RGB image of LAD frame. On top right, PC coefficients with variance values 89.65, 7.67 and 0.45. On the bottom left, the endmembers. On the bottom right, the comparison among the most significant spectra of the eigenvalues derived from Frame LAD, and the pointwise spectra of Cyan, Magenta and Yellow.

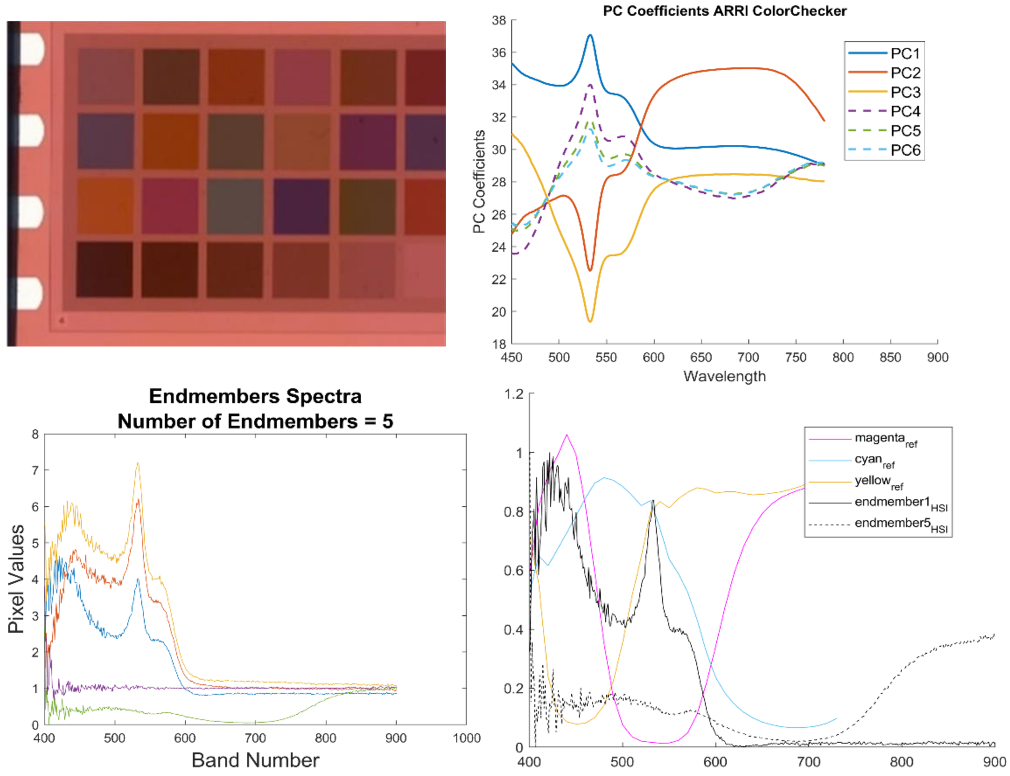

Fig – 4 On the top left, the RGB image of CC frame. On top right, PC coefficients with variance values 89.27, 7.50 and 0.593. On the bottom left, the endmembers. On the bottom right, the comparison among the most significant spectra of the eigenvalues derived from Frame CC, and the pointwise spectra of Cyan, Magenta and Yellow.

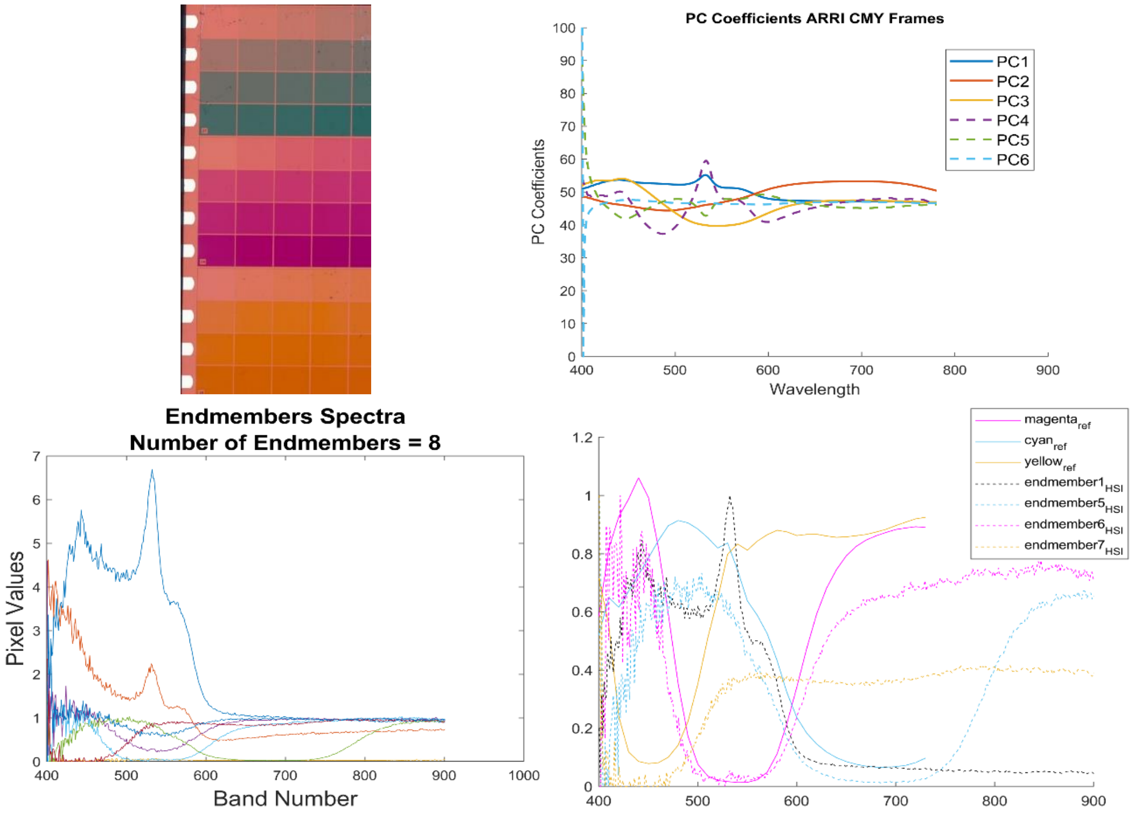

Fig –5 On the top left, the RGB image of CMY frame. On top right, PC coefficients with variance values 70.33, 15.64 and 9.65. On the bottom left, the endmembers. On the bottom right, the comparison among the most significant spectra of the eigenvalues derived from Frame CMY, and the pointwise spectra of Cyan, Magenta and Yellow.

Kodak Vision 3

PCA and spectral unmixing were also applied to Kodak Vision 3. Although PCA effectively identified spectral components, the separation of individual dye spectra was challenging due to pigment mixing.

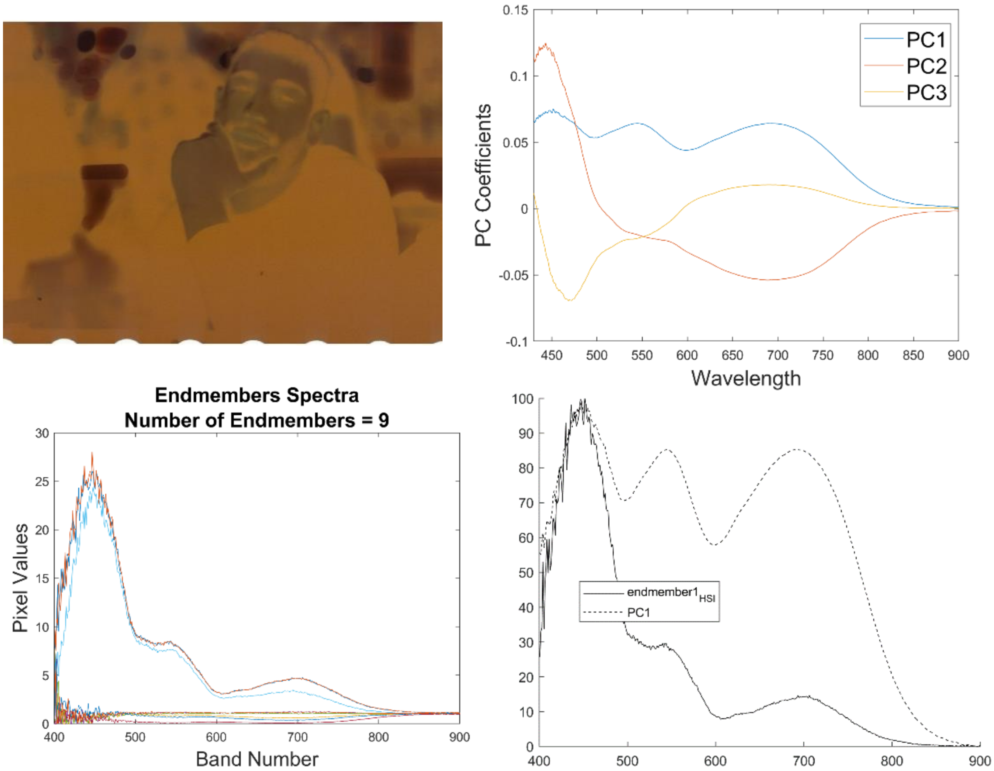

Fig – 6 On the top left, the RGB image of one frame of Kodak Vision P3. On top right, PC coefficients. On the bottom left, the endmembers. On the bottom right, the comparison among the most significant spectra of the eigenvalues derived from the frame.

Discussion and Conclusion

This study confirms that HSI is a promising tool for studying photographic and cinematographic films, providing a non-destructive method to analyze the materials' spectral properties. The hyperspectral data analysis method in this study employs PCA and N-FINDR for spectral unmixing to identify chromogenic dyes in films. While effective in isolating some spectral components, this approach faces limitations due to overlapping dye absorptions and low spectral variance, which challenge the accuracy of unmixing results. Consequently, while N-FINDR supports preliminary dye separation, its reliability is constrained by these inherent spectral complexities, suggesting a need for complementary methods to enhance precision. Furthermore, the lack of comprehensive databases for material identification further complicates the process.

However, future developments could address these limitations. Integrating HSI with other analytical techniques could lead to automated spectral unmixing, enhancing the ability to separate overlapping spectra. For example, the use of Non-Negative Matrix Factorization should be tested. Additionally, applying HSI to older photographic systems with higher spectral variability could open new avenues for research. The ability to compare HSI spectra to RGB images from standard digitization systems also shows promise, especially for refining image correction protocols and improving digitization fidelity.

In conclusion, HSI has the potential to significantly contribute to the digitization of film materials, particularly by generating image correction protocols that simulate outputs from traditional HSI systems. However, current limitations such as data handling, overlapping spectra, and low spectral variability in chromogenic films must be addressed to fully realize its potential.

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Evaluating the stability of colour slides: 30 years of natural ageing at the National Museums of Denmark

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Keywords: colour slide; chromogenic reversal film, densitometry; natural ageing; fading

Introduction

Chromogenic reversal films (CRFs) are colour transparencies with a direct positive image. When mounted in a frame, prepared to be projected in a slide projector, they are commonly called colour slides (Weidner, 2013).

A CRF is a multi-layered material. After processing, it is composed of overlapping emulsion layers containing yellow (Y), magenta (M), and cyan (C) dye clouds in suspension in gelatine, over a plastic base (Pénichon, 2013). Chromogenic dyes are highly susceptible to oxidation and hydrolysis both induced by relative humidity (RH) and temperature (T) - dark fading - and by radiation - light fading (Wilhelm and Brower, 1993). The continuous contact with environmental agents gradually disrupts the chromophore structures of the dyes. This leads to a gradual loss of colour and detail (Reilly, 1998). Since each dye fades at a specific rate, depending on its molecular structure, the image is prone to shift the original colour balance. If residual colour couplers (compounds used to produce dyes during processing) are present in the emulsion layers, these will also tend to oxidize and create yellowish degradation products, contributing to colour shift (Bergthaller, 2002). Other factors can also cause degradation, such as pollutants or residual chemicals from processing (Wilhelm and Brower, 1993). Depending on the film type and on its history (storage, usage, display), different degradation pathways can occur.

In 1992, Jesper Stub Johnsen and Karen Brynjolf Pedersen, both working as photograph conservators at the National Museum of Denmark (NMD), created a 35 mm colour slide reference collection. In the 1990s, while in widespread use, there was a raising awareness of the instability of these materials. In the NMD, colour slides were used to document the objects from the collections. In this context, Jesper and Karen gathered different CRF types available at that time to study their degradation. Also concerned about the impact of unproper processing, they explored the presence of residual fixer, known to be an agent of degradation. The sets were placed in different locations at the National Museum and left to age naturally. To monitor the degradation of the samples, they recorded the initial optical densities of the samples using a densitometer. In 2005, they re-measured some of the samples and the results were presented in the 14th ICOM-CC conference in Hague (Pedersen *et al.*, 2005).

In 2024, the reference collection was donated to the Royal Danish Academy - Institute of Conservation (RDA-IC), together with all the documentation that was produced in 1992 and the densitometer. This paper presents the results of the re-assessment of all the colour slides after more than 30 years of natural ageing. The goals of the present study were to measure optical density variations, identify degradation pathways of different film types in different storage conditions, check the influence of residual fixer in the degradations of the CRFs, and try to compare the obtained results with the literature.

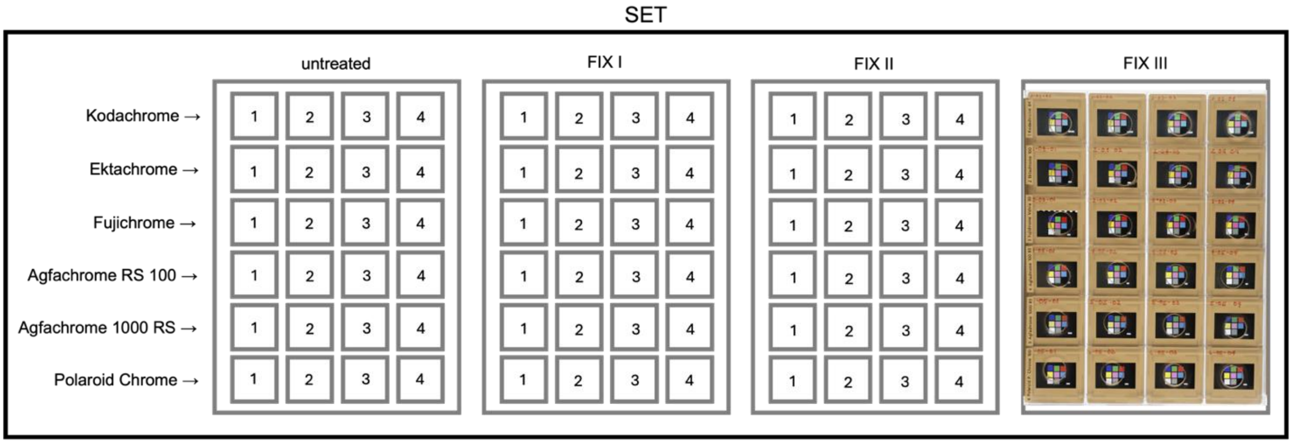

Fig. 1 – Example of set from the reference collection.

Experimental procedure

The reference collection is composed of different 35 mm CRFs from 1992: i) Kodak Kodachrome (ISO 64), ii) Kodak Ektachrome (ISO 100), iii) Fuji Fujichrome Velvia (ISO 50), iv) Agfa Agfachrome RS 100 (ISO 100), v) Agfa Agfachrome 1000 RS (ISO 1000), and vi) Polaroid Presentation Chrome (ISO 100). The 6 film types were gathered and prepared in 1992 as explained hereafter.

All CRFs were exposed to a colour checker. The films were processed in the same day in a commercial laboratory (Colour Lab, Copenhagen) using E-6 processing for all film types, except Kodachrome films that were sent to a Kodak's laboratory to be processed with K14. A part of the samples was left untreated and the other was subjected to one of the following fixer baths with increasing concentrations (Ilford F23:H_2O): i) FIX I - 1:1000, ii) FIX II - 5:1000, or iii) FIX III – 10:1000. The films were then cut and framed in plastic mountings. Each set was originally composed of 80 samples, stored in 4 hard plastic folders for 20 slides. Holes were drilled in the folders in front of each slide to allow for the direct contact of air with the samples. Each folder contained the 6 film types, with quadruplicates of each type of sample (Fig. 1). A reference set was kept in a freezer, and the others were placed in 8 different rooms at the National Museum in Brede and Copenhagen. One of the sets (location 3) has been in two different locations during the last 32 years. The 7 sets that could be retrieved in the present are presented in Table 1.

In 2024, the T and RH conditions of the different locations where the slides have been kept were monitored and the optical densities of all the samples were re-assessed.

T and RH measurements were recorded every hour between mid-May and the end of August 2024, using dataloggers Tinytag Ultra 2.

The optical densities of the samples were registered resorting to the densitometer used in 1992, Barbieri Electronic Densy 301. To follow the fading of the dyes, the primary colour patches were measured using the complementary coloured filter (status A): Y patch using blue filter (B), M patch using green filter (G), and C patch using red filter (R). The neutral grey patch (N) was measured with the 3 filters. Finally, the white patch (W) was measured with the B filter, to estimate the production of yellow stain.

Results and Discussion

Table 1 shows the T and RH values measured with dataloggers between mid-May and the end of August 2024. Based on the analysed period, the T and RH values in the different locations were similar in average. The T ranges 24ºC in most locations, being a little higher in one of the rooms of location 3. Regarding the RH, more variations can be seen, although the average values are between 40 and 47%. The reference samples were kept in a freezer at circa -21 degrees and 46% of RH. Although this results only represent a small part of the year, it can be said that, in general, the storages present unappropriated T and RH values for this type of materials, that should be kept in colder and drier climate (Lavédrine, 2003). Nevertheless, it is expected that during the rest of the year, considering Danish weather, the T and RH reach more suitable values, especially during winter.

Table 1 – Temperature and relative humidity values measured between May and August 2024, in the different locations where the sets have been kept since 1992.

Location	Description	T_{min} (ºC)	T_{max} (ºC)	T_{max} - T_{min} (ºC)	**T_{avg} (ºC)**	RH_{min} (%)	RH_{max} (%)	T_{max} - T_{min} (%)	**RH_{avg} (%)**
0 Reference (Brede), NMD	freezer	-33.4	-21.6	11.8	**-21.3**	30.6	51.9	21.3	**45.9**
1 Ship History Laboratory (Roskilde)	storage room, inside drawer in a metallic cabinet	21.7	25.7	4.0	**24.0**	39.8	56.8	17.0	**47.2**
2 Ethnographic Collection (Copenhagen), NMD	storage room, in open shelf	22.2	26.0	3.8	**24.5**	42.3	48.4	6.1	**46.3**
3 Near-east Antiquities (Copenhagen), NMD	office, in open wooden shelf servers room, inside wooden cabinet	20.8 23.2	27.7 28.8	6.9 5.6	**24.8** **26.5**	27.4 28.8	57.5 51.3	30.1 22.5	**42.1** **39.8**
4 Conservation Department (Brede), NMD	storage, inside drawer in a metallic cabinet	22.1	26.9	4.8	**24.3**	28.2	63	34.8	**44.7**
5 Modern Times News (Copenhagen), NMD	storage, inside drawer in a metallic cabinet	21.3	26.9	5.6	**24.7**	36.0	48.4	12.4	**43**
6 Photo Conservation Office (Brede), NMD	office, in open wooden shelf	21.0	27.8	6.8	**24.5**	38.1	57.3	19.2	**45.4**

Based on the thermohygrometric graphics, the locations can be divided in 3 major groups with similar characteristics (excluding the reference samples in the freezer):

- 1st group: comprising location 2, in which the T and RH are very stable during the overall measured period;
- 2nd group: comprising locations 1, 3, 4 and 5, with fluctuations of RH and to a lesser extend also T, with quite high amplitude, sometimes within short timeframe periods (less than 24 hours);
- 3rd group: comprising location 6, with high frequency oscillations of RH, also reaching high amplitudes sometimes in short timeframe periods.

Just by observing the colour slides over a light table, slight differences can be seen between the reference samples and those kept in regular climate conditions. Samples from location 6 clearly present visible colour change, particularly Kodachrome.

Figure 2 to 4 show the difference between the optical densities measured in 1992 and in 2024 (average of the quadruplicate samples). The optical densities on the Y patch were D_{min} corrected, i.e. the value of the W patch was subtracted to the value of the Y patch, to discount the yellow stain produced in the Y patch and better assess the Y dye fading (Wilhelm and Brower, 1993).

As expected, no significant changes were measured in the references samples kept in the freezer (Fig. 2). Nevertheless, very slight variations can be seen in Ektachrome, Fujichrome, and Agfachrome 100 films in Y patch. T= -21ºC was enough to greatly reduce the degradation rate of the dyes, although not completely stopping the chemical reactions (Lavédrine, 2003). No differences can be noted between untreated and treated samples.

In location 2, considered the most stable storage (1st group), variations between unaged and aged samples can be observed. Under this climate conditions, it can be stated that Kodachrome and Ektachrome are the most stable films. Depending on the film type, different degradation pathways are visible. In Kodachrome, M is the dye fading faster. In Ektachrome, Fujichrome and both Agfachrome films, the limiting dye is Y. Polaroid Chrome shows the highest variations, being C the least stable dye, immediately followed by Y. As reported in the literature (Wilhelm and Brower, 1993), it can be noted that the dyes degraded faster in pure colour patches, than in N patches. Regarding Y stain, that can be assessed by looking at W patches, it is basically negligible. As expected, Kodachrome does not show any yellow stain due to the absence of residual colour couplers responsible for the formation of yellowish degradation products (Wilhelm and Brower, 1993). The samples treated with fixer do not seem to be more degraded than the untreated samples.

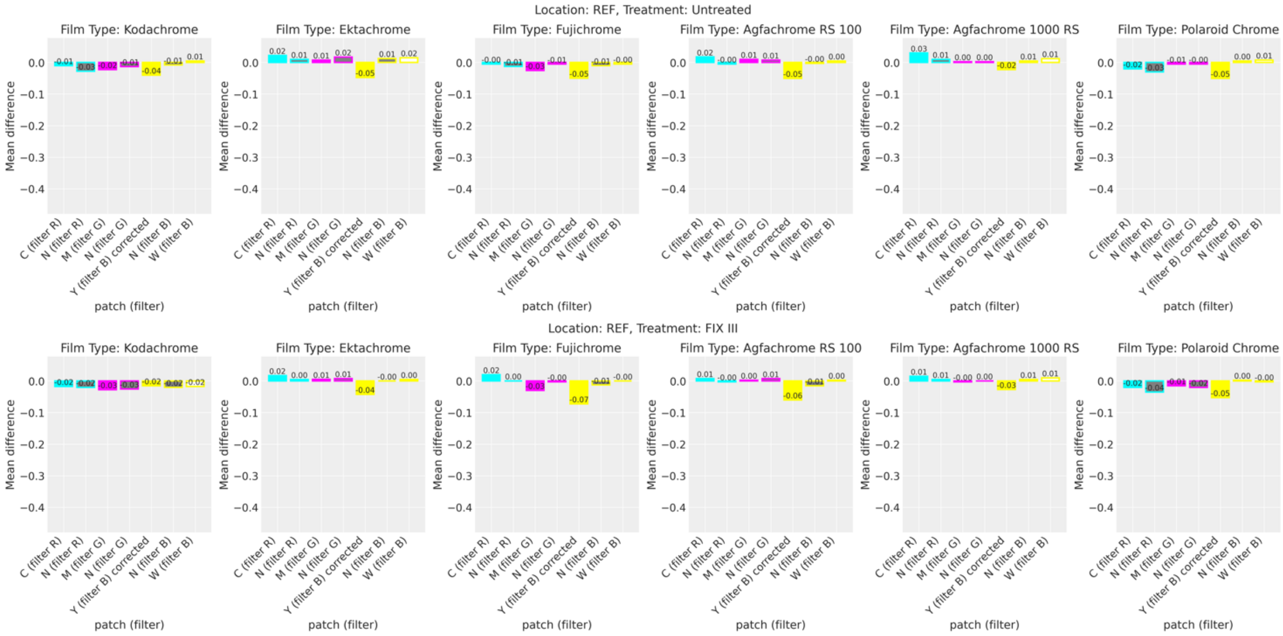

Fig. 2 – Mean difference between the optical densities measured in 1992 and in 2024 (absolute values) in reference samples placed in the freezer, calculated in each different patch for each film type. Top: untreated samples; bottom: treated with FIX III.

Figure 3 shows the results for location 4, representing the 2nd group of storages with regular T and RH fluctuations with high amplitude. Curiously, the results are very similar to those obtained in location 2. The same trends can be established, although in these storages Ektachrome can be considered the more stable film type.

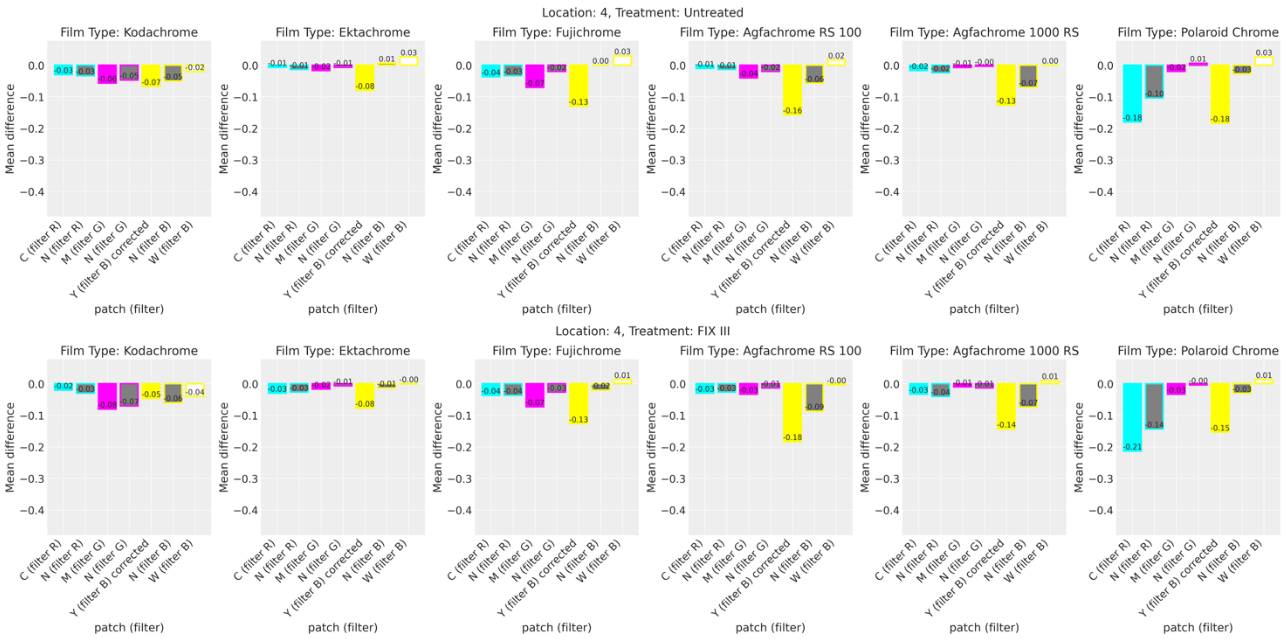

Fig. 3 – Mean difference between the optical densities measured in 1992 and in 2024 (absolute values) in samples placed in location 4, calculated in each different patch for each film type. Top: untreated samples; bottom: treated with FIX III.

Figure 4 presents the results for location 6, the one with high frequency fluctuations of RH (3rd group). In this location, different tendencies can be seen. In general, all the film types are more degraded, sometimes having doubled the levels of fading. Kodachrome clearly becomes the least stable film type, but Ektachrome maintain its place as the most stable. A clear difference between samples untreated and samples treated with FIX III can also be seen, showing higher levels of degradation, especially for Kodachrome and Agfachrome RS 100. It also seems that in Ektachrome and Fujichrome, FIX III particularly affects the M dye, which turns as the limiting dye under these conditions. This general increase of degradation can be a consequence of the high frequency of RH oscillations. Frequent cycles of T and RH fluctuations are known to cause stress in the materials (Lavédrine, 2003), and this can have an impact in the stability of chromogenic dyes. Another hypothesis for these results is the contribution of light fading summing to dark fading, considering that this set has been kept in an open shelf close to a window. Although there was no direct sun over the samples, it is possible that some light was reaching the interior of the transparent folders, especially those placed on the top, as is the case of Kodachrome. According to Wilhelm and Brower (1993), Kodachrome is by far the least stable CRF in relation to light fading, being M the limiting dye under projector fading conditions.

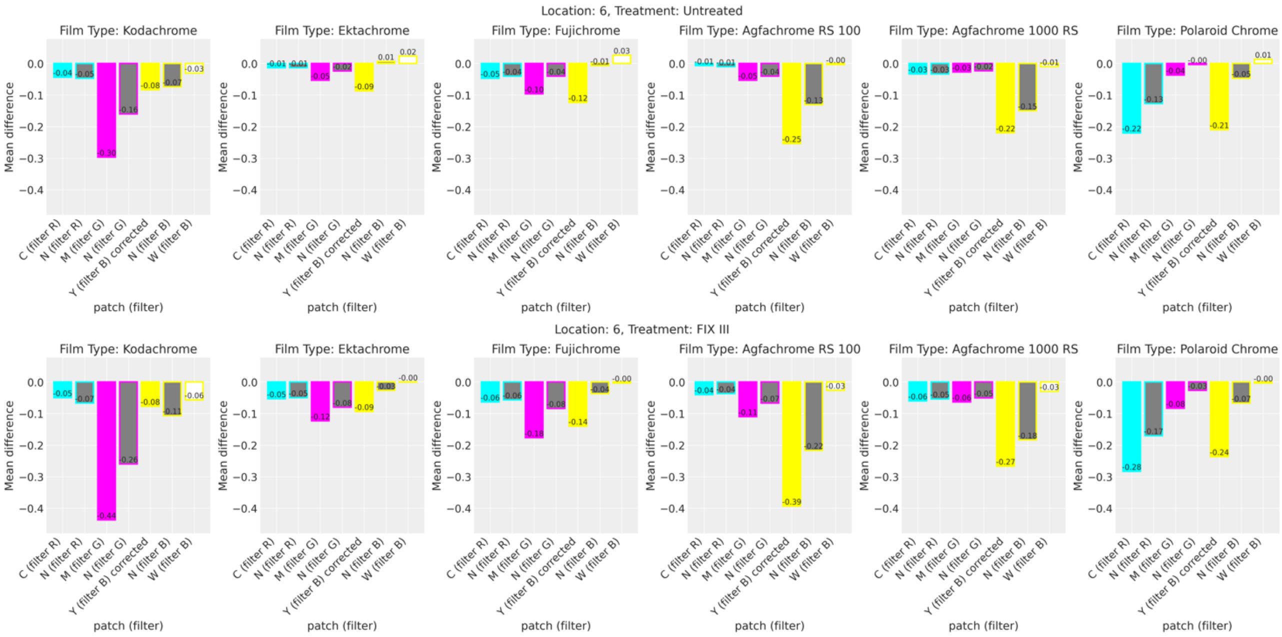

Fig. 5 – Mean difference between the optical densities measured in 1992 and in 2024 (absolute values) in samples placed in location 6, calculated in each different patch for each film type. Top: untreated samples; bottom: treated with FIX III.

One of the goals of the present work was to compare the results of the natural ageing test with the literature, especially the book by Wilhelm and Brower (1993) where the results of several artificial ageing tests were compiled. It can be said that some discrepancies were found in several aspects. According to Wilhelm and Brower (1993), Kodachrome is the most stable CRF by far in the dark. However, in the present study, Ektachrome was generally the most stable, and Kodachrome was clearly the least stable in location 6. In terms of stability by film type, and respective limiting dyes, some differences were also found. Another interesting point is the high concern with yellow stain in the book. The authors state that the most significant issue in E-6 films stability is the high levels of yellow stain (Wilhelm and Brower, 1993). However, in this study, it clearly seems to be a minor issue.

Conclusions

Based on this study, the positive influence of freezing the CRFs can be highlighted. On the contrary, location 6 has clearly proved to gather inappropriate environmental conditions. Interestingly, no significant differences could be established between the other locations when analysing the densitometry measurements.

In terms of film type stability, although it is not completely straightforward, in most locations Ektachrome / Kodachrome > Fujichrome > Agfachrome 1000 RS > Agfachrome RS 100 > Polaroid Chrome. In storage 6, the order changes slightly, being Ektachrome the more stable, and Kodachrome clearly the more unstable.
In most cases, Y dye is the limiting dye, except for Kodachrome (M) and Polaroid Chrome (C, although Y also high).
One surprising result was the low levels of yellow stain obtained in all samples. Also, the influence of residual fixer does not seem to be a major problem, except in storage 6 and particularly affecting M dye.
The obtained results suggest that there may be significant differences between studies carried out with naturally or artificially aged samples.
In the future, the sets will be placed back in their locations to continue the natural ageing experiment. The environmental conditions of the locations will also be monitored to complete at least a full year of measurements, in order to better understand the different storage conditions.

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"Your memory is our history: recovery, digitization and distribution of vernacular video production"

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Abstract

In the process of empowerment of society, the search for innovative solutions to update and strengthen the relationship between communities and their cultural heritage - material and immaterial - and the territory is fundamental. From this perspective, the inclusive and participatory enhancement of cultural heritage and the experimentation of new models of communication and use can contribute both to strengthening the sense of place and to defining a heritage community. Since 2015, in Carbonia, in the Southern Sardinia region (Italy), the "Centro Servizi Culturali della Società Umanitaria - CSC" (i.e. Centre for Cultural Services of the Humanitarian Society) has started the project "Ex Dì Memorie in Movimento - La Fabbrica del Cinema" (i.e. Ex Dì Moving Memories - The Cinema Factory) aimed at preserving, collecting, promoting and post-producing the historical audiovisual memory of the territory. The working hypothesis is that small private stories can transform into public testimonies of the daily life of both the community and the nation. The recent collaboration between the CSC and the project "Reinventing Industrial Museums for a New Image of Italy - 2023-2025" (ReMusIt - Home, 2024), constitutes a further experimental activity.

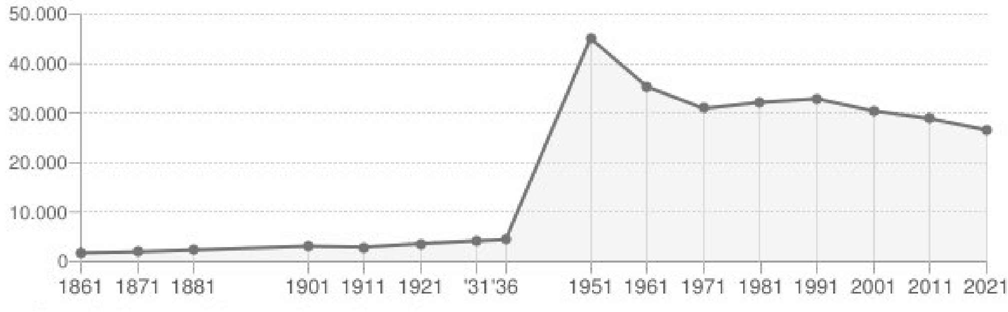
This study traces some of the most significant activities undertaken by the Sardinian Center and illustrates the hypotheses of collaborative work within the ReMusIt project. In the final part, new possible joint research scenarios will be outlined.

Keywords: vernacular film, cultural heritage preservation, documentary film, mining culture, color family film.

Introduction

History is a complex tapestry of interwoven memories, a set of narratives that define us and connect us to the past, reinforcing the sense of belonging to a society and a territory. Carbonia, in Southern Sardinia region (Italy) is a founding city, created to ensure the supply of coal in the Italy of Fascist autarchy to reduce dependence on foreign imports. Inaugurated on 18 December 1938, in the presence of Mussolini, it saw an intense economic migratory phenomenon converge on it that delineated a peculiar social characterisation and experienced changing fortunes, until the definitive end of mining era (Graph. 1). The preservation of memory is a topic of significant interest that can be used both for the pure documentation of events and for the suturing of a sense of belonging to a legacy that is difficult to accept (Peghin and Sanna, 2009; Peghin, 2010; Sanna and Sanjust, 2020).

Carbonia is home to the "Centro Servizi Culturali della Società Umanitaria - CSC", this is the Sardinian headquarters of the "Società Umanitaria" at Milan, a non-profit organization, founded in 1893. The organization has made itself known with over one hundred years of social battles, combining assistance and work, social commitment and education, progress and training, emancipation and culture (La Nostra Storia, no date). The CSC was inaugurated in Iglesias in 1967, before moving to Carbonia in 1982, first in the Velio Spano Hall and then, in 2015, in the offices of the former Mining Directorate in the Grande Miniera di Serbariu complex. The same year the La



Graph. 1 - Population of Carbonia as of census date.

Fabbrica del Cinema (i.e. The Cinema Factory) project was launched, aiming at preserving, collecting, promoting and post-producing the historical audiovisual memory of the territory.

Since 2017, the Region of Sardinia has granted the Center funding for the activation of a "Cineport hub", an attempt to develop the local cinema industry. Of considerable interest is the "Your memory is our history" project promoted by the three Sardinian CSC of the "Società Umanitaria" (Cagliari, Carbonia and Alghero). It is based on family (or vernacular) cinema, which aims to recover the audiovisual historical memory that private citizens have produced through home movies from the 1960s-70s onwards and eventually forgotten in attics and cellars, and then transform these small private stories into public testimonies of daily life and local culture. Thus, these vernacular film materials are not only valuable documentation, free from the political propaganda that characterizes the enormous archive of Istituto Luce productions during Fascism, but are also fundamental pieces for scholars, historians and film enthusiasts who want to build a stronger social framework, based on sharing and mutual understanding thanks to new productions that seek to fill cultural gaps or address neglected aspects of the island's culture and history. The Carbonia's La Fabbrica del Cinema stands out as an example of excellence in the integration of art, science and society. Through its commitment to memory preservation and scientific dissemination, it demonstrates the transformative power of art and culture in building a shared and conscious future.

Carbonia and the Italian Center for Coal Culture, the Great Mine of Serbariu and the Coal Museum are subject of studies into the project "ReMusIt - Reinventing industrial Museums for a new image of Italy 2013-2025" (PRIN 2022 – Funded by EU - NextGenerationEU - M4.C2.1.1., project n. 2022X5KWKT, CUP Master_B53D23034050006). Promoted by the National Research Council of Italy in collaboration with the University of Milan and the University "Mediterranea" of Reggio Calabria, the ReMusIT proposes an interesting model of collaboration between stakeholders intended, on the one hand, to strengthen the socio-cultural and economic role of the Great Mine of Serbariu, also with a view to tourism development of the territory, and, on the other, to strengthen the attachment of the community to this place and, in a broader sense, to its past. Between the supporter and collaborators of the multidisciplinary Remusit research team there's also the CSC – "La Fabbrica del Cinema".

The "La Fabbrica del Cinema" and the "Your Memory is Our History" project

In the context of the "Società Umanitaria" and its mission, "La Fabbrica del Cinema" has launched the project "Your memory is our history", a regional campaign aimed at creating an archive of private and family memories of Sardinians (Cinema and Family - the project, no date). The campaign is dedicated to the collection and enhancement of vernacular or family films, shot until 1985, in various formats, documenting moments of private and public everyday life, places, traditions, faces and celebrations, which portray life far beyond the rhetoric of the Istituto Luce propaganda films. In addition to family films, the collection also includes amateur material, documentaries and fiction films made by associations from various backgrounds. This project has made it possible to create a valuable, unpublished audiovisual corpus that is important for the study of local history and culture, as well as for the analysis of the social, economic, anthropological and landscape development of the territory.

The "Your memory is our history" project is being developed in four stages: collection, digitization, cataloguing and dissemination.
The collection can be carried out by accidental discovery (for example, when emptying cellars or garret) or by direct delivery; the "Società Umanitaria" can take charge of the original films in the form of temporary storage (coinciding with the time required for digitization), long-term storage or donation. The latter will then be conserved in their original format at the "Cineteca Sarda" (i.e. Sardinian Cinematheque) della "Società Umanitaria" in Cagliari and made available to the community according to the procedures established in agreement with the owner.
Once the films have been collected, the "Società Umanitaria" carries out an initial evaluation and classification by creating a file card uniquely linked to the reel through a relational database. The films then undergo a light conservative restoration (removal of dust, dirt and grease) and minor repairs to damaged parts. Only after this preparatory phase is the film ready for conversion to digital video and storage for archival preservation.
To date, thanks to 799 contributions 11,754 videos have been collected, mostly in 8mm and Super 8 format, of which 11,680 have been digitized (Fig. 2). Digitization takes place using the Scanner Film technology for 9.5 mm Pathé Baby, 8 mm and Super8 formats, and with the telecine film transfer process for 16 mm and 35 mm formats.
The D-ARCHIVER 2 2K scanner (Fig. 1) used for digitization is equipped with a drag system that guarantees the highest film security. A high-definition sensor allows the entire frame to be digitized thanks to an LED light source that generates a short flash for each frame, so that the three primary colours can be controlled independently; in addition, the system can read films with single- or double-track magnetic audio. The choice of this film scanner was mainly dictated by the high quality of its output (2K, Pro-Res file format) but also by the possibility of capturing different formats and its general ease of use. The two digitization operators have the possibility to do colour correction and image stabilization during the acquisition process. Each operation is recorded on the film review sheet.

Contribution	**799**
8 mm	5232
Super 8	6200
16 mm	186
9,5 mm	118
35 mm	18
TOTAL	11754
Digitalized	11680
Other materials included in the contributions other than film footage	881

Graph. 2 - Number of videos by format. Elaboration on data from "La Fabbrica del Cinema", 2024.

In the final phase of the project, the collected audiovisual material will be carefully catalogued in order to allow quick and organized access through the creation of a database. This database will indicate the contents by keywords, allowing for targeted and immediate consultation. The "Società Umanitaria" will develop a computerized cataloguing system that will be made available online through the official website of the "Cineteca Sarda" (Home Page società Umanitaria CSC Cagliari, no date), thus facilitating public access to the content.
The work of cataloguing and documenting the films is carried out, whenever possible, in direct dialogue with the creators of the material and their families, who are an indispensable resource for accurate historical and social reconstruction. This dialogue will make it possible to restore the films

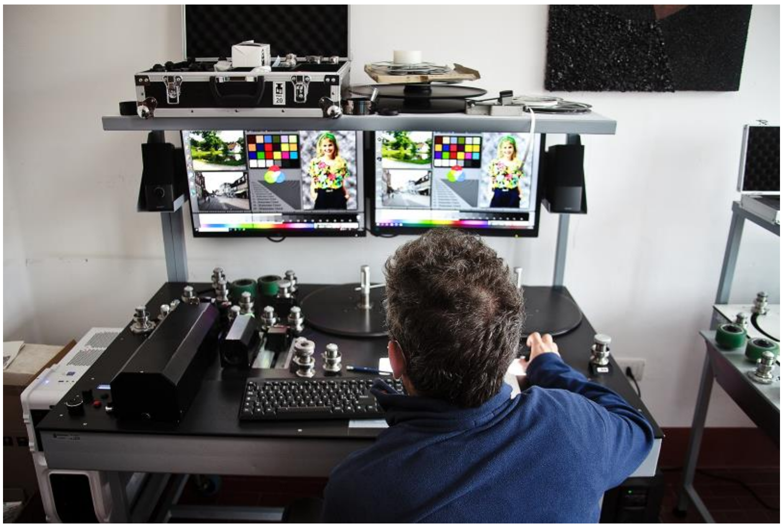


Fig. 1: La Fabbrica del Cinema's Scanning Station

to their full testimonial status, placing them in the cultural and personal context in which they were produced.
In order to further enrich the archive, the owners of the material are encouraged to provide, along with the reels, other supporting elements such as photographs, written documents, prints or any other resource that can contribute to the reconstruction of the original context of the footage. In this way, the project not only preserves the historical value of the films, but also promotes and realizes a more complete audiovisual memory, returning a consultation tool that enhances the complexity and authenticity of Sardinian history and culture (Cinema and Family - Project, no dates). The films collected are stored in acid-free boxes. Improvements are underway that will soon allow the boxes to be stored in a room with constantly controlled ventilation, humidity (<50%) and temperature (<15°C), and with adequate fire protection.
The "Società Umanitaria" develops the archive thus created by promoting research and study activities, by disseminating the films and the project through meetings and events, but also by directly producing or participating in the production of audiovisual or multimedia materials that deal with or use the family films.
It is also useful to mention here another project of the "La Fabbrica del Cinema" Cineport hub, this time in the role of a training centre. The archive and materials produced by the "Your memory is our history" project are linked to the activities of the "Carbonia Cinema Giovani Film Lab", a project aimed at bringing new generations closer to the world of audiovisual production and film culture: addressed to young high school and university students, the Lab offers a comprehensive training experience, ranging from an introduction to filming and editing techniques to the realization of real film projects, through meetings with directors, scriptwriters and industry professionals who enrich the participants' education and inspire them with direct experiences in the world of cinema.

The students who participated in the 2023 edition of the "Cinema Giovani Film Lab" have produced a film entitled "Seemingly Never Ending". In this film, they have successfully employed a technique whereby archive material is juxtaposed with new footage. This film will have its premiere at the Carbonia Film Festival 2024, which is scheduled to take place between 13 and 17 November 2024.

ReMusIt and the audio video research

The ReMusIT aims to advance knowledge to support the development of industrial museums through a multidisciplinary approach with several complementary objectives. The project aims to support museums in developing new interpretation frameworks for the tangible and intangible values associated with their collections and their local contexts, in order to broaden and improve their cultural offer in terms of communication and audience engagement. ReMusIT also provides strategic advice on management, community engagement and resilience to strengthen museums against various challenges, while promoting a broader understanding of the value and potential of Italian industrial museums through selected case studies. The project also supports museums in developing innovative communication strategies by digitizing and promoting their photographic and audiovisual archives through new technologies.

To achieve the second goal, the University of Milan's MIPS Lab leads research focusing on multimedia processing, assessment, and visualisation, particularly for cultural heritage applications such as colour management and film restoration. This work includes advanced research in audiovisual heritage acquisition, restoration, and museum visualisation, analyzing communication methods and multimedia tools in case studies, and supporting local stakeholders in developing new strategies for photo and video restoration and the enhancement of industrial museum values.
The research is based on some main activities, as follows: a) assessment of photographic and audiovisual archives of each case study, in terms of film types, numerosity, conservation state, as well as implemented scanning techniques and available devices and softwares for film digitization, restoration and visualization in museal context. In particular, the assessment methodology will focus on the accuracy of the digitization protocols, to extract accurate digital information to be used in the following steps of the project. In this context, the digitization phase will be followed by the development and implementation of automatic and unsupervised methods of frames restoration and color/tones enhancement, which could improve the current state-of-the-art in this field and strongly reduce the costs in money and time to retrieve and restore images and video of historical relevance; b) identification of criticalities and evaluation of suggested improvements regarding the content, digitization, photo and video restoration, and state of archives and their communication, access and enhancement. The assessment of partners archives will regard film types, numerosity, conservation state, etc. and will result in a series of suggested improvements regarding the content, digitization and state of archives and their communication and access. Partner's archives will also be the base of research and tests on digitization techniques, mainly focused on the accuracy of the digitization protocols, the test of automatic unsupervised methods for video and images restoration, and processing, image quality tests and measures (Plutino *et al.*, 2020; Plutino and Rizzi, 2021).

The collaboration with "La Fabbrica del Cinema" will regard to provide technical consultancy and software solutions that align with the specific needs.
For example, The MIPS Lab at the University of Milan will provide "La Fabbrica del Cinema" with the necessary support to navigate the initial compulsory step in the process of film digitization, namely the decision to proceed with film restoration. Should this decision be taken, the MIPS Lab will also offer guidance on the selection of the most appropriate tools for the restoration process. The decision to undertake a film restoration project is, in essence, confronted with two principal types of problem.
The first is the dependence on commercial software which has limited offer on the market, is less maintained and which requires operator training more on the software package than on the restoration

process. This creates the problem that the restoration process adapts to the capabilities of the software and not vice versa. Furthermore, another problem is that an operator who is expert in a software often finds it problematic to switch to an alternative software, underlining as well that all the skills had adapted to the software and not to the restoration process.
The second problem is the time it takes to restore a movie. Restoration is essentially a process that takes place frame by frame and therefore requires similar operations that are very repeated over time. This translates into a very high cost of restoration in terms of man-months.
The main proposal is the use of algorithms called Spatial Color Algorithms (SCA). These algorithms are based on computational models of the human visual system and have the characteristic of processing each frame automatically and unsupervisedly. With the simple press of a button the algorithm is able to autonomously equalize the color and contrast of the degraded frame and restore colors closer to the original ones. In many cases the simple application of these algorithms guarantees a good recovery of color and contrast, but where these are not sufficient, their modifications can be considered as a useful starting point for a final color correction, still saving a lot of time to the restorer (Rizzi *et al.*, 2006; Rizzi and Chambah, 2010; Rizzi *et al.*, 2014; Plutino *et al.*, 2021;). These algorithms have been widely tested and are available to any film library that requests them.

Conclusions

Initiatives to promote audiovisual memory in Carbonia, such as the "Your memory is our history" project, highlight the importance of preserving and making accessible cultural heritage through innovative processes of collecting, digitizing, cataloguing and disseminating vernacular films. Projects such as these make a fundamental contribution to the historical and social understanding of the community, filling in the gaps left by the official narratives, which are often limited or partial, and are capable of restoring the sense of belonging to a territory rich in discordant legacies. This reinterpretation not only allows the city's historical identity to be addressed, but also creates a space of re-appropriation for the community and new generations. Educational projects such as the "Carbonia Cinema Giovani Film Lab" reinforce this mission. By integrating tradition and innovation, the Lab provides young people with practical experience and a strong connection with the local cultural heritage, stimulating a new sensitivity towards the past and opening up future perspectives for the community.
In the context of the ReMusIt project, the Carbonia experience highlights the dynamic role of industrial museums as spaces for critical and inclusive reflection on the cultural heritage of the territory. Through dialogue with the local community and the direct involvement of material owners, these museums promote access to cultural heritage and strengthen the sense of belonging to collective memory. In conclusion, Carbonia stands out as a model for the promotion of industrial memory and film culture, demonstrating how the use of audiovisual media, combined with dialogue between institutions and communities, can contribute to the construction of a shared memory and a deeper social awareness.

Acknowledgement

This research was carried out in the framework of the project PRIN 2022 – Funded by EU - NextGenerationEU - M4.C2.1.1., project n. 2022X5KWKT, CUP Master_B53D23034050006 and has been made possible thanks to the support and collaboration of many people and institutions: we would like to thank the "Società Umanitaria" di Carbonia for its commitment to the valorization of the local cultural heritage and for the access to the audiovisual archives, which made it possible to integrate the analysis of this study. We would also like to thank the team of "La Fabbrica del Cinema" and all those who have participated in various capacities in the "Your memory is our history" project, whose dedication has made it possible to collect and digitize valuable local audiovisual material.

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Fading memories: Assessing colour slide film's cultural impact in Portugal and abroad

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Abstract

The early development of colour slide film is associated with the photographic industry in North America and Europe in the 1930s. Distributed through a globalized market, such objects became a part of people's daily lives through a myriad of uses. Despite decades-long commercial success with both professional and amateur photographers and use in educational and artistic contexts, slide film has been progressively replaced by digital imaging technology since the early 2000s. In fact, even though slide film can be a memento, its memory is fading away from our lives. This entire branch of the industry has died out, and, if no action is taken, so will the recollections of its impact. To transform these materials into enduring cultural memories, it is crucial to collect and organise information related to their production context and related experiences.

This study focuses on colour slide collections while exploring their manufacture, use, decay, values, and significance. To assess the opinion of a broad national and international audience about slide film, data was collected through Portuguese and English versions of an online questionnaire using Microsoft Forms®. Participants were asked about their personal and professional experiences related to colour slide film and their views on the photographic industry. A total of 445 individuals from 53 countries from varying age groups, training backgrounds, and professional fields replied to the questionnaire. Results were analysed statistically and through data visualisation tools, showing that differences in perspectives can be related to a slight generational divide, as well as a range of geographical and socio-economic backgrounds. Furthermore, the cultural impact of colour slides is often associated with the images they carry, but the significance of the scientific and technological context in which they were created seems to be underestimated. To complement standardized answers, participants were encouraged to add personal comments, many of which emphasized the power of slide film in triggering personal memories.

The survey documents how colour slide film's broad societal impact can be felt across generations and countries. Furthermore, the provided statements demonstrate that caring for these photographs should go beyond preserving materiality and is a process that needs to be supported by a deeper grasp of a technology's cultural and social impact. This paper elaborates on the obtained results and demonstrate how online surveys and visualization tools are useful methods for studying obsolete technologies, helping different communities recover and rediscover their social, cultural and artistic meaning.

Keywords: colour slide film, chromogenic photography, online survey, value, cultural memory.

Introduction

The desire for colour images has existed since the birth of photography, but it was only in the mid 1930s that both Agfa (Germany) and Kodak (U.S) revolutionized the medium by introducing chromogenic dyes into photographic emulsions (Pénichon, 2013). Advertisements for colour slide film targeted amateur photographers and underlined the medium's ability to capture memories (Eastman Kodak Company, 1960s). Used in artistic, commercial, documental, educational, personal, and scientific contexts, the societal impact of these materials has yet to be studied in depth beyond regions where slide film manufacture took place.

This study seeks to fill that gap in knowledge through a survey directed to an international audience. It investigates whether colour slide film became a carrier of memories, and if so, whose memories, in which contexts they formed, and which values are still associated with these photographs. Such information can help conservation professionals to make better decisions relating to the preservation and establishment of priorities in a collection of such objects. The survey also researched the photographic industry's impact in Portugal, a country culturally isolated through a dictatorship that lasted until 1974, and compares it with other realities. Furthermore, it studies how their decay is perceived and the main conservation challenges that these materials face.

Fig. 1 – 35 mm colour slide in Kodachrome 200 Professional (Daylight) film, developed in June 1988. No information is known about the person or location represented in the image. However, the dot between the K and the O on the word "K·ODAK" indicates that it was manufactured by the Eastman Kodak Company in Rochester (NY), U.S. and it was also processed in the same city (Layton 2020; see text on the top edge). Private collection, L. Fernandes.

Methodology

An online questionnaire available in English and Portuguese was designed to investigate the opinions of the general public about colour slide film through the analysis of the values that are associated with them. The chosen values were, inspired by the overview summarized in Fredheim and Khalaf, 2016. The survey also looks to measure knowledge and interest for the production and preservation of these materials. Participants answered twenty questions, of which nine were mandatory and eleven were optional. Among these, four open-ended fields provided space for additional comments. The first questions were designed to build the participants' profile according to their age, country of residence, gender, professional field and education level. Respondents were asked to choose their level of agreement with sentences related to colour slides using a Likert 5-point scale: "Strongly agree", "Agree", "Neutral", Disagree" and "Strongly disagree" (Nishisato, 2023). Evaluated words or expressions were alphabetically ordered and the language style used in both surveys was as informal and neutral as possible. The questionnaire was designed in the Microsoft Forms® platform, which simultaneously gathered data online (Oliveira Fernandes, 2023a).

The survey was distributed on social media platforms, websites, newsletters, as well as through email and in-person invitations.[8] Participants were asked to forward the survey to other potential contributors, increasing the sample size through a non-probability, snowball method. This document discusses the responses collected between Nov. 14th, 2023 and June 8th, 2024. Responses were

[8] Including the American Institute for Conservation's Emerging Conservation Professionals, Global Conservation Forum and Photographic Materials Group communities; APOYOnline - Association for Heritage Preservation of the Americas; Australian Institute for the Conservation of Cultural Material - Photon Special Interest Group; British Photographic History Blog; DCR NOVA FCT; Fédération française des conservateurs-restaurateurs; Gruppo del Colore - Associazione Italiana del Colore; History of Photography European Network; International Association of Book and Paper Conservators; International Council of Museums – Conservation Committee Photographic Materials Working Group; International Network for the Conservation of Contemporary Art; During poster presentation, at the "Bridging the Gap: Synergies between Art History and Conservation" conference, Nov. 23-24, 2024, The National Museum, Oslo.

analysed in Microsoft Forms®, and exported as Microsoft Excel® files. A single file was created to compile information obtained in the two separate languages. For easier comparison, overall results are presented alongside relative percentages per group of analysis. Additional comments were analysed by the frequency of the words utilized by respondents and grouped into topics.

Results

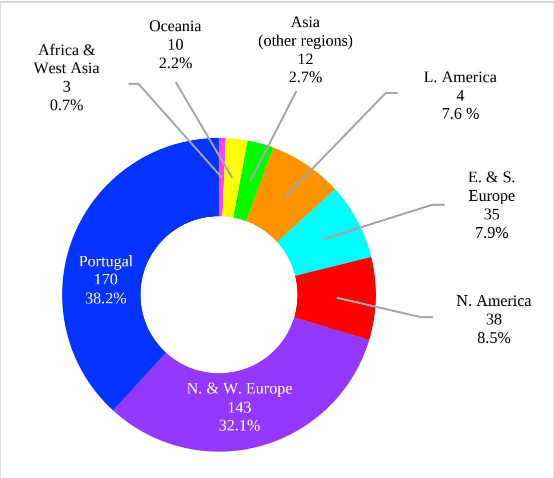

Fig. 2 – Participants' region of residence.

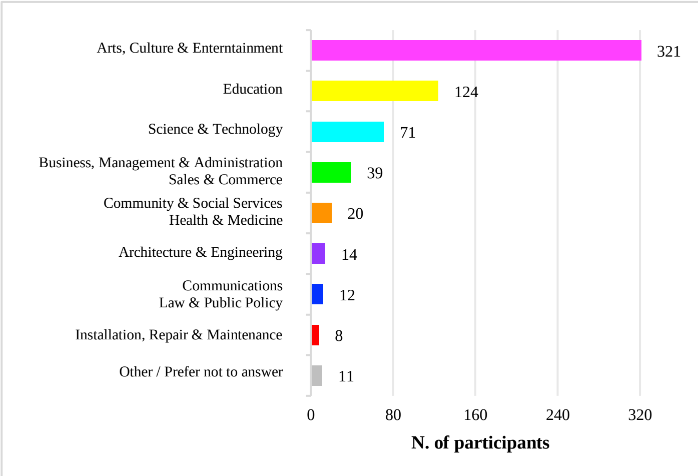

Fig. 3 – Participants grouped by professional fields (multiple answers possible).

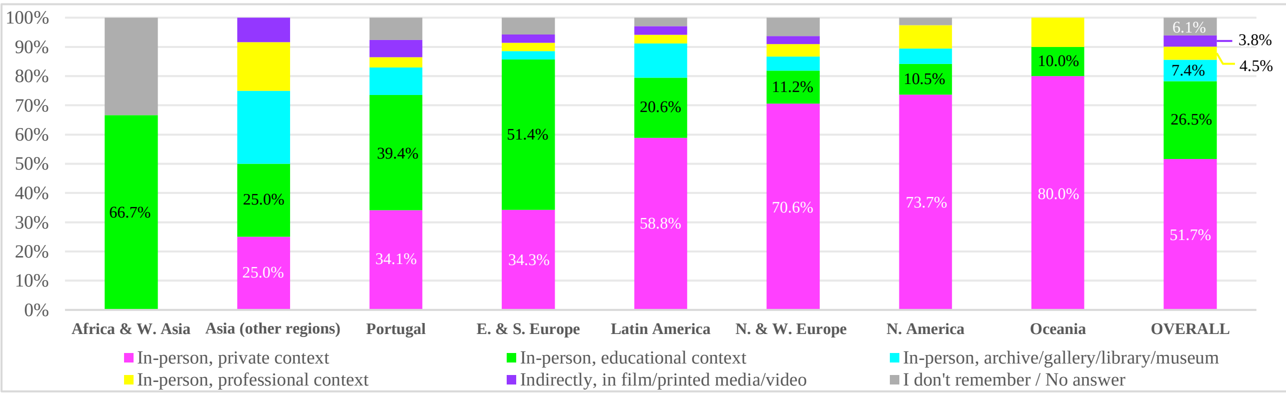

Fig. 4 – Context of first time participants viewed colour slide film, according to region of residence.

Of the 445 survey participants, 443 completed all mandatory questions in an average of c. 24 minutes. Most identified themselves as women (296, 66.5%) and men (140, 31.5%). Respondents associated with a total of 53 countries were analysed in separate geographic areas (United Nations, 2024).[9] Most participants reside in Europe (348, 78.2%) (Fig. 2). Although their birth decades range from before the 1940s to after 2010s, results were condensed into four groups: born before 1969 (120, 27.0 %), in the 1970s (113, 25.4%), in the 1980s (116, 26.0%) and after 1990 (96, 21.6%). The majority of respondents have a professional connection to the Arts, Culture & Entertainment (321, 72.1%), followed by Education (124, 27.9%), and Science & Technology (71, 16.0%) (Fig. 3). About a third

[9] Represented regions & countries: Africa (AGO, BWA, EGY, MOZ, NGA, ZAF) & Western Asia (LBN, SAU, TUR); Asia (other regions) (AFG, CHN - including Taiwan, IDN, IND, JPN, SGP); Eastern Europe (CZE, POL, ROU, RUS) & Southern Europe (BIH, ESP, GRC, HRV, ITA, MLT, SRB, SVN); Latin America (ARG, BOL, BRA, CHL, MEX, PER, VEN); Northern America (CAN, USA); Northern Europe (DNK, FIN, GRB, IRL, NOR, SWE) & Western Europe (AUT, BEL, CHE, DEU, FRA, LUX, NLD); Oceania (AUS, NZL); Portugal (analysed individually).

of all respondents specified that their professional activities are related to conservation (153, 34.4%). Other professional fields are also represented (e.g. Health & Medicine, Sales & Commerce).

Colour slides were associated with various contexts and only 14 people (3.1%) had not heard of or did not remember these materials. The first interaction commonly occurred in a private (230, 51.7%) or an educational setting (118, 26.5%) (Fig. 4). Most participants experienced these materials for the first time between 1980-1999 (207, 46.5%), a value that is similar to both those residing in Portugal and abroad. Simultaneously, the period most often mentioned in open-ended comments is the 1980s.

Overall, the sentence "Colour slides are carriers of detailed images" had a consensual evaluation, with only 10 participants (2.3%) expressing disagreement (Fig. 5). More than half (262, 58.9%) find colour slide film difficult to preserve, with similar results across geographic regions. Concerns about the decay of these materials were expressed in the comment sections (e.g. colour change, mould growth). The most divergent answers were expressed when considering these materials' rarity and long-lasting nature.

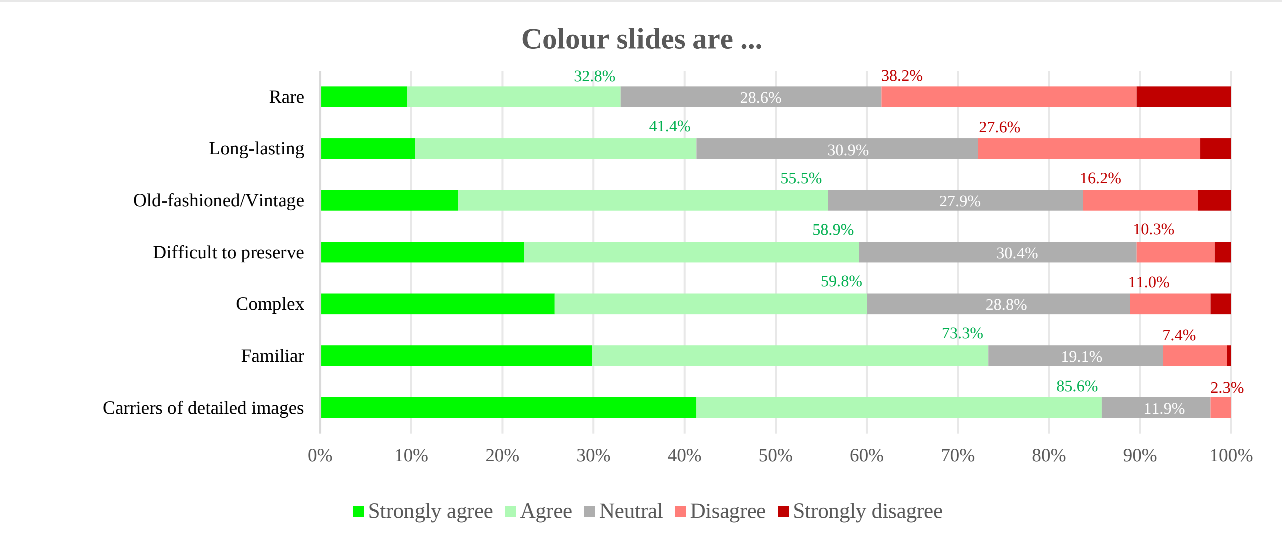

Fig. 5 – Overall responses to the prompt "Colour slides are…".

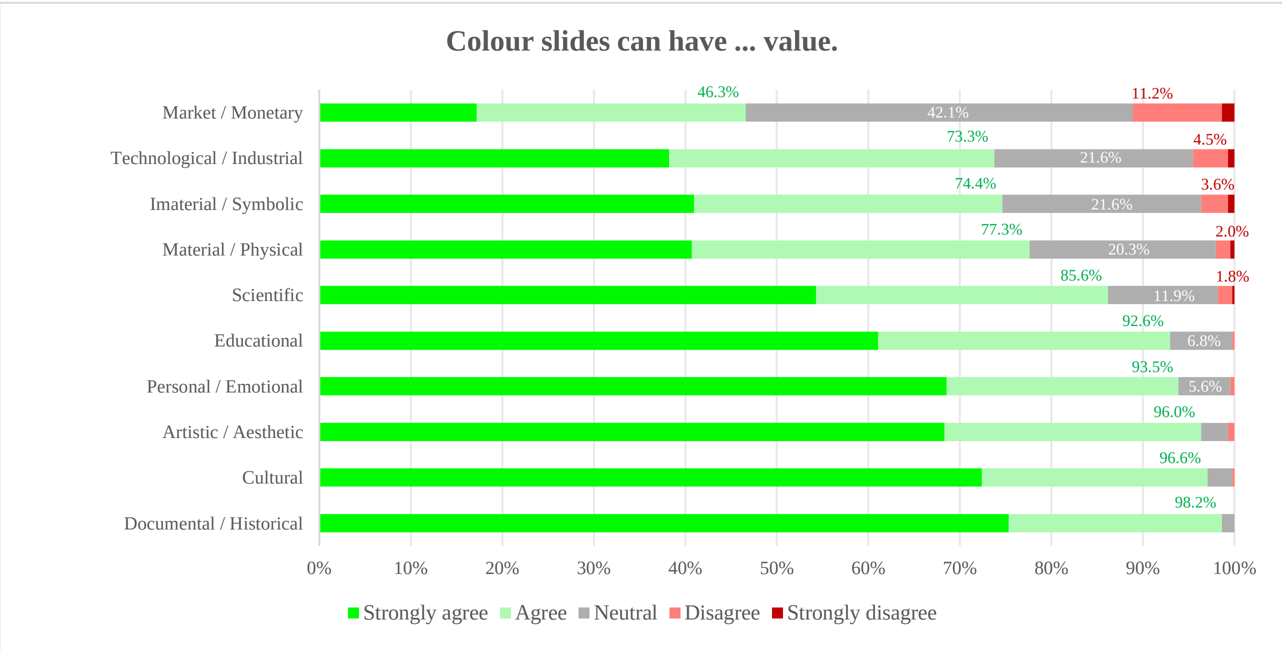

Fig. 6 – Overall responses to the prompt "Colour slides can have … value".

The value most participants associate with colour slides is Documental / Historical, with an overall agreement of 98.2% (437 people) (Fig. 6). Over 90% of participants agree that these objects can also have Cultural, Artistic / Aesthetic, Personal / Emotional and Educational value. A tendency towards neutral answers and disagreement is detected when considering Material / Physical, Immaterial / Symbolic, Technological / Industrial value, and Market / Monetary value. The latter was the value that produced the most varied opinions, with 187 of respondents (42.1%) choosing a neutral answer. Colour slide film may be considered valuable if associated with specific artistic practices, but it is not made with materials that are considered precious.

The cultural and environmental impact of colour slide film was evaluated with a wide range of opinions (Fig. 7). Over 80% of survey participants agree that these materials have had a strong impact on society, but a minority (16, 3.6%) does not share that view. More than half of all respondents provided neutral answers when evaluating the medium's environmental impact (255, 57.2%). Even so, 217 people (48.8%) agree that the production of these materials should continue. The sentence with the highest disagreement rate was "These materials had higher quality than digital-born photographs" (69, 15.5%).

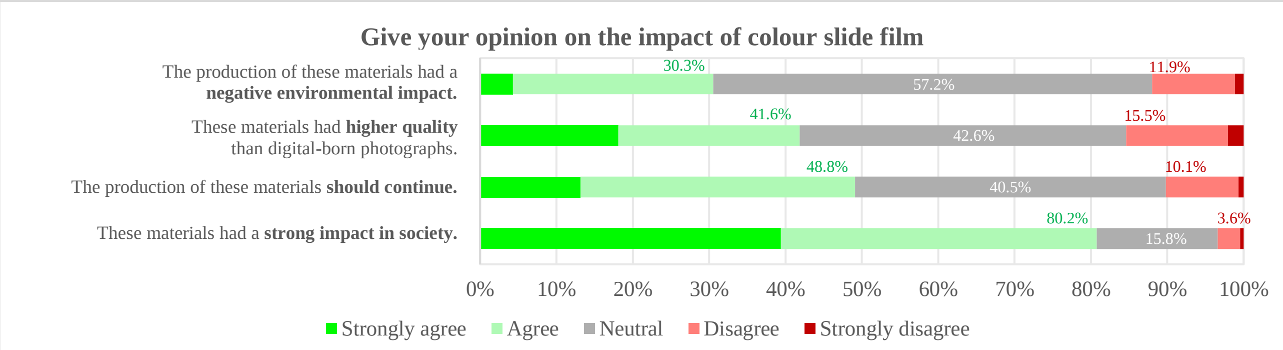

Fig. 7 – Overall responses on prompts related to the impact of colour slides.

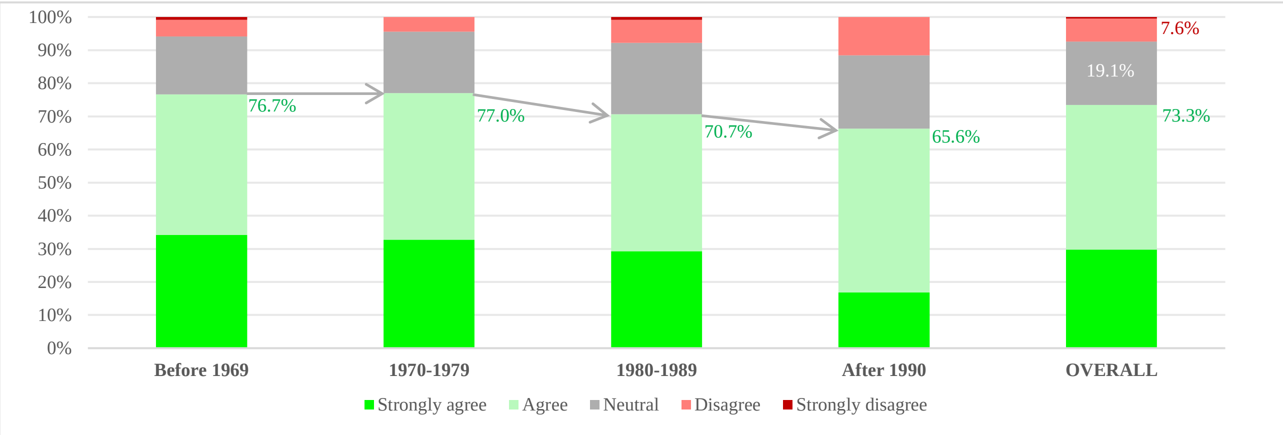

Fig. 8 – Responses to the prompt "Colour slides are familiar" according to birth period.

Discussion

The survey focuses on a type of photographic material that is no longer common and the analysis of birth periods demonstrates that younger generations are slowly becoming less familiar with these objects (Fig. 8). Most respondents born after 2000 (13, 2.9%) have a connection to conservation, and came across them in an educational environment. However, individuals from the same age group with different professional backgrounds are likely less familiar with these materials.

Socio-economic situations are often reflected through the analysis of data collected from different geographic regions. Ideally, the distribution of participants per region should be proportional but few responses were obtained from people residing in Africa & Western Asia, Asia (other regions), and Oceania, (25, 5.6%). Even so, these contributions provide insight into potential trends in those regions. There are some distinctions between the experiences of those residing in different regions: people living in Portugal, Africa & Western Asia, and Eastern & Southern Europe often associate their first experience with colour slide film with an educational context (between c. 39% – 67%) (Fig. 4). On the other hand, those living in Latin America, Northern & Western Europe, Northern America, and Oceania often had their first contact with these materials in a private setting (between c. 59 – 80%), which reflects the overall trend.

146 of respondents (32.8%) agreed with the sentence "Colour slides are rare" (Fig. 9). This result reflects the participants' individual concept of rarity, which is subject to their personal and professional contexts, as well as their socio-economic backgrounds. Those who do not consider them rare tend to associate them with a private context, but this is not linear. Such assessments are connected to those regions' socio-economic conditions and relationship with the global photography industry – either as a producer or consumer. As mentioned, in Portugal, they are often associated with education (e.g. slideshows during school lectures). A large portion of participants are connected to the Arts, Culture and Entertainment field but do not have a consensual opinion when it comes to the objects' rarity. It is possible that many do not have regular contact with slide film, if, for example, they work in institutions with no colour slide collections. Neutral answers are related to a lack of in-depth knowledge about the topic and the need to provide more complex answers.

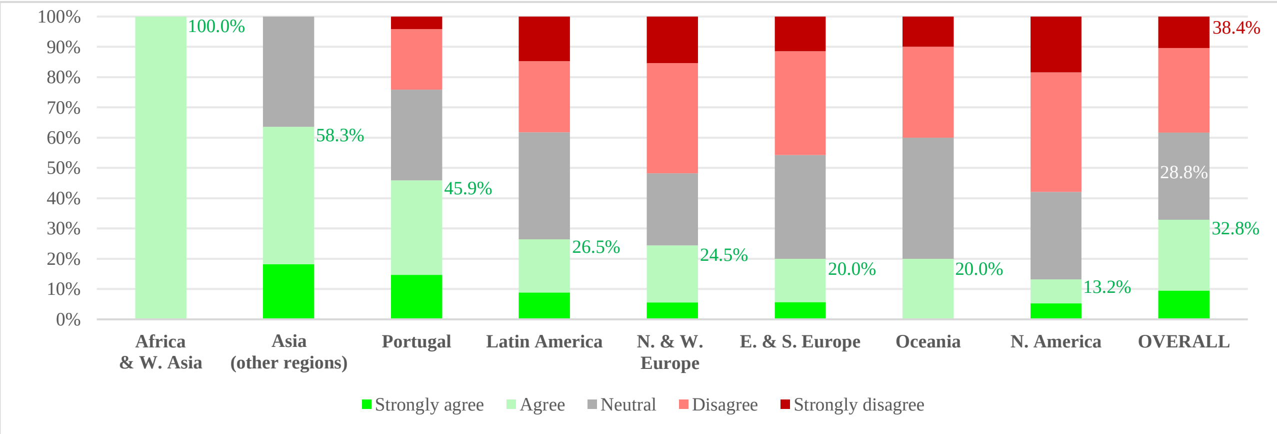

Fig. 9 – Responses to the prompt "Colour slides are rare", according to region of residence.

Often, the comment section underlines how for most respondents the primary way to ascertain the value of a photograph depends on the content of the image it carries. The materials and the scale of the industrial production processes necessary to manufacture colour slide film are not fully appreciated. Although colour slide film only exists due to the specialized scientific and technological knowledge of those who worked in the photographic industry, these values remain largely unrecognised (Fig. 6). Its connection to mass production and standardized processing in commercial labs makes them seem common and easily obtainable, especially when compared to handmade photographs. In a world that craves the newest devices, there is a struggle to understand how previous technologies inform contemporary practices.

Personal / Emotional value is recognized by most participants (416, 93.5%), independently of their age, country of residence, gender, professional interests, etc. In the comment sections, some of the most frequently mentioned words and ideas referred to people the respondents had a relationship with (e.g. parents, siblings, grandparents, friends) and formative periods (e.g. adolescence, childhood).

Colour side film was a social medium, the source of home entertainment, documenting and creating moments of leisure (e.g. holidays, gatherings, special occasions, Sunday afternoons, traveling). Specific feelings and moods are also noted (e.g. cosiness, familiar comfort, nostalgia). These photographs are often linked to people's private lives and their identity (e.g. ancestors, heritage, memories, remembering, traditions). However strong this connection might be, it will probably decrease as time goes by, unless the memories and emotions that colour slide film triggers are documented. It underlines that perceived value is very dependent on maintaining associations, and not only on an object's rarity (Fredheim and Khalaf, 2016).

The obtained scores reflect how the preservation of cultural heritage has a paradoxical relationship with environmental impact. Even though some respondents recognize that continuing the production of such materials might have had a potentially harmful effect on the environment (135, 30.3%), many showed interest in continuing its manufacture (217, 48.8%) (Fig. 7). However, the need for new, unexpired colour slide film continues, especially in the artistic world, where multiples of the same object are often necessary, either due to the production of various editions of the same work, and/or related to conservation strategies (e.g. Sommermeyer *et al.*, 2019). Even so, continuing production is unlikely unless it is deemed a profitable venture. Few references provide an in-depth view of the relationship between raw materials, film production, and environmental impact (e.g. Shanebrook, 2016, 65, 308; Levin, Ruelfs and Beyerle, 2022). Making such information widely available would provide a clearer perspective about these materials' effect on the environment and their sustainability.

Detailed comments mentioning material decay were often provided by participants connected to cultural heritage preservation and conservation. Many expressed their concerns when assessing the preservation and treatment of slide film. Prompted by the sentences "Colour slides are long-lasting" and "Colour slides are difficult to preserve" (Fig. 5), participants pointed out that high temperatures and humidity, light exposure and dark fading cause degradation. These factors were often mentioned by those who are aware of the importance of climate-controlled environments and perceive changes in colour and cellulose acetate film-base decay, as well as the development of potentially harmful microorganisms. A need for efficient and safe treatment methods is expressed, especially as decay is closely related to loss of value. In a contemporary art context, unwanted colour change often justifies the multiplication of photographic artworks (Sommermeyer *et al.*, 2019). This process can be very complex, as it is potentially manipulating its material and immaterial integrity.

Conclusions

The different perspectives surrounding these materials are not absolute truths, but specific to this group of participants. The obtained results are therefore considered conveyors of trends and denote the need to approach the subject with nuance, for example by obtaining feedback from more specific target groups in the future. While the survey design was overall considered efficient, some aspects could have been structured differently. For example, some participants expressed in the comment section that they chose the "Neutral" option as the equivalent of "I don't know". However, this is distinct from not choosing another answer because the participant has enough knowledge to evaluate the prompt's subjectivity and feels the need to provide a more complete and subtle response.

Colour slide film may no longer at the forefront of imaging technology, but it is currently still in the minds of older generations – to whom it is a carrier of memories and identity. On the other hand, the drive behind the medium's artistic revival needs to be explored and documented. To better understand colour slide collections, the practices and experiences that they were associated with need to be documented before this knowledge is completely lost and forgotten or they will not make the transition from communicative to cultural memory (Assmann, 2008). Furthermore, recognizing immaterial significance highlights their sociocultural value. Advocating for the preservation and cultural relevance of colour slide film, should emphasise not only material decay but also how the value of these photographs is reduced by a progressive loss of personal connection.

Although potentially more impactful in countries with histories closely connected to the establishment and development of the photographic industry, this survey shows how colour slide film reached people of different ages and regions, making an enduring mark across the visual culture of multiple societies. The survey's wide reach also corroborates that these materials are actively decaying in many regions due to lack of climate controlled storage. In cases where preventive conservation is no longer enough, issues such as colour change and mould growth need to be tackled through the development of more specific tools and treatments.

Due to its peripheral role in the photographic industry, the data gathered though this online survey helps discern that the Portuguese context has specificities that need to be reflected upon. Following this research, the questionnaire's outcome will be compared with the results of collection surveys that will explore the materiality, use, values and condition of objects in several Portuguese institutions.

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Infinito by Luigi Ghirri - Restoration and diagnostic imaging: an opportunity for further reasoning

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Abstract

The restoration of Luigi Ghirri's artwork *Infinito* 1974 was made possible thanks to the ministerial call *Strategia Fotografia*, which allowed the recovery of unique pieces from the Ghirri Fund (consisting in total of more than 1,600 preserved works) by the Centro Studi e Archivio della Comunicazione (CSAC) of the University of Parma. *Infinito* was exhibited in its entirety for only a few weeks in Parma, in 1979, at the Scuderie della Pilotta, in the anthology exhibition *Luigi Ghirri/Vera fotografia*, and could be considered one of the very rare site-specific installations by the great photographer.

Consisting of 365 chromogenic colour photographs taken of the sky for a year from 1973, one per day, the work was assembled indeed in 1979 and later stored, disassembled into its 12 panels, in the CSAC's storage rooms. While chromogenic colour photographs are among the most unstable materials in the history of photography, those of Luigi Ghirri and *Infinito* in particular, appear in many cases to have been matted with inhomogeneous materials, sprays of various kinds, and then glued in several places with double-sided tape onto unsuitable cardboard, subsequently nailed on two plywood panels side by side. In order to investigate how the state of preservation of the images had changed over time, a comparison with a photographic reproduction of the individual panels, carried out in 1992 also at the CSAC, was essential, showing how the images had chemically altered only in part, displaying in some cases very obvious toning, in others much less.

A Ultraviolet Fluorescence imaging diagnostic was used to analyze the famous "sky image mosaic" for restoration purposes. The diagnostic not only revealed insights into the methods used to create the artwork, but it also highlighted the various materials used in its construction. Additionally, the diagnostic shed light on considerations regarding the toning of the author's photographs. The restoration process, described in the contribution, emphasized the importance of investigating little-explored materials such as chromogenic development photographs. The article also discusses the deterioration of the original photographs, as evidenced by a comparison with archival images. This comparison, along with the applied diagnostics, led to the recommendation of periodic monitoring to track colour changes in each photograph and determine any intrinsic or extrinsic causes. The objective was to trace the cause of deterioration and assess potential changes during future placements of the artwork.

Keywords: Luigi Ghirri; chromogenic prints; colour fading; diagnostics imaging;

Introduction

The ministerial call for proposals *Strategia Fotografia* allowed the recovery of unique pieces of the Ghirri Fund preserved at the *CSAC* of the University of Parma, which are the composite artwork *Infinito* of 1974 that will be discussed in the article, the two leporellos, *Slot-machine* and *Km 0.250* and the two portfolios, *Colazione sull'erba* and *Paesaggi di Cartone*, all made with mixed materials. The remaining part of the fund, consisting of more than 1,600 preserved works, on the other hand, was the subject of conservation filing and detailed analysis of the degradations present.

Luigi Ghirri and the creation of *Infinito*

Luigi Ghirri began taking photographs in 1968, immediately turning to the art world, and is one of the few research photographers to systematically use colour photography. Known for his use of mixed materials in his work, a practice that reflects his attention to detail and the craftsmanship of his work, Ghirri had the ability to make even the editing process an essential part of the aesthetic experience of his photographs.

Entire works such as the portfolios (*Paesaggi di Cartone* and *Colazione sull'erba*) and the leporellos, also the subject of the aforementioned restoration, are in fact photographic objects composed of various materials: pressed wood, faesite, ribbons of various kinds, and cardboard of different types and weights, often accompanied by texts and annotations written in "letraset", transferable characters that create a narrative context for the photographs.

The finalization of the artwork *Infinito* took place in the spring of 1979 and was the conclusion of a research conceived in 1973, a year in which Ghirri decided to take one photograph a day for an entire year. We do not know whether this project was originally intended to arrange all the photographs in a single table, or whether, as with the other series exhibited in the *Luigi Ghirri/Vera fotografia* retrospective and published in the accompanying catalogue (Mussini et al. 1979), it was an arrangement of the photographs taken during that year in a combinatorics conceived for the exhibition.

In the 1979 exhibition, indeed, the large work *Infinito* closed off the space of the long hallway of the Sala delle Scuderie in the Pilotta Building in Parma, and with its 365 prints pasted on 12 large-format cardboards, it constituted a striking backdrop, which one was confronted with almost suddenly, and in this sense we can consider it as a site-specific work, conceived and created precisely for that space (Barbaro *et al*., 2010).

The construction of the artwork was probably conceived in the author's home, only to be completed at the exhibition site itself: many photographs are in fact already "matted", probably in the studio of Arrigo Ghi, then the printer of choice for Ghirri, as well as for the few colour photographers active in Modena, such as Franco Vaccari, Beppe Zagaglia, and others were also reprinted for the occasion in other industrial workshops, such as, for example, those of Villani and Galotti. The new prints were then pasted onto cardboards, on which thin slender pencil grids can be seen, then erased, or in some cases retouched with Kodak's Pearless anilines, and then subjected to further matting, presumably with an opaque fixative for charcoal drawings.

The individual cardboard panels were then nailed to plywood panels, in some cases with double-sided tape on the back to prevent sagging and bending once the assembly was placed vertically for the exhibition.

The environment of the Sala delle Scuderie lacks conditioning, resulting in uncontrolled values for the duration of the exhibition, which extends over a period of two and a half months. In contrast, the air-conditioned room within the CSAC, where the work was divided into 12 panels, was subsequently conditioned to maintain a constant temperature and humidity range of 14-17°C and 40-60% RH, respectively.

Even after the CSAC's collections were moved, first to the Padiglione Nervi (in 1991) and then to the Abbazia Valserena in Paradigna (nel 2007), *Infinito* has always been kept at a constant temperature and humidity.

The posthumous life of the artwork has seen only two integral exhibitions, at the Mole Antonelliana in Turin and at the Biblioteca Palatina in Parma, with an exhibition project that included its suspended horizontal arrangement, later abandoned for reasons of the artwork's safety.

Description of the artwork

Infinito consists of twelve rectangular panels of coated cardboard on which are mounted a total of 365 C-Print photographs, each measuring approximately 14 x 8 cm. The photographs are evenly distributed but vary in number, depending on the size of the panel. In fact, the panels do not have the same dimensions, but they range from a maximum of 67.9 centimeters in height and 76.7 centimeters in width to a minimum of 48 centimeters in height and 75.8 centimeters in width. Each panel is characterized by the presence of a progressive number from one to twelve written in pencil on the verso, and corresponding to the sequence in which the panels were assembled in the case of an exhibition. Also shown on the twelfth is the diagram of the placement devised by the artist, which involved the arrangement of the panels in three rows of four elements. When assembled, the large-scale work would measure 1.84 x 3.04 meters (Fig.1).

Fig. 1 - *Infinito* 1974. Digital restitution of the mounted artwork

Although Ghirri himself carried out the realization of the artwork, the method of assembling the photographs and the materials used on the panels do not follow a specific pattern, an aspect that further emphasizes the photographer's personality by highlighting the artistic process that led him to the final stage of the artwork. Specifically, both glossy and semi-matte photographs are identified on the work, while their application to the panels is distinguished by the type of adhesive used and the method of applying the adhesive to the back of the photographs. These characteristics of heterogeneity can be found on all the panels in more or less obvious proportions.
The first panel of the artwork, for example, consists of thirty-five photographs, with twenty-eight having a glossy finish and seven having a semi-matte finish. The method of gluing the photographs to the panel also varies. In most cases, the glue drafts are applied near the upper and lower margins, but in three instances, the drafts are applied on all four margins. In one case, the drafts are limited to the side margins and upper margin. These differences suggest that the artwork was a result of a long and creative process, rather than being hastily completed. The complexity of the work, both in terms of materials and concept, required special attention during the restoration process. The restoration intervention aimed to secure the work and establish a preservation method, including periodic monitoring to control the progressive colouring of the photographs.

State of conservation in visible light: a comparison with the 1992 photographic survey

Prior to entering the laboratory, the work was observed to be disassembled within a folder crafted from conservation cardboard. Each panel was interleaved with tissue paper for the purpose of preservation. The initial analyses, which were conducted with the objective of defining the work's state of conservation and subsequent restoration, were performed in visible light and immediately revealed a generalized yellowing of the coated backing boards and a consistent presence of foxing, which was particularly evident on the lower band of each.
Additionally, the reverse side of each panel exhibited substantial abrasions to the superficial layers of the cardboard, which are presumed to have been caused by the disassembly of the supports from a larger surface, likely the plywood panel utilized in the installation of the Sala delle Scuderie exhibition. The edges of the panels also exhibited substantial dents, tears, and flaking of the corners. The photographs were generally in a state of preservation that could be described as poor. The prints

displayed evident mechanical damages, including slight flaking at the corners and dents with lifting of the first photographic layer at the edges. The damage was more or less severe, with tears evident in some cases. The surface of the photographs also showed substantial surface deposits and adhesive residue, derived from mounting, which was visible on the image side of the photographs. As anticipated, even in visible light it was detectable, in addition to the perimeter yellowing caused by the oxidation of the adhesive used, a steady chromatic decay that led most of the photographs to take on a hue tending toward magenta and yellow, in more or less pronounced percentages. Despite the adequacy of the materials and parameters used for preservation at the CSAC, a significant change in the colour of the photographs was immediately apparent, compared to what could be verified from the 1992 photographic campaign carried out by Dr. Paolo Barbaro (Fig.2-3).

Fig. 2 - Panel n.1 in a photograph taken in 1992 and the same panel today

Fig. 3 - Panel n.6 in 1992 and the same panel today

At this point, however, it proved extremely difficult to visually hypothesize the causes that might have accelerated the process of colour fading of some photographs compared to others: among them could be the mounting method and glue used, the type of finish/varnish, the type of photographic paper, the printing year. Our work is therefore part of a process of documenting the conservation evolution of the artwork, which continues the one begun in 1992. In this way, our work introduces a new piece to the existing corpus of knowledge about the artwork.

For this reason, it was decided to allocate a part of the research to the realization of high-resolution Ultraviolet Fluorescence photographic images, with the objective of identifying potential discrepancies between the materials utilized in the artwork. Ultraviolet Fluorescence is, in fact, a practical diagnostic investigation technique that can be documented by photographic acquisition. It is currently a widely used non-destructive examination technique in the field of conservation of works of art. In the field of conservation and restoration of photographic materials, however, the application of this technique is still somewhat circumscribed.

Ultraviolet Fluorescence Analysis

In this initial phase of the study, an analysis was therefore proposed that would encompass the entirety of the work, including all 365 photographs, while maintaining a reasonable cost. The hypothesis of using techniques such as X-ray fluorescence (XRF) or Raman spectroscopy to obtain more detailed chemical and structural information at the individual case level would not have provided an overall view of the artwork, as the data obtained would not have been representative of the entire set of 365 photographs. Therefore, this hypothesis was not deemed to be the most suitable for the purposes of this study. Ultimately, Ultraviolet Fluorescence analysis was considered the most suitable method for acquiring as much data as possible, with the dual objective of resolving the research questions and establishing a foundation for future studies and analyses.

The analyses were carried out in a totally darkened environment, with the panels placed on a Polaroid MP4 repro photo stand, with a black background. The photographs were taken with a medium format sensor camera, using the current ministerial parameters (ICDP, 2022). Two Wood's lamps with peak emission at 365 nanometers, consisting of twenty tubes with length equal to 60 centimeters, were used for the analysis (Fig. 4).

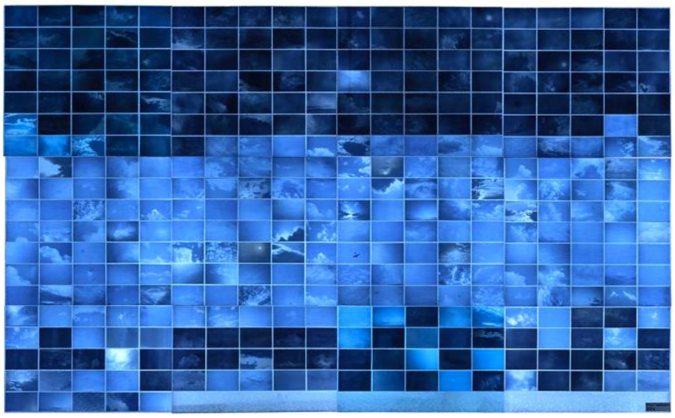

Fig.4 - Digital restitution of the mounted artwork under UV Fluorescence

In examining the ultraviolet fluorescence of *Infinito*, there were identified two discernible categories of response. Some of the prints displayed a pronounced fluorescence when exposed to ultraviolet light, whereas others exhibited minimal fluorescence. The less fluorescent photographs also tend to remain dark in the lighter areas, corresponding to the white of the clouds, thus generating an image with almost homogeneous tones. Upon further examination, it was observed that the photographs with the most pronounced fluorescence were characterised by a semi-matte finish. However, this finish was not exclusive to the highly fluorescent photographs, as it was also found on other photographs with muted fluorescence, which typically had a glossy finish. In such scenarios, the key differentiating factor between these two categories of fluorescence is the presence of a unique finish on the less fluorescent objects, characterised by a dense, irregular, dotted network, bearing resemblance to a spray paint treatment (Fig. 5). In contrast, the more fluorescent images appear to have undergone a further surface treatment, applied with a brush, in which horizontal brushstrokes are identified (Fig. 6).

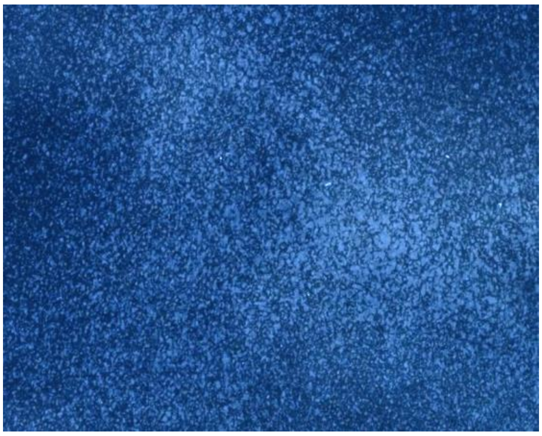

Fig.5 - Magnification 2x of dotted pattern

Fig.6 - Magnification 2x of horizontal layers

When viewed in their entirety, it is evident that these brushstrokes have imparted greater resistance to ageing and colour change, as they all appear less degraded to the eye. Proof of this, worthy of note, is the presence of a particularly fluorescent milky percolation, almost invisible to the naked eye, on a photograph belonging to those with dark fluorescence (Fig. 7). The percolation displays a fluorescence that is comparable to that observed in photographs with a horizontal brushstroke finish. This evidence therefore leads to the hypothesis that the percolation may indeed be referable to a type of varnish applied only to certain photographs.

Fig.7 - Bright percolation under UV fluorescence

Another piece of evidence that supports this hypothesis is the presence of stains and fingerprints, which are visible as dark patches on the most fluorescent photographs. In these cases, the chemical and mechanical removal of the second protective layer, which results in a decrease in ultraviolet brightness, demonstrates that the fluorescence is not caused by the type of paper or printing, but is instead due to a surface coating that, where missing, leaves a glimpse of a surface entirely similar to the other darker photographs.
In conclusion, the data indicates that all the photographs in the work were initially treated with a spray paint, and that only some were subsequently brushed over with other liquid paint.

Considerations for preventive and planned analysis and conservation

These considerations, derived from an integrated optical and multispectral examination, provide precise indications regarding the photographer's creative process and may lead to more specific insights into the chemical nature of the different surface treatments of prints in the future. Most relevant is the determination of the use of different coatings in the context of a single work. Additionally, the evidence of how these different coatings can contribute to the preservation of the photographic material over time is noteworthy.

The analyses of the state of preservation, supported by examinations in visible and ultraviolet light, were ultimately decisive in determining the restoration method, which aimed to eliminate traces of residual adhesive, fingerprints, and inconsistent deposits. Additionally, the method highlighted the numerous original retouches that would otherwise have remained undetected.
The intricacy of the work, both in terms of its material composition and conceptual underpinnings, necessitated a meticulous approach to restoration. The primary objective was to safeguard the work, while the secondary objective was to establish a preservation strategy and implement a monitoring system to regulate the progressive colouring of the photographs.
As a result, it is challenging to make long-term projections regarding the chromatic deterioration of chromogenic developed prints. At present, it is not possible to state with certainty whether the decay process has slowed down or whether it will continue to accelerate until the photographs are completely different. It is also unclear whether the less toned photographs will deteriorate drastically in the short term or whether, in a few years, the difference between one group of photographs and the others will become even more pronounced. Furthermore, it is uncertain whether a better tonal balance will be perceived.
The artwork *Infinito* was deemed to be of sufficient importance and uniqueness to serve as a prototype for a prospective colour detection campaign. This campaign would assess the progressive decay of the work and could potentially be extended to the entire Luigi Ghirri Collection, which is preserved at the CSAC.
The project entails the implementation of an annual monitoring system for colour, whereby colourimetric measurements are acquired and translated into numerical values. In the case of *Infinito*, a black cardboard mask was constructed to the same dimensions as the photographs, with a central compartment measuring one centimetre by one centimetre. This was done to enable the measurement to be taken consistently by placing the measuring instrument in the same location on each occasion (Fig. 8).

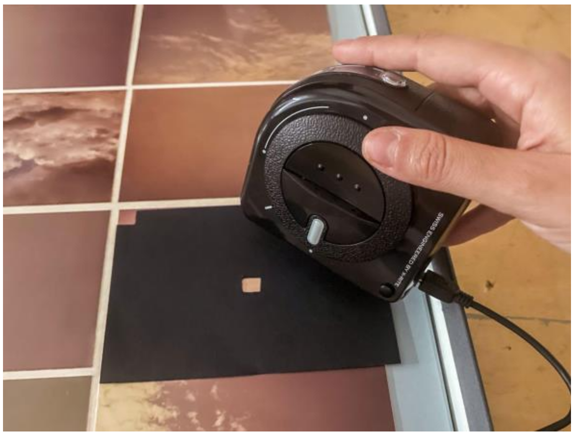

Fig. 8 - Colour percentage measurement on a photograph of *Infinito*

In this project, the *X-Rite ColorMunki Color Picker* was employed for the purpose of measurement. The measurement entailed the acquisition of ten values for each photograph, with a weighted average calculated for the percentages of the RGB channels, translated into HTML codes. This resulted in a universally recognised numerical value for each colour. The objective is to maintain control over time over the average of the values taken through a repeatable measurement at regular intervals. In the event of significant variation in the values, a new photographic acquisition campaign may be required to assess the variation.

Conclusions

The following conclusions may be drawn from the evidence presented.
The restoration of an artwork as iconic and complex in its polymatericity as *Infinito* requires careful investigation and the selection of appropriate imaging diagnostics. The choice of imaging diagnostics, moreover with limited costs, has proved effective in providing an overall view of all the prints with

chromogenic development as well as highlighting certain elements related to chromatic decay, the presence of adhesives and retouches.
The selective cleaning, consolidation and even structural and pictorial restoration were carried out with the support of Ultraviolet Fluorescence, which enabled the two disciplines of restoration and diagnostics to communicate and rely on each other.
Subsequently, the proposed periodic monitoring enables the control of chromatic variations over time, utilising a straightforward yet informative instrument for the long-term conservation of a unique work of art.

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Colour change tools to assess Honey Syndrome and Vinegar Syndrome in motion picture films

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Abstract

Motion picture films with support in cellulose nitrate or cellulose triacetate are extremely vulnerable. Deterioration is mainly attributed to the depolymerization of cellulose polymers, leading to the emission of gaseous nitric or nitrous acid and acetic acid, respectively. The acidity (pH) of any state of matter (liquid, solid, or gaseous) can be friendly and readily detected using pH indicators. Among these indicators, the most employed is litmus paper, which changes colour following a known chromatic scale in accordance with the pH level. Various tools are used by the community of professionals and insiders in cinematographic archives. In the case of acetic acid emitted by cellulose triacetate films subjected to Vinegar Syndrome, the Acid Detection (AD) Strips® (Image Permanence Institute), Danchek Strips® and Danchek Control Eye® (Dancan Cine Film Service S.L.), and Gastec Detector Tubes® (Gastec Corporation) are the most widely used. Conversely, less known are the efforts to develop similar tools for the early detection of Honey Syndrome affecting cellulose nitrate films. Pros and cons in employing these tools are outlined in this contribution. Although assessing the progress of both syndromes based on the colour change tools is user-friendly and cost-effective, the interpretation of outcomes can be significantly influenced by the user's perception.

Keywords: cellulose triacetate film, cellulose nitrate film, colour change, early warning tool, monitoring.

Introduction

This contribution focuses on the use of colour change tools to monitor Honey Syndrome and Vinegar Syndrome in cellulose nitrate and cellulose triacetate motion picture films, respectively. This activity is pivotal for the preventive conservation in film archives (EN 15898:2011; ICOM-CC, 2008; AIC, 2018), since effective monitoring and control of the conservation state of films and microclimate conditions ensures timely interventions, prolonging their lifespan. Indeed, the conservation state of cellulose nitrate and triacetate films is strongly influenced by microclimate conditions and by the presence of acidic compounds. While protocols for microclimate monitoring are well established, the monitoring of gaseous compounds has yet to be standardised.

Nevertheless, some colour change tools have been developed to serve as early warning tools, enabling the detection of acidic compounds emitted by films in syndrome. The literature documents various attempts, more or less successful, to employ tailored litmus papers-like and grains-like indicators. Specifically, paper strips and silica gel grains imbued with pH-sensitive dyes have been used to provide early detection of film chemical instability and assess their preservation state.

Cellulose nitrate and cellulose triacetate motion picture films chemical deterioration

Historical motion picture films with support in cellulose nitrate or cellulose triacetate are polymeric materials, that depolymerize, emitting gaseous acidic compounds: nitric or nitrous acid in case of cellulose nitrate, and acetic acid, for cellulose triacetate.

Cellulose nitrate was first used as support for photographic roll film by George Eastman in 1889, and it became widely employed in the motion picture film industry from the 1890s until the 1950s. It is characterized by its intrinsic extreme flammability, and its primary chemical decay is commonly referred to as the "Honey Syndrome".

Cellulose triacetate, introduced as a support for motion picture films in 1948, gained widespread use from the 1950s onwards, replacing nitrate film. It remained the dominant film support until the 1990s, when it was eventually replaced by polyester. As polyester, cellulose triacetate is often called "safety film" because is non-flammable, unlike its predecessor. The main chemical decay affecting cellulose triacetate films is commonly known as the "Vinegar Syndrome".

The progression of Honey Syndrome can be described in five macroscopic stages:

1. Bleaching of the silver image, giving the film an amber colour;
2. The film becomes sticky and brittle;
3. Surface bubbles form, resembling liquid sugar, which gives rise to the term "nitrate honey";
4. The film becomes soft, welding to adjacent film layers;
5. The film degenerates into a solid mass of brown powder.

At the microscopic level, Honey Syndrome involves the depolymerization through a radical propagation mechanism. In this process, nitro groups detach from the cellulose chain, leading to the formation of nitrogen oxides (NO_x). These oxides react with free water vapour available, forming nitrous acid (HNO_2) and nitric acid (HNO_3). This causes a lowering of film's pH, thereby accelerates further degradation (Nunes, *et al.*, 2020).

The Vinegar Syndrome follows a similar five-stage macroscopic progression:

1. A distinct vinegar-like odour emerges;
2. The film deforms and shrinks;
3. Emulsion loss occurs, rendering the image unreadable;
4. Plasticizers exude, forming crystals on the film surface;
5. The film softens until it eventually liquefies.

On a microscopic level, Vinegar Syndrome consists in a hydrolytic deacetylation mechanism, where acetyl groups detach from the cellulose chain, causing a reduction in the degree of polymerization and the release of gaseous acetic acid (CH_3COOH). This acid lowers the film's pH, further exacerbating the process (Nunes, *et al.*, 2020). The autocatalytic nature of Vinegar Syndrome is particularly notable, as acetic acid acts both as a product and a catalyst, further triggering deacetylation. Moisture plays a crucial role for the hydrolysis initiation, while temperature higher than 15°C accelerates the reaction rate. Once triggered, the presence of acetic acid is the most critical factor, perpetuating the autocatalytic cycle of deterioration.

Colour change tools to detect Honey Syndrome

This section provides the main tools used for assessing Honey Syndrome in cellulose nitrate films.

Dyed silica gel grains are generally contained in glass vials with a graduated scale. Gastec and Dräger (Grzwacz, 2006) tubes are filled with silica gel grains imbued with a pH indicator dye and are commonly used to detect gaseous nitric acid (HNO_3). These tubes are only available in an active form, meaning they require the use of a pump to collect air samples. To assess whether a nitrate film is degrading and, therefore, emitting nitric acid as a byproduct of Honey Syndrome, air in close proximity to the film is collected into the vial using the pump. This process takes just a few minutes, after which the result can be immediately and directly read. The greater the concentration of detected nitric acid, the more advanced the deterioration of the film. In Gastec Detector Tubes (model 15L, range 0.1-40 ppm) the colour shifts from light-yellow to reddish-purple, while in Dräger Detector Tubes (model 1/a, range 1-15 ppm or 5-50 ppm) the colour changes from blue to yellow. Similar detection tools are available for sampling nitrogen oxides (NO_x) (Grzwacz, 2006), which are released during the depolymerization of nitrate films and react with water vapour to form nitrous and nitric acids. These tools can be used in both active and passive mode. The active tubes work with a pump. For example, in active Gastec Detector Tubes for nitrogen oxides the colour changes from white to yellow-orange (model 9L, range 0.5-125 ppm) or from white to brown-orange (model 9P, range 0.02-0.2 ppm). While active Dräger Detector Tubes for nitrogen oxides show a colour change from grey-green to blue-grey (model 0.1/a, range 5-30 ppm or 0.1-5 ppm) or from yellow to blue-grey (model

2/c, range 5-100 ppm or 2-50 ppm). The passive tubes are designed for longer exposure times, typically over 24 hours, but they can be left in place for up to a month. In this case, the vials are placed within the film can and air in contact with the film is sampled into the vial by passive diffusion. The indicator dye impregnating the silica grains changes colour in response to oxidizing compounds present in the air. In passive Gastec Colour Dosimeter Tubes for nitrogen oxides the colour changes from white to green (model 9DL, range 0.01-3.0 ppm) or from white to yellow (model 9D, range 0.1-30 ppm). Similarly, passive Dräger Colour Diffusion Tubes for nitrogen oxides show a colour change from white to yellow-orange (model 10/a-D, range 1.3-200 ppm). The results are read directly from the graduated scale, and various vials are available to cover different concentration ranges. Specific colour changes can vary between different types of vials, depending on the compound being sampled and detection range required.

No commercially available tools made of paper strips imbued with pH indicator dyes currently exist for assessing Honey Syndrome. However, in 1995, Fenn proposed a promising experimental method consisting in soaking non-buffered filter paper with an aqueous or alcoholic (methanol or ethanol) solution of Cresol Red or Cresol Purple (Fenn, 1995). Both Cresol Red and Cresol Purple are pH indicator dyes, that change colour in response to variations in pH. Specifically, their colour shifts from yellow to red as the acidity increases starting from neutral conditions. In this method, the paper strip, initially yellow, is placed within the film can for a period comprised between 1 to 5 days. If no colour change occurs, the film is stable and not emitting harmful compounds. However, if the strip turns red, it signals an increase in acidity, indicating that the film is affected by Honey Syndrome and undergoing deterioration. The purple colour, indicative of a basic pH, is not relevant in this context. Although this approach has shown potential, unfortunately it remains in the experimental stage, and such strips are not yet commercially available (Hatchfield, 2004; Roldão, 2018).

Colour change tools to detect Vinegar Syndrome

Due to the autocatalytic nature of Vinegar Syndrome, it is essential to have an effective early warning tool capable of detecting the initial stages of decay in individual cellulose triacetate films, allowing for the isolation of affected ones to safeguard the rest of collection from "cross-infection". Among the most widely used tools for this purpose are Acid Detection Strips® (IPI, 2022), Danchek Strips® and Danchek Control Eye® (Fischer & Reilly, 1995), and passive/active Gastec Tubes® or Dräger Tubes® (Grzwacz, 2006; Kemper & Herm, 2023).

A commonly employed method involves the use of acetic acid passive samplers in the form of dyed paper strips. These strips are imbued with Bromocresol Green, a pH indicator that changes colour depending on acidity: from blue (di-anionic form), passing shades of green, to yellow (mono-anionic form). As acetic acid emissions increase due to the progression of Vinegar Syndrome, the film's pH decreases, determining a corresponding colour change in the strips. A fresh unaffected film, with a pH of approximately 6, does not release acetic acid, and the strip remains blue. As degradation progresses, the strips turn green, indicating rising acidity, and finally yellow, signifying a severely affected film with high acetic acid emissions and a substantially reduced pH (below 4). These strips are among the most frequently used tools for monitoring the stability of cellulose triacetate films and assessing the onset and progression of Vinegar Syndrome. There are two available commercial brands for these strips: Acid Detection (AD) Strips®, developed by the Image Permanence Institute (IPI), and Danchek Strips®, produced by Dancan Cine Film Service S.L. IPI AD Strips® come with a discrete colour scale, printed on a pencil or card, correlating the colour changes to acetic acid concentrations in parts per million (ppm) (IPI, 2022), whereas Danchek Strips® come with a discrete colour scale linking colour changes to the film pH values (Fischer & Reilly, 1995).

Additionally, tools based on dyed silica gel grains are available for assessing Vinegar Syndrome in cellulose triacetate films. The Danchek Control Eye®, for example, is a passive tool that can be inserted into the side of the film can through a small hole. Within the transparent plastic container of the "eye", silica gel, imbued with the pH indicator dye Bromocresol Green, changes colour based on the acidity of the air within the film can. The advantage of this tool is that archivists can monitor the condition of a film without opening the can. A colour shift from blue to green or yellow in the "eye" silica gel grains indicates that the film is emitting acetic acid and, thus, undergoing deterioration. Gastec and Dräger colour-change tubes can also be used to assess the presence of acetic acid (CH_3COOH) emitted by cellulose triacetate films (Grzwacz, 2006; Kemper & Herm, 2023). These tubes work similarly to those used for detecting nitric acid or nitrogen oxides in nitrate films affected by Honey Syndrome. They can be used actively, by pumping air into the vial, or passively, by leaving the open vial within the film can for a period typically ranging from days to weeks. For instance, passive Gastec Colour Dosimeter Tube (model 81D, range 0.5-100 ppm) and active Gastec Detector Tubes (model 81, range 1-100 ppm, or model 81L, range 0.125-23 ppm) change colour from pink to light-yellow when sampling acetic acid. Similarly, passive Dräger Colour Diffusion Tube (range 1.3-200 ppm) and active Dräger Detector Tube (model 5/a, range 5-80 ppm or 40-800 ppm) shift from blue-violet to dark yellow.

Conclusions

This review addressed both commercial and experimental colour-change tools available for the early detection of both Honey Syndrome in nitrate films and Vinegar Syndrome in cellulose triacetate films. Some advantages and limitations can be outlined in the use of these tools. These tools are generally easy to use and handle, and the cost is relatively low, typically under $100/packet. Passive samplers require at least 24 hours, depending on storage temperature, while active samplers provide results in few minutes. This makes it possible to obtain a real-time and direct reading. The method is suitable for large-scale application, which is beneficial for huge film collections usually stored in cinematographic archives. However, pH indicator dyes may fade when exposed to light and colour change can be influenced by other chemicals compounds. Additionally, results are relative and not quantifiable in absolute terms as depend on user's sensitivity. The subjectivity in the interpretation of outcomes can be overcome refining the methodology to read colour changes (Hackney, 2016; Townsend, *et al.*, 2023; Zachman, *et al.*, 2023). This is pivotal to bring this method from a theoretical concept to a practical application, making it a reliable tool for film archives (Vergelli, *et al.*, 2023).

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Color and original soundtrack restoration of experimental films by Italian artist Roberto Taroni

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Abstract

This paper presents the restoration work carried out on several experimental color films by Italian artist Roberto Lucca Taroni, all of which were originally shot on small gauge films in the 1970s and presented serious color fading issues. The artist boasts an extensive body of experimental film production [1], often delving into Expanded Cinema, emphasizing the cinematic experience as a total event by pushing the boundaries of the medium through innovative use of screening, sound, and space. Taroni's work includes films shot in 8 mm, Super8, and 16 mm, along with numerous audio sources recorded on various sound formats, mostly magnetic. Some of these works were originally conceived as multimedia art installations, comprising both films and external sound elements, the latter of which were generally controlled live by the artist or by a tape-loop system. This posed a major challenge during the restoration process, as some of these works needed to be adapted into a single-channel version suitable for screening. Other materials also saw the re-activation of the original installations after their digital restoration by exploring the usage of modern technologies such as Virtual Reality (VR) in recreating the original environment. The films materials were previously digitized by the Camera Ottica Lab of the University of Udine in 2022, when the first author of this paper was part of the intervention team. Due to the significant color fading issues and deterioration, the digitized film materials required an extensive color correction intervention to reestablish their original color palette. The color correction intervention was also carried out based on the indications provided by the artist, who participated in the restoration process by supervising the operational decisions. The original soundtracks, which were digitized by the Centro di Sonologia Computazionale (CSC) of the University of Padua [2] from ¼" open-reel tapes and audiocassettes, underwent a considerable digital restoration intervention as well, due to the numerous audio signal issues, such as a significant amount of noise, harmonic saturations, signal dropouts, and generally poor-quality audio. In this contribution, the materials by Taroni are investigated by means of concerns and techniques employed for the restoration of both soundtrack elements and film materials, underlining the choices made during the color correction and the digital audio restoration in revitalizing the original artworks.

Keywords: color correction; film preservation; audio restoration; experimental film; art installations

Introduction

In 2014, the Centro di Sonologia Computazionale (CSC) of the Department of Information Engineering (DEI) of the University of Padua (Canazza and De Poli, 2020) started to investigate the topic of preserving multimedia art installations (Bressan and Canazza, 2014). Our effort led to the development of the Multi-level Dynamic Preservation (MDP) model for documentation, preservation, and reactivation of original complex artworks (Fiordelmondo *et al*., 2023). Currently, we are carrying out our research activity proceeding with case studies, and working with several artists to reactivate and restore their original artworks. Some examples are the reactivation of *Il caos delle sfere* by Italian composer Carlo De Pirro, and of *Il tempo consuma* and *Autoritratto per 4 camere e 4 voci* by Michele Sambin (Fiordelmondo, 2019, Russo et al., 2024). Among these projects, a particularly interesting case study concerns the digitization, restoration, and reactivation of the audiovisual archive of Italian artist Roberto Taroni. Since the 70's, Taroni has been a central figure in the Italian artistic scenario, particularly significant in the fields of Expanded Cinema (Youngblood, 2020) and multimedia art installations. His work sits at the intersection of visual and sound experimentation, exploring the boundaries of traditional film medium. His multimedia installations focus on the interaction between the audience and the artwork, breaking conventional barriers between art, cinema, and technology. Taroni stands out for his ability to blend different expressive languages, anticipating trends that would later become central in contemporary art. Taroni's audiovisual archive includes original film and sound materials of various formats used in his artistic production. However, these documents, often filmed/recorded on obsolete formats, required a digitization and restoration intervention to allow their future preservation. An initial digitization project was undertaken by the Camera Ottica Film and Video Restoration Lab of the University of Udine (Comin, 2022) in 2022, focusing primarily on the artist's film materials. The project was related to *Taroni-Cividin. Performance, Video, Expanded Cinema (1977-1984)*, (Malvezzi and Pitrolo, 2023) supported by the Directorate-General for Contemporary Creativity – Italian Ministry of Culture under the Italian Council program (2021). In 2023, the CSC took over Taroni's audio archive, initiating a process of digitization and restoration of the audio documents used in the original performances and installations of the artist. In the following sections, we present the restoration work carried out at CSC on three experimental films of the artists, *Camera Car* (1979), *Around About* (1979), and *Speedy Life* (1979) which features both sound and film elements.

Film and sound materials

Taroni's film work includes small-gauged films, such as 8 mm, Super8, and 16 mm, along with numerous audio materials recorded on various sound formats, mostly magnetic. Several of his works were originally conceived as multimedia art installations, featuring external sound elements that were controlled live by the artist or by a tape-loop system. Taroni's audio archive comprehends 1/4" open-reel magnetic tapes and various types of audiocassettes, including endless tapes, which were used by the artist to create loops ranging from 3 to 12 minutes in length. The original documents were digitized applying the preservation methodology developed by the CSC and improved within numerous preservation projects (Pretto et al., 2020). For the digitization of the open-reel tapes we used a Studer A810 (2-channel tapes), an Otari MX5050 (4-channel tapes) During the restoration process, the Fostex 8-channel open-reel recorder, originally used by the artist to record his tapes, was also repaired and later used for the A/D transfer of 8-channel tapes. In fact, the magnetic tapes featured different configurations, with recordings ranging from 2 to 8 channels, since Taroni often worked with multiple channels to create immersive audio environments.

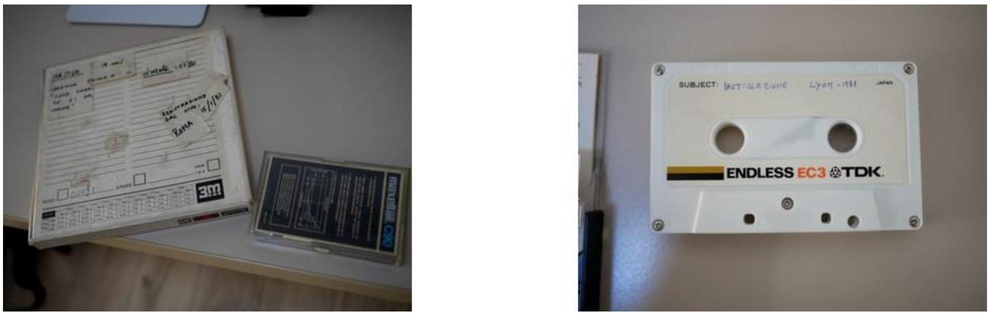

Figure 1 - Original open-reel tape and endlesss cassette from Taroni's audio archive.

Case Study 1 – Camera Car (1979)

The experimental film *Camera Car* (1979) is an interesting work that features both visual and sound elements. It consists of 18 scenes, each paired with a specific musical composition by renowned composers, and documents an artist's road trip across America in 1978. The film alternates between color and black-and-white sequences and displays the changing landscape of the journey filmed from the car's perspective. The original audio fragments, initially recorded on magnetic tapes, were later transferred onto an audiocassette, used by Taroni for performing live. In fact, what makes this artwork particularly captivating is its interactive aspect: during the film's screening, the artist used a tape recorder to play the audiocassette with the pre-recorded sound loops, introducing an additional layer of complexity and unpredictability. Taroni used the fast-forward and the rewind buttons to move between the loops, and since the analog media didn't allow a perfect sync, each screening became a unique and unrepeatable event.

Case Study 2 – Around About (1979)

The experimental film *Around About* (1979), originally shot on 16mm with magnetic soundtrack, is a work that alternates between black-and-white and color scenes, with occasional negative inserts. The central concept of the film is to present successive fast shots of the artists Roberto Taroni and Luisa Cividin moving their heads from left to right, creating a continuous visual motion. Over time, the film exhibited a pronounced magenta fading, altering the original colors. The soundtrack, an electronic music composition marked by an obsessive rhythm, mirrors the film's visual elements through the use of numerous layers that create a continuous loop. Composed and recorded by Roberto Taroni using synthesizers and drum machines, the soundtrack complements the repetitive sequences of the visual counterpart.

Case Study 3 – Speedy Life (1979)

Speedy Life (1979) was shot on 16mm with magnetic soundtrack, and captures everyday scenes of artists Roberto Taroni and Luisa Cividin, filmed from a fixed camera within a room. The original footage was significantly sped up, creating an effect of frenzy and temporal distortion. Presented in black and white, the film conveys a sense of heightened movement and energy. The soundtrack, composed of electronic music, utilizes the phaser effect, creating, together with the visuals, a continuous sensation of motion. This effect was enhanced by the acceleration of environmental sounds recorded in the room, including those from the street and outside the building.

Color Correction

The color restoration of the three experimental films required specific interventions to match the distinct aesthetics and intentions of each work. For *Camera Car*, the original footage exhibited a prominent bluish dominant cast, which altered the atmosphere of the scenes. Since the original materials were rehearsal films, the intervention was carried out without a proper reference, in collaboration with the artist, following his indications. In line with the artist's vision, color correction efforts were directed towards warming the tones of the scenes, restoring a vibrant, nostalgic feel to the images. For the black-and-white sequences, the adjustments focused on enhancing only contrast and brightness, respecting the inherent monochrome look without introducing additional color shifts.

Figure 11 – Still frames from Camera Car (1979) before (up) and after (down) the color correction intervention.

However, certain shots presented an added challenge in achieving a consistent color match. For example, in several scenes, the car's front windshield had a strong graduated blue tint. This required further consideration to balance the colors realistically without distorting the natural lighting and tone. For *Around About*, the restoration intervention was mainly focused on removing the severe magenta fading that affected the color scenes, which was particularly disruptive.

Figure 12 - Frame from Around About (1979) before (on the left) and after (on the right) the color correction intervention.

The film's quick, repetitive sequences also exhibited variations in exposure and contrast, which made abrupt shifts in brightness and contrast that could distract from the film's rhythmic structure. Lastly, *Speedy Life*, filmed entirely in black and white, presented a slight green dominant cast, which was removed. The rest of the intervention was mainly aimed at improving the contrast of the scene, allowing the restored version to retain the authenticity and raw quality of the original film.

Soundtrack Restoration

For all three films, the first stage of the audio restoration involved the removal of clicks, pops, and other impulsive noises, followed by the reduction of the characteristic magnetic tape's hiss and hum.

The sound restoration intervention was carried out with the software Izotope RX10 and Adobe Audition. The most challenging restoration intervention was carried out on *Camera Car* since one of the stereo channels was severely compromised due to a poor connection during the transfer from the original open-reel tapes to the audiocassette, leading to significant distortions and electrical and impulsive noises. After reducing hiss and hum and removing clicks, pops, and other impulsive noises, it was necessary to compensate for short drop-outs through digital interpolation. In tackling these issues, the restoration process aimed aimed at preserving the stereo image, avoiding the fallback solution of using only the intact channel, which would have resulted in a mono configuration. Instead, we decided to maintain the spatial depth of the audio by manually duplicating "intact" segments from different moments within the same channel's recording. By processing, equalizing, and slightly detuning these segments, we were able to reconstruct and preserve the original stereo configuration of the recording. This process helped to retain the spatial and immersive character of the original soundtrack, ensuring a listening experience faithful to the original, despite the technical difficulties encountered during restoration.

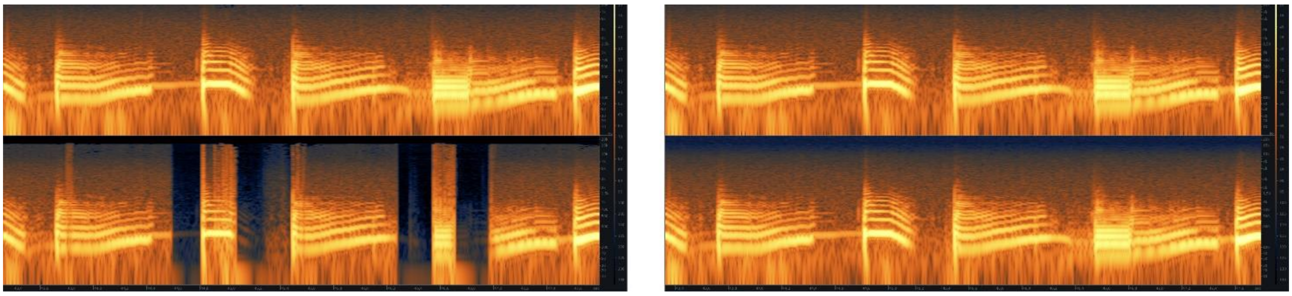

Figure 13 - STFT multi-resolution spectrogram of an audio fragment from Camera Car (1979) before and after the audio restoration intervention. In the image on the left, damaged and missing audio sections in the right channel are clearly visible.

After the restoration process, the original loops were synced to the film scenes to adapt the original artwork to a single-channel version suitable for screening. Furthermore, the audio archive of the artist includes several open-reel tapes containing the preparatory materials used for creating the soundtrack of A*round About*, which were restored and digitized. A potential next phase of this restoration project could focus on mixing and combining these loop materials to recover the original quality of the soundtrack before its transfer on the 16 mm film magnetic strip.

Conclusions

The digitization and restoration of Taroni's sound archive carried out by the CSC of the University of Padua complements the important work of recovering his film materials carried out by the *Camera Ottica Lab* of the University of Udine, significantly contributing to the preservation and accessibility of the artist's original archive. The digitization and restoration of these materials pave the way for new opportunities to re-present his works and expand their dissemination, offering new perspectives for their valorization and access. As a result of this effort, the restored versions of *Camera Car*, *Around About*, and *Speedy Life* were screened at the 53° International Film Festival of Rotterdam in January 2024, giving an international audience the chance to appreciate these works for the first time in a renewed format. In fact, this was the first time these films had been shown since the 1980s. Currently, at CSC, we are still working on preserving Roberto Taroni's artistic heritage. In particular, we are investigating new technologies to create virtual versions of some of his key works, including *La(m)pelle di Ahmad* (1979) (Russo *et al*., 2024), *Casa dolce Casa* (1978), and *Dissonanze Circolari* (1999). This process not only preserves the artist's legacy but also reimagines it in an accessible and innovative form, allowing a new audience to explore the works in a virtual context without any limitation of space and accessibility.

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Training the eye, an exploration of hand-coloured daguerreotypes and their examination

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Abstract

The daguerreotype was the first commercial photographic technique in the world. Objects made by the daguerreotype technique are negative and positive simultaneously. Made on a metal plate with a silver surface polished to a mirror finish, they are amazing and unique pieces with a rich history. But, since their very beginning, they were berated for lacking colour. Attempts to add colour thus ensued and many experiments were performed. Manuals were written and patents were registered, however, as often happened within the photographic field, little documentation of the precise practices was recorded.

This research focuses on the instructions for documenting the negative and positive views and the value of visual inspection when examining daguerreotypes. Furthermore, a concise guide to inspecting the surface of daguerreotypes for traces of hand colouring will be provided, based on the knowledge obtained by examining daguerreotypes in the Museum Ludwig in Cologne and the reconstruction of historical hand-coloured techniques. The guide indicates how to spot hand-colouring techniques, as fading or tarnishing can obscure the recognition of additions of colours and some tell-tale signs of the different materials and techniques with the help of visual aids.

Keywords: hand-coloured, daguerreotype, identification, techniques, visual examination.

Introduction

The daguerreotype usually has a copper base with a top layer of silver highly polished where the image was obtained (Lavédrine, 2009, 27). Due to the nature of the technique and how it ages, daguerreotypes can exhibit a myriad of colours. These colours can make an appropriate assessment of what is on the surface difficult. This paper focuses on the basic techniques that can be found in the literature both in terms of hand-colouring and documentation, as well as advocating for careful documentation and inspection of the surface of the daguerreotype. Proper recognition of the application of hand-colouring can and should influence treatments. If the eye of the conservator (Marchesi, 2017, 59) is not trained, the hand colouring can be unnoticed. Failing to consider this essential component of the daguerreotype may lead to overlooking the intricate work and time dedicated to incorporating colours, thereby hindering a comprehensive understanding of the object.

There is little research specific to hand-coloured daguerreotypes. "Coloriage des Epreuves: French Methods and Materials for Coloring Daguerreotypes." by conservator Alice Swan (1989) focuses on techniques and how the photographic community responded to them. "In Living Color: Process and Materials of the Hand Colored Daguerreotype" by Sara H. Ferguson (2008) is an examination of the processes in a historical context as well as a commercial and manufacturing context. In both cases, there are few images to illustrate the techniques and help with visual identification.

"The History and Conservation of Coatings Applied to Daguerreotypes" by Adrienne Lundgren (2005) is relevant despite focusing on coating as the topic is intimately related to hand-colouring. "Colour and the Daguerreotype" by Michael G. Jacob (2014) has some visual aids for recognition of hand colouring.

A technical source can be found in "Imaging the Surface of a Hand-colored 19th Century Daguerreotype" by Kozachuz, et al. (2018), which focused on the identification of the red colourant on a daguerreotype. Promising research in analytical studies of daguerrotypes has been done in "The Colors of the Butterfly Wings: Non-Invasive Microanalytical Studies of Hand-Coloring Materials in 19th-Century Daguerreotypes" by Quintero Balbás et al. (2022).

Historical techniques, historical objects and reconstructions
While searching, knowing "what" and knowing how that "what" looks is a key part of finding it. The techniques found in the literature, from patents, journals and other sources can be divided into coatings, no coating, and others (Ogayar Oroz, 2022, 27-28, see Fig. 1). Sadly, many if not most daguerreotypes with hand-colouring lack the exact documentation on how they were made. Therefore a precise identification is hard to achieve as there is a lack of references to compare them against.

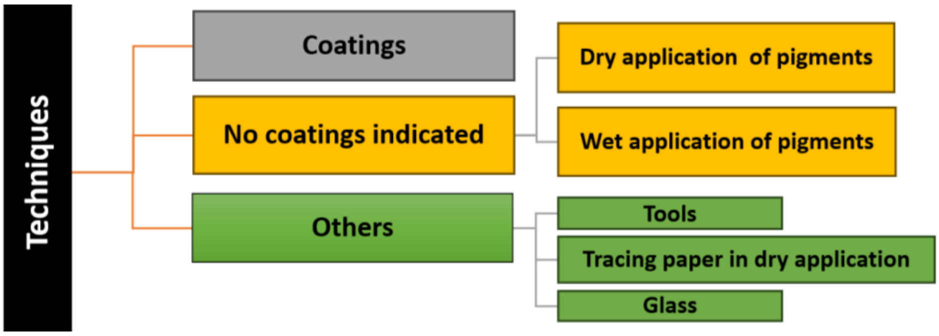

Fig. 1 – Categories and subcategories of techniques found in patents, journals and the literature.

To tackle that problem, two avenues were explored. First, extensive documentation of hand-coloured daguerreotypes from the Ludwig Museum in Köln, Germany was performed. Secondly, the reconstruction of techniques was endeavored. From the more than twenty references to techniques found in 19th-century literature, five were attempted and four were completed with different levels of success by the author on four new daguerreotypes created for this project (Ogayar Oroz, 2022).

Documenting
Not all institutions with daguerreotypes have big budgets or resources with the latest technology. Even if they had access to more advanced options, the first obstacle is found in the glass of the housing. Sometimes this element is in a poor state, which can cause difficulty in reading the image layer. But, as part of the housing and therefore of the object, opening the assembly is only done when an active treatment is required. This first results in a limitation of close inspections but also adds a restriction on the techniques that can be used. Finally, sampling is not advisable as the surface of the daguerreotype is extremely sensitive to abrasion, and the quantity of materials, pigments or bindings, over it is far too little to avoid overpowering the image.

A conservator with proper training, keen observation skills, a camera, and a microscope can extract valuable information about hand-coloured daguerreotypes. The use of cameras for documentation and communication is needed, as visual inspection does not provide permanent records for sharing or comparison. Given that daguerreotypes simultaneously exhibit negative and positive views, it is imperative to record both states, which requires custom equipment for photography.

It is recommended to place a black cut-out cardboard between the lens hood and the camera to reflect a dark surface on the daguerreotype. For the positive image, light at a 45-degree angle should be used. For the recording of the negative view, following Ravines et al. (2014, 22) the light should be set up at a 90-degree angle. A piece of borosilicate glass is located at a 45-degree angle between the camera and the object to redirect the light to the object, from which it will go up to the camera (see Fig. 2 in next page).

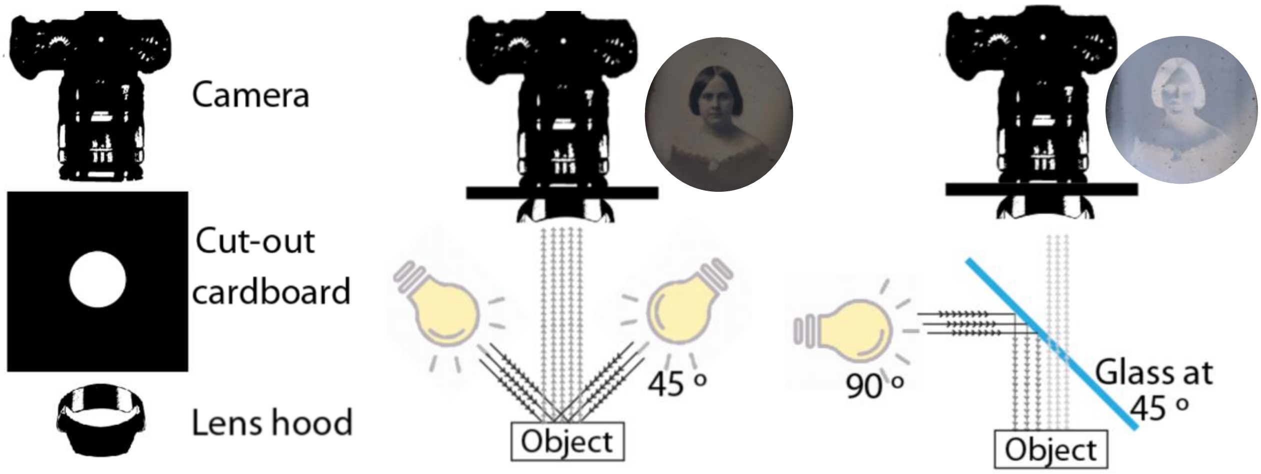

Fig. 2. On the left side, basic equipment recommended for documenting daguerrotypes. In the middle, lights are set up for the recording of the positive view. On the right side, is the set-up (Ravines et al. 2014) for recording negative view.

A portable set-up was developed during this research to make the recording of negative view easier, portable and inexpensive. This design was based on Ravines et al. (2014) and the set-up used at the Rijksmuseum (NL) and designed by photography conservator Martin Jürgens. It can be stored flat and built up when needed. As one side (the first from the left side in Fig. 3) allows the joint to be slid to different lengths, the user can work with various glass panel sizes.

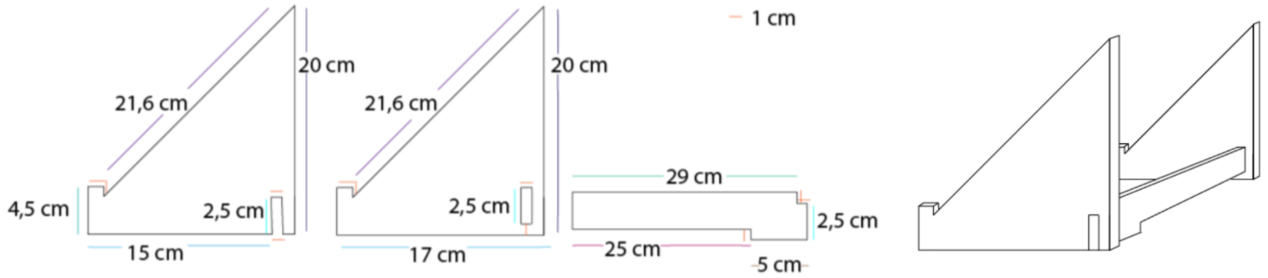

Fig. 3. Pieces and measures of the travelling set-up and final assembly.

How to look

The following section is based on the knowledge obtained from the reconstruction and the consultation of originals from the Ludwig Museum, Köln, for further information refer to Ogayar Oroz, 2022. While looking at daguerrotypes, is important to take into consideration that the surface of the daguerreotype sometimes has a dusty appearance (see Fig. 4). The image is made of an amalgam of silver, mercury and gold. Gold is only present if the daguerreotype is gilded, which was common practice for any image that was hand-coloured. The process makes the surface slightly more resistant to abrasion (Barger and White, 2000, 38).

Fig. 4. Detail of two daguerreotypes from the Ludwig Collection. Left with the inventory number FH 02193 is a view from a 45-degree angle. Right, is ML/F/SL 0043 under the microscope with a magnification of 2.0.

While techniques such as picking, which means making an indentation with a sharp object to create a scattering of light resembling jewels (Humphrey, 1858, 51) or painting the glass cover instead of the daguerreotype itself (Willats, 1845-46, 17) are easier to recognise. Alas, others are easier to overlook and looking closely for added colouring is essential. The hand-colouring usually blends nicely with the positive image, as it was made to strengthen it, not overpower it. Working with light from both sides at a 45-degree angle (see Fig. 5) can make the hand-colouring more obvious. Avoiding looking just from above, as is the tendency while looking at photographs to prevent deforming the perception of the image, helps in the first attempt to evaluate the hand-colouring.

Fig. 5. Anonymous author, Martin Jürgens collection. In the image on the left, the colour is less obvious before treatment. In the image on the right, the same daguerreotype after removing the broken cover glass lights coming from a 45-degree angle making the hand-colouring on the skin evident.

Ultimately, if in doubt about the presence of hand-colouring on a daguerreotype, consider that the application will usually result in the loss of some sharpness in the image layer, as it means the application of a layer of material that is not completely transparent and is accompanied by a motion (see Fig. 6 and 7).

Fig. 6. Anonymous author, Martin Jürgens collection. Note that the central area of the arm has a warmer tone in the hand and wrist, while the details of the bracelet are more diffused in the centre.

Fig. 7. Detail images from two daguerreotypes in the Ludwig Collection. On the left ML/F/SL 0041 and on the right is FH 01039. Note how on the left the sharpness of the textile is lost under the application of colour and on the right, the application of the warmer tone has lost definition on the hand. The highlights in the jewellery were done by picking.

When inspecting a portrait, the more telling parts are the cheeks or lips, as many examples of hand-colouring are limited to a subtle hit of colour in those areas. The same should be done when looking at the negative image, as pigments used in hand-colouring can fade. Even if faded, the material will still be present on the surface and change the reflection captured, there is a chance that they will still be visible in the negative view (see Fig. 8.)

Fig. 8. From left to right, the positive view of the daguerreotype, negative view, and positive view (obtained by inverting the negative with software). See the change in colour on lips and cheeks. Private collection.

Once the colour is distinguished in the surface of the daguerreotype, the question that should follow is "coating or no coating?". This is not always obvious. Sometimes around the edges, marks of the pouring can be found. The coating on daguerreotypes was usually poured and not applied with a brush as it would have removed the image layer. If the area is protected by a coating, the tarnishing occurs differently. A more detailed guide around identifying coating was done by Lundgren (2005, 58-59). Another tell of a coating is the visibility of the brushed-on pigment on the surface. If the marks appear as darker lines (in positive view) there is no coating as the image layer was removed by the motion of the application and the amalgam was lost (see Fig. 9.). If the marks appear but the image under it is visible, sometimes having a haze to it as it has been rubbed and slightly scratched, a coating is present otherwise it would have resulted in darker lines previously mentioned (see Fig. 9.).

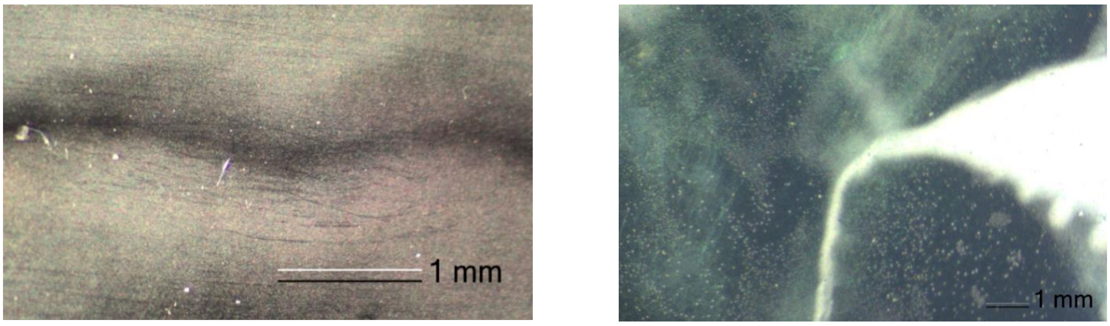

Fig. 9. Left, detail of dark lines due to the removal of image material in lips (Clara Tomasini's collection). Right, Magnification 4.0. detail of daguerreotype FH 00379 from Ludwig collection, magnification at 2.0, note the haze of the application which indicates a coating.

To gain further information about the application of pigment with brushes, the negative view can be enlightening. A heavier application of pigments, either wet or dry, will be visible as a darker area (Jacob, 2014, 15). The wet application tends to leave a sharper edge and a direction, indicated by the accumulation of material on the end of an applied path through the surface (see Fig.10).

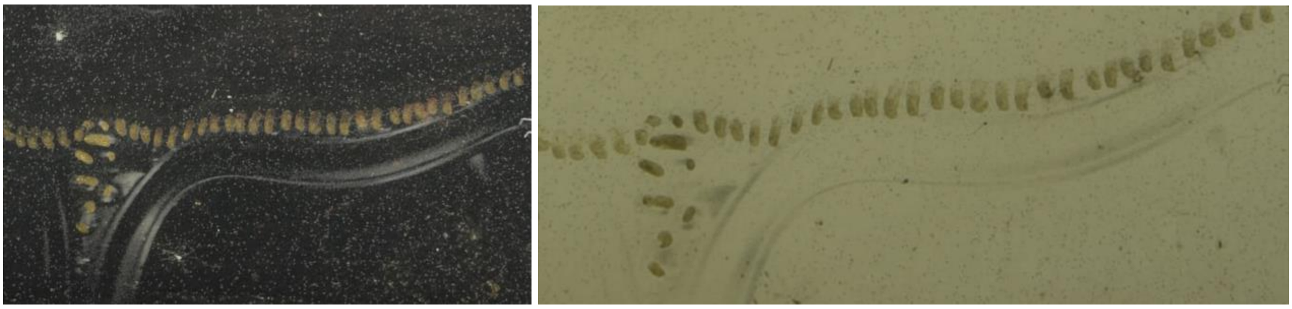

Fig. 10. Detail of the daguerreotype from the Ludwig Collection with inventory number ML/F/SL 0043. On the left, positive view of the detail of the wet application of colour. On the right, details of the same area in the negative view. Note that changes from lighter to darker following the application motion and the concentration of material.

The dry application presents a cloud shape, as the pigment was deposited with a slight touch on the surface (see Fig. 11.). In some cases, the wet application was done by a subtle touch as well and the concentration of material is in the middle of the colour area. Therefore, another clue in the application of wet techniques is the presence of a concentration of pigments on the middle and edges of round areas.

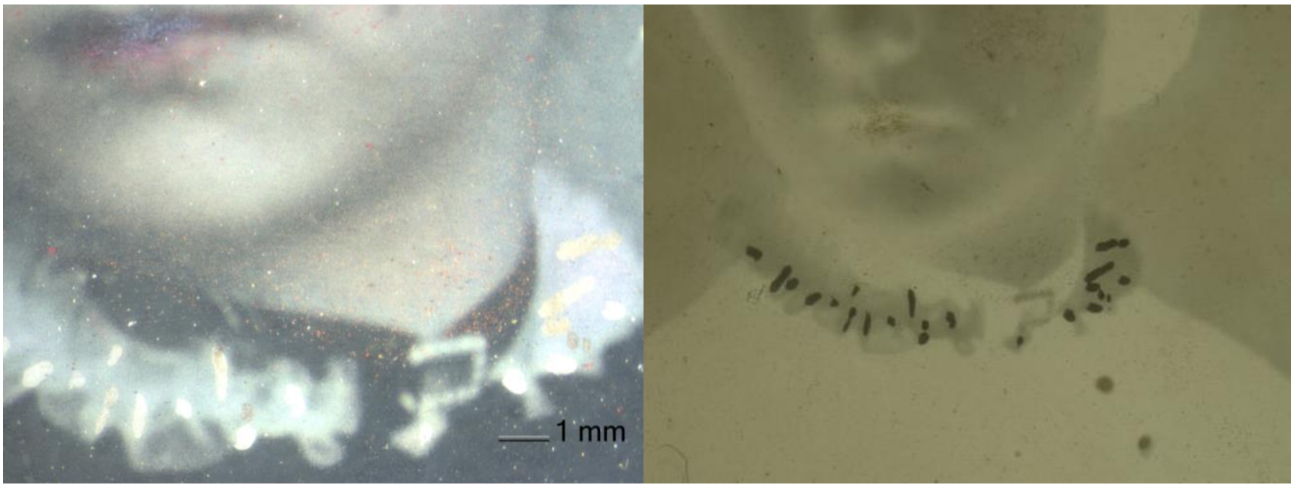

Fig. 11. On the left side, detail of the face area of the daguerreotype ML/F/SL 0044, from the Ludwig Collection. There are applications of both dry and wet techniques. On the right side, magnification 2.0. of the same area was recorded with the camera as a negative. Note the shape of the application of dry colour in the lips and the concentration of material in the wet application.

Fig. 12. Daguerreotype FH 00379 from Ludwig Collection. On the left side, detail from the dress, next to the hands, where the wet application to the dress is more visible. On the right overall view of the object.

Conclusions

A close inspection of the surface of the daguerreotype with basic tools, such as microscopes and cameras, can help in the correct identification of applied hand colouring when the professional is aware of its signs (see Fig.13). Furthermore, it can be done without compromising the housing, a crucial part of the daguerreotype, as it can be performed without disturbing it. This makes an ethical way to gain knowledge about the daguerreotype with minimal hazard to the object. Currently, no exact knowledge can be gained about these types of objects and it is difficult to determine exactly what was done in each case. Despite this, documenting them to the best of our capacity will make the task of fully understanding hand-colouring daguerreotypes easier in the future while making sure that the craftsmanship that was put into the objects is not overlooked.

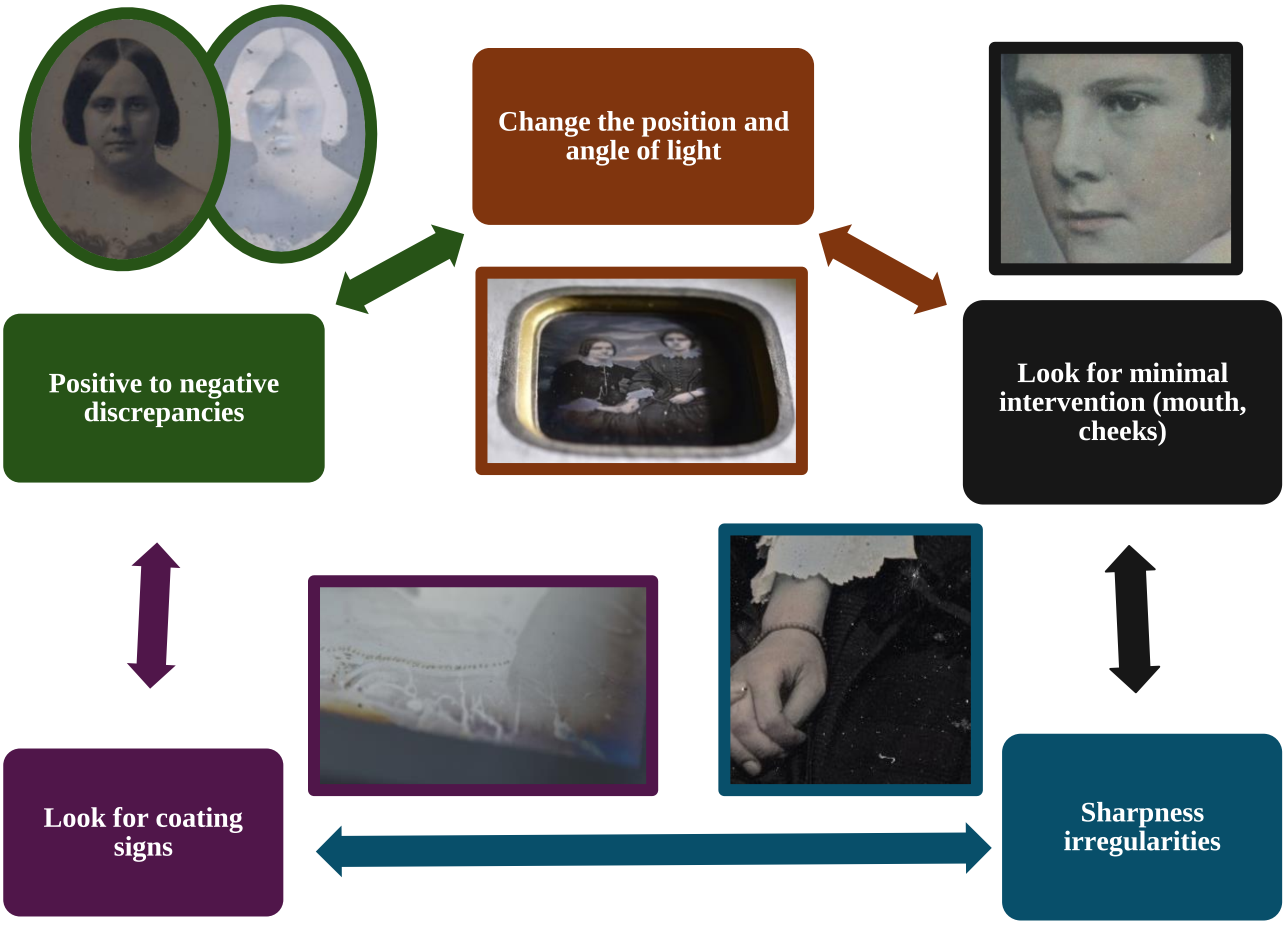

Fig. 13 – Main signs to look for in the identification of application of hand-colouring in daguerrotypes. Examples of daguerrotypes from left to right and top to bottom, private collection negative and positive portrait of a woman with discrepancies on lips and cheeks area; Ludwig Museum collection ML/F/SL 0043 with a magnification of 2.0., portrait of a young man with minimal intrusion; Martin Jürgens collection, portrait of two ladies with hand colouring that became more obvious with a different angle of light; Ludwig Museum collection ML/F/SL 0043, detail of coating sign; Martin Jürgens collection, detail of hand in which the sharpness of the image was affected by the application of colour.

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Investigating solvents and treatment methods on a matte pigment inkjet print

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Abstract

This study investigates the influence of various solvents and application methods on an aqueous pigment ink matte microporous Hahnemühle PhotoRag inkjet print, aiming to ascertain the susceptibility towards solvent treatment of inkjet prints meant for the fine art market. Thirteen solvents commonly employed by conservators are subjected to assessment through three distinct application methods: drop application, damp cotton swab application with various amounts of friction applied, and a subset underwent exposure in vapour chambers. These tests are complemented by comprehensive photo documentation (normal, raking, and UV-radiation), spectrophotometer measurements, and HIROX microscopy to determine changes to the objects. Alongside these experiments liquid chromatography-mass spectrometry, paper-spray mass spectrometry, and Fourier-transform infrared spectroscopy were employed for identifying ink components and to assess the solvent's dissolving capabilities. The outcomes emphasise that the method of solvent introduction significantly influences the impact on these types of photographic media. Application with friction, especially in combination with water-containing solutions, results in displacement of the colourants. Therefore, the choice of solvent still has an impact as certain solvents induce alterations in either ink and, or the additives in the paper support than other solvents.

Keywords: inkjet photography; aqueous pigment ink; matte microporous coating; solvent treatment; chemical composition.

Introduction

The introduction of digital inkjet technology for the fine art market dates back to 1991 (Wilhelm, 2000), which in its early stage were predominantly aqueous inks utilising dyes and a paper support. Since then, the industry has witnessed remarkable expansion, both in terms of the variety of materials available and the number of companies offering them. The combinations of ink and media, however, influence not only the aesthetics but also the long-term stability of the resulting photographic object. Fortunately, with this realisation emerged an understanding of the susceptibility of inkjet prints to factors like light, humidity, temperature, and air pollutants, leading to the establishment of preservation guidelines (Fischer, 2007). However, the treatment of fine art inkjet prints remains underexplored. This can be attributed to several factors; firstly, the relative novelty of inkjet printing as a photographic process, leading to limited treatment research; and secondly, the rapid evolution of formulations and the multitude of companies supplying materials for inkjet printing, making comprehensive research a complex undertaking.

Notwithstanding these challenges, a few articles have shed light on the impact of solvents on inkjet prints such as Gadomski (2009) and Ploye (2011). Both studies were published over a decade ago and considering the likelihood of changes in ink formulation and substrate composition, the behaviour of inkjet prints towards solvents might differ now. Therefore, this research aims to address this knowledge gap and provide further insight in contemporary inkjet material by investigating and differentiating the effects of solvents and mechanical action when used for conservation treatment. The effectiveness of solvents, for example to remove dirt or adhesives, was not part of the scope of this research and hence not assessed.

Methodology

Material of the samples

The selection of the print material was based on a brief survey conducted among five fine art printing studios asking what their most common paper support used by photographers was at the time (December 2022). Therefore the research focused on one particular type of inkjet print: Hahnemühle PhotoRag paper where a target image made of colour gradient blocks cyan, magenta, yellow, and black was printed on. According to Hahnemühle, PhotoRag paper has a matte micro-porous image-receiving layer (IRL), consisting out of polymeric binder and inorganic pigments (Wexler and Reczek, 2012) on a substrate made of pure cotton and is acid- and lignin-free (Hahnemühle website, 2024).

The printing was carried out using the Epson SureColor P20000 printer, a piezo inkjet printer employing aqueous pigment ink. This printer model is compatible with both Epson Ultrachrome Pro ink and Epson Ultrachrome K3 ink, and for this research a combination of these ink series was collected based on availability for analysing. Liquid ink samples were retrieved directly from those cartridges that were donated by two local printmaking studio's. The composition information of the specific cartridges from the Safety Data Sheet (SDS) is given in Table 1.

Epson Ultrachrome Pro T8002 Cyan Ink	**Epson Ultrachrome Pro T8005 Light Cyan Ink**
65%~80% water 10%~12.5% glycerol 1%~3% triethanolamine	65%~80% water 10%~12.5% glycerol 1%~3% triethanolamine
Epson Ultrachrome K3 T5914 Yellow Ink	
50%~65% water 12.5%~15% glycerol 0.5%~1% triethanolamine <0.05% 1,2-benzisothiazoline-3-one 3%~5% ethylene glycol	
Epson Ultrachrome K3 T5913 Vivid Magenta Ink	**Epson Ultrachrome Pro T8006 Vivid Light Magenta Ink**
50%~65% water 15%~20% glycerol 1%~3% triethanolamine <0.05% 1,2-benzisothiazoline-3-one 1%~3% triethylene glycol monobutyl ether	65%~80% water 10%~12.5% glycerol 1%~3% triethanolamine 0.1%~0.25% 2-pyrrolidone 0.0015%~0.05% 1,2-benzisothiazolin-3-one

Table 1 - Overview of the composition information obtained from their respective safety data sheets of the examined ink cartridges in the analytical research part. All SDS consulted on the website https://www.epson.eu/safety-data-sheets on 10-05-2023.

Testing and Analysis

Common solvents and solvent mixtures frequently employed by photograph conservators were selected: demineralised water (demi-water), 50:50 demi-water ethanol, 30:70 demi-water ethanol, ethanol (Merck, Absolute Ethanol for analysis), iso-propanol (2-propanol Biosolve Chimie SARL, LC-MS grade), acetone (VWR Chemicals, technical grade), ethyl acetate (Acro Organics, 99,5+% for HPLC), methyl ethyl ketone (2-butanone Sigma-Aldrich, ACS >99%), hexane (VWR Chemicals, AR 99.3%), heptane (VWR Chemicals, AR 99.3%), iso-octane (Merck, AR grade), benzene (Sigma-Aldrich, for HPLC ≥99.9%) toluene (Acros Organics, 99%+), xylene (Fischer, AR grade), and Kodak Photo-Flo 200 (1:200 surfactant, propylene glycol and octylphenoxypolyethoxyethanol, in water). Applying the solvents to the inkjet prints was done via two distinct methods: directly as a drop onto the surface where the solvent could naturally evaporate, and with cotton swabs. While applying drops directly onto the surface of a photographic object is not a frequent practice due to its aggressive nature, it was chosen to distinguish between solvent interaction and mechanical action, aiding in a more comprehensive understanding of the results. In the cotton swab test, two different application techniques were employed: firstly, the damp cotton swab was gently dragged along the surface of the ink in a linear manner while rotating the swab; and secondly, the damp cotton swab was used in a three-times circular motion within a 1x1 cm square area similar to the method described by Morrison (2005).

Lastly, a subset of inkjet prints was exposed to vapours of the following solutions: demi-water, 30:70 demi-water ethanol, ethanol, iso-propanol, and ethyl acetate. These solvents were chosen due to their common use in practices such as flattening, mould disinfection, and adhesive removal. Each print was placed within a vapour chamber for a duration of two hours and afterwards left unrestricted while drying. The time duration of this vapour chamber experiment was based on research conducted in the field of mould treatment for photographic objects (Lucas, Déniel and Dantigny, 2017).

The impact of the solvents and their application on the ink and support was assessed via CIE Lab spectrophotometry using a Konica Minolta Spectrophotometer (CM-26000d, SCI M/I+E, UV 100%, 10°/D65). Photo documentation was performed using a Nikon digital camera D750 to capture images under normal and raking light, and UV-radiation. Moreover, HIROX microscopy was also employed to observe ink and, or surface alterations.

Adjacent to this research, analytical research was conducted to determine dissolving capabilities of the solvents and to identify ink components. Fourier transform infrared spectroscopy (FTIR), liquid chromatography coupled with a photodiode array and mass spectrometer (LC-PDA-MS), and paper-spray mass spectrometry (PS-MS) were used for this purpose. FTIR and LC-PDA-MS techniques were used to analyse liquid ink from the collected ink cartridges. Cut-outs were made from the inkjet print and functioned as physical samples for PS-MS to analyse the interaction between solvents, printed ink, and IRL. The specific methodology for the respective analytical techniques as well as more detailed descriptions and discussions about these experiments can be found in the thesis (Maillette de Buy Wenniger, 2023). Below a shortened version of the methodology is given.

Parameters

FTIR: Pike GladiATR coupled to a PerkinElmer Frontier FTIR was used and IR spectra collected with Perkin Elmer Spectrum software. After an air background, spectra were obtained with the parameters 4 cm^{-1} resolution, 4000-400 cm^{-1} scanning range, and one scan per sample using liquid ink samples from the cartridges.

UV-VIS: a Varian Cary 50 Bio UV-Visible Spectrophotometer with baseline correction was employed to obtain UV-Vis spectra. A quartz cuvette (4 mL, dimension 1x1 cm) was first used to measure a blank (Milli-Q water), and afterwards for the liquid ink samples scanning between 200-700 nm. The Yellow, Cyan, and Magenta were diluted 10x1000 and the Light Cyan and Light Magenta diluted to 10x200 with Milli-Q water.

LC-PDA-MS: a UPLC Waters Acquity H-class system equipped with a PDA detector (configured to scan between 200 and 800 nm) was coupled to a Thermo Scientific Q Exactive Focus Orbitrap mass spectrometer (set in MS/MS mode). The LC system used a 150x2.1 mm Zorbax Eclipse Plus C18 column with 1.8 μm particles in combination with a mobile phase gradually going from mobile phase A (aqueous) to B (organic) in 60 minutes. The method was based on Astefanei *et al.* (paper submitted).

PS-MS: a Thermo Scientific LTQ Velos mass spectrometer with an Orbitrap coupled to a Velox360 Prosolia sample dispenser set to dispense 10 µL per run was used. Acquisition time set to 1 minute (6 sec. 0V, 48 sec. 4000V, 6 sec. 0V), scanning between 100-2000 m/z, normalized collision energy 34 eV, and capillary temperature set to 200°C.

Results and Discussion

Composition of the inkjet print

A comprehensive understanding of the ink's composition was achieved using a combination of LC-PDA-MS, FTIR, and PS-MS techniques. Using the liquid samples obtained from the cartridges with ATR-FTIR revealed the specific pigments employed in the ink formulation: Pigment Yellow 74 was identified in the T5914 (K3) Yellow ink, while either Pigment Red 122 or Pigment Violet 19, both quinacridone pigments, was found in the T5913 (K3) Vivid Magenta, and T8002 (Pro) Cyan contained a variant of the phthalocyanine pigment (Pigment Blue 15). Identification of the pigment for the light cyan and light magenta inks was not possible via FTIR, but the two FTIR spectra are almost identical to each other, suggesting that even though the pigments are different, their composition is identical. Fortunately, UV-Vis spectroscopy confirmed that the same pigment for T8006 (Pro) Vivid Light Magenta ink is used as T5913 (K3) Vivid Magenta ink, and for T8005 (Pro) Light Cyan ink the same pigment blue 15 as T8002 (Pro) Cyan ink is used. Moreover, through the UV-Vis spectra it is shown that the colour difference between a standard and its respective light ink (e.g. cyan and light cyan ink) results from pigment concentration, which for the light ink was calculated to be 5-6x more diluted (Fig. 1). Only the pigment utilised in the Yellow ink cartridge could be confirmed and identified through LC-PDA-MS, eluting at 39.7 and 58.2 minutes with an absorption peak around 413 nm (Fig. 2). The chosen LC method was not suitable for the magenta and cyan pigments as they are too hydrophobic for the selected mobile phase. Fortunately, the mentioned additives in SDS could be confirmed with LC-PDA-MS. The biocide, triethylene glycol monobutyl

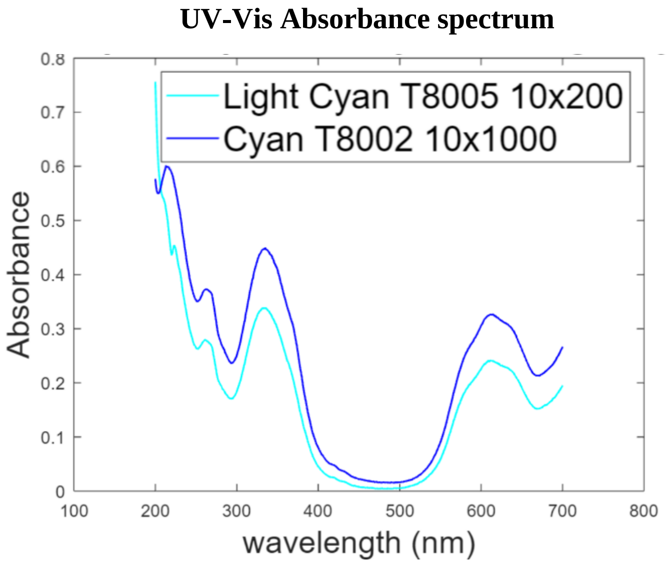

Fig. 1 - UV-Vis spectrum comparing Epson Ultrachrome Pro T8002 Cyan ink (10x1000 times diluted in Mili Q water) and T8005 Light Cyan ink (10x200 diluted in Mili Q water). The absorption spectra of the two inks are identical except below 250 nm where the water in the light cyan takes over. The similarity between the two spectra signifies the same pigment is added to the cyan and its respective light cyan ink.

ether eluting at 13 minutes, was identifiable via the PDA spectrum while the other additives could only be verified through the MS spectrum (Fig. 2).

Pigments are per definition insoluble in water and to employ pigments in aqueous inks the manufacturer exploits polymeric dispersants that, according to patents, will be film forming once printed (Miyabayashi *et al.*, 2001). The polymeric dispersant is stated to microencapsulate the pigments. However, in the material safety data sheets of the inks no molecule or polymer is listed that would function as a polymeric dispersant. The analysis conducted via LC-PDA-MS uncovered the presence of four distinct polymers eluting between 5 to 35 minutes within all the examined ink cartridges. Patents discussing micro-encapsulated pigments often refer to polymeric binders composed of styrene and acrylates in their examples (Sano *et al.*, 2001; Miyabayashi, 2007), which are monomers with a larger molecular mass than the identified 44 mass-to-charge (m/z) monomer (Fig. 2). Nevertheless, this 44 m/z monomer was present across all analysed ink cartridges, whether belonging to the Ultrachrome Pro or K3 ink series, in both LC-PDA-MS and PS-MS analyses, suggesting a different polymer being used as the dispersant. Moreover, PS-MS results indicated again a monomer of 44 m/z of the binder within the IRL of the Hahnemühle PhotoRag paper which in this case would likely be polyvinyl alcohol when referencing literature (Lee, 2004). More research is required to obtain a more in-depth identification of the polymers both found in the ink and IRL.

Dissolving capabilities of the solvents

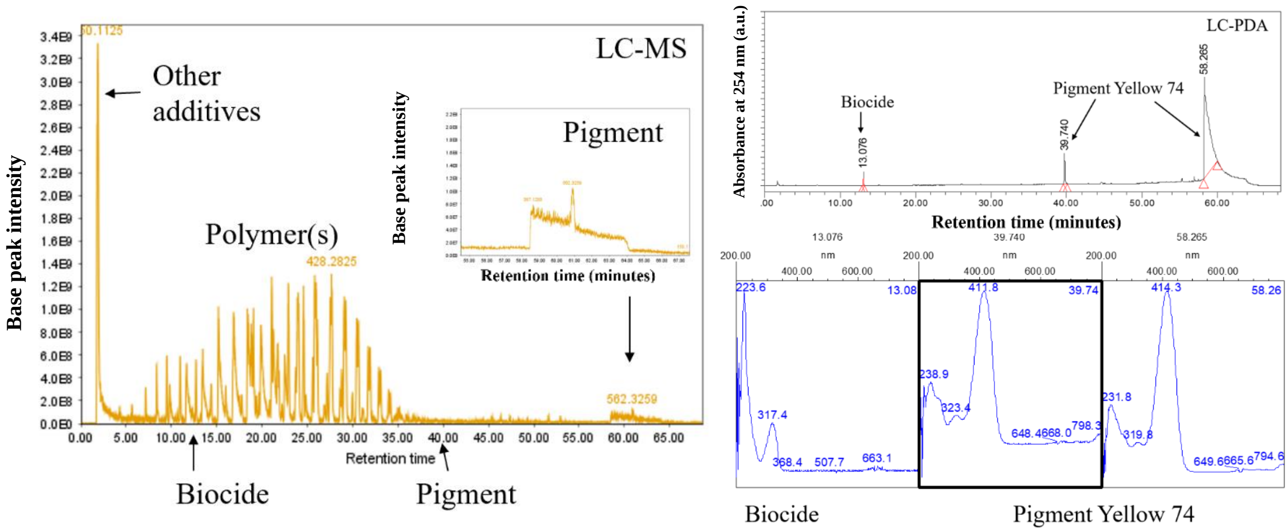

Fig. 2 – LC-MS (left) and LC-PDA (both on the right) spectra for Epson Ultrachrome K3 T5914 Yellow ink. The combination of both techniques resulted in confirmation of the additives, biocide, pigment, and polymers.

Even though full identification of all ink components was not achieved, the solvent sensitivities of individual liquid ink components could be deduced by the LC-PDA-MS elution time (Fig. 2). As expected, the additives, encompassing surfactants and biocides, exhibited a highly hydrophilic nature, while the pigments demonstrated very hydrophobic tendencies indicated by their retention time. The polymer's character was established through its elution gradient spanning in between the environmental change within the column from 80% aqueous (A) and 20% organic (B) mobile phase to 40% A and 60% B mobile phase. This suggests its potential for solubility in more hydrophilic solutions.

Incorporating the PS-MS technique further enriched our understanding of the behaviour of the inkjet towards solvents. The data generated from this experiment offered indications on the solvent´s ability to affect the printed ink, IRL, or both by dissolution. This information can be deduced from this analytical technique as a solvent is directly applied on to the physical print sample, the inkjet with ink and IRL cut to a sharp point (Fig. 3), that is facing directly the injector port. The sharp point of the paper sample and an applied voltag e cause the solvent to go towards the port and form stable ion droplets. If the solvent was able to dissolve a component of the sample it will be present in this ion droplet and can be detected. The summarized results, presented in Table 2, highlight instances where a stable ion droplet was formed due to the solubilisation of a component or when no signal was detected, meaning that nothing was dissolved. Not all solvents mentioned in the methodology could be used during this experiment due to the correct purity grade (MS grade) not being available. Interestingly, pure ethanol exhibited the ability to dissolve both the IRL and the ink binder. Furthermore, a visual observation emerged in relation to the yellow inkjet print samples exposed to toluene and 2-butanone, following two runs a definite disappearance of the yellow colourant was observed that was not reflected in the gathered spectrum.

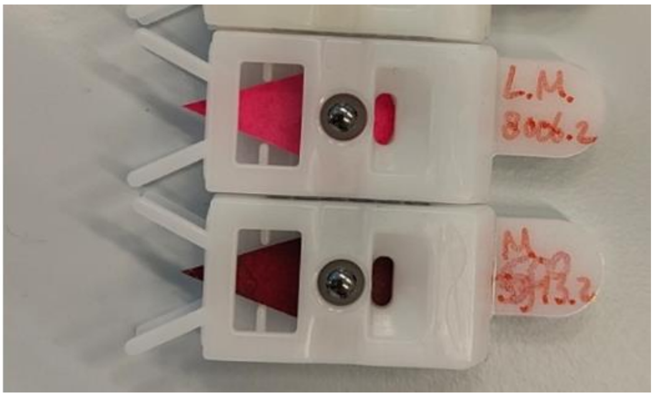

Fig 3 – Cut outs of Whatman filter paper to correct size and shape for PS-MS. The paper is loaded with ink from the cartridges, creating samples with only ink components present.

No Signal	Signal
Water	Ethanol (IRL and ink)
Water:ethanol solutions (50:50 and 30:70)	Iso-propanol (IRL)
Heptane	Ethyl acetate (IRL)
Toluene	2-butanone (IRL)

Table 2 - Summarised results of the paper spray mass spectrometry experiments.

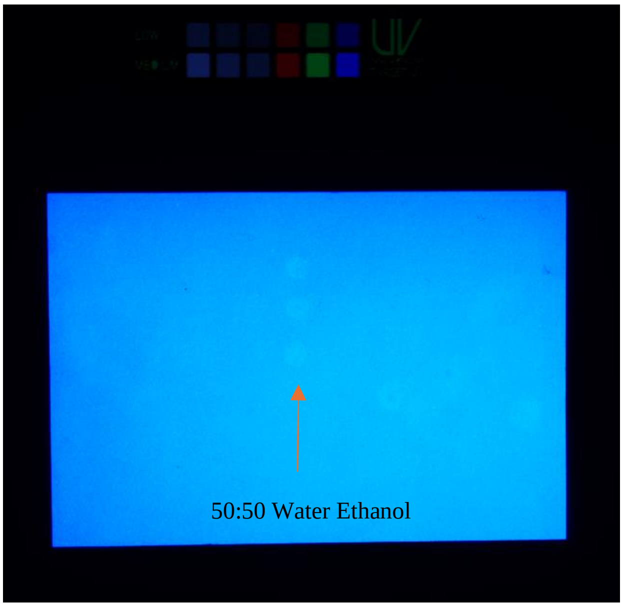

Fig. 4 - Verso as seen under UV-radiation. Bright circular spots can be seen that can be contributed to the effects of 50:50 water ethanol solution affecting the OBAs in the paper support.

Solvent Introduction

Solvent drop test

The examination through photo documentation utilising UV-radiation accentuated the impact of solvents on the optical brightening agents (OBAs) within the paper. This impact was particularly prominent in the form of luminous circles observed from the verso (Fig. 4). These luminous circles were only observed in areas that came into contact with water-ethanol solutions. On the other hand, the influence of iso-propanol, acetone, 2-butanone, xylene, and ethyl acetate was irregular and presented itself as darker circles with the most pronounced effects observed on the yellow colour blocks.

C*otton swab test*

Unlike the drop test with water-ethanol solutions, no prominent bright spots were observed under UV-radiation after application of the swab tests. However, distinctive darker areas were visible, particularly evident with the combination of 2-butanone, ethyl acetate, or toluene on yellow ink areas. When looking into detail via spectrophotometry at an applied solvent to a specific ink (magenta, yellow, and cyan), no pattern can be established that would indicate a distinct different behaviour of one solvent or one colour.

Comparing circular versus linear movement of the cotton swab demonstrated that a gentler motion makes a significant difference. Subjecting the print to increased friction (circular motion) tends to lead to abrasion where the pigments themselves are displaced rather than being dissolved (Fig. 5). Notably, water containing-solutions (water, water-ethanol mixtures, and Kodak Photo-Flo 200) and to a lesser degree ethanol caused displacement of the ink.

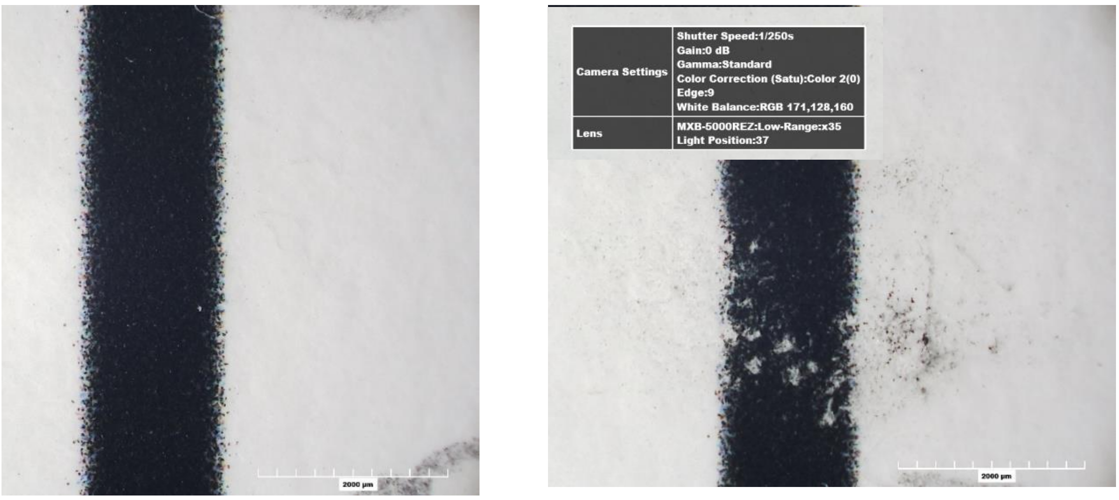

Fig. 5- Linear rotation (left image) and circular rotation (right image) using Kodak Photo-Flo 200 images demonstrating the effect of friction. Increased friction results in displacement of the pigment. Image made with HIROX microscopy, Bright field, 35x magnification lens.

Vapour chamber test

The results from the vapour chamber experiments reiterated that employing a more delicate application method when introducing solvents tends to preserve the colourants, OBAs, and planarity of the prints. No change to the surface texture and sheen, OBAs, ink, and overall colour was observed while examining these prints. Comparative spectrophotometer measurements between the application experiments mirrored the findings. According to the CIE Lab theory, deviations exceeding 2 ΔE units could be perceivable by an untrained observer (Mokrzycki and Tatol, 2011), however, in this study, calculated ΔE values surpassing 2 did not correspond to noticeable differences.

Conclusion

The experiments regarding solvent and application method indicated that for a matte micro-porous fine art inkjet print the introduction method of the solvent is the primary factor when considering treatment options. Applying friction will cause major alteration to the surface and the pigment ink, especially with Kodak Photo-Flo 200 and to a lesser degree other water-based solutions, causing ink displacement rather than dissolution. Using less friction such as linear rolling or using drops of solvent affects primarily the OBAs with most of the tested solvents, creating either luminous or dark circles which was only observable under UV-radiation. This occurrence, however, happened irregularly. The inkjet prints from the vapour chamber test showed no alterations. Thusly, reducing the amount of solvent and mechanical action seems to be the right course of action for treating fine art matte inkjet prints.

The experiments and the analytical research indicated that each component in an inkjet print (IRL binder, OBAs, colourant, polymeric ink binder, and additives) can be impacted by a solvent. However, the behaviour of each component in an inkjet print toward solvents is influenced by their function within the photographic object. For example, the ability of the IRL to carry water away from the surface indicates interaction with water and thus a certain sensitivity, which is reflected in the cotton swab results, but the pigments, chosen for their lightfastness, are very hydrophobic and so no significant interaction with water will occur. Therefore, as expected no universal solvent could be deduced from this research that would not influence any of the components. On the other hand, 2-butanone and toluene are suspected to have a more pronounced influence on the yellow ink then on cyan or magenta.

More research is required as this research could only investigate a small sample size and one type of inkjet print as well as limited solvent application methods. Furthermore, during this research the effectiveness of the solvents and cleaning method was not considered. Nevertheless, the comparison with previous research gives a more general indication of the behaviour of fine art inkjet prints towards solvents and treatment. A gentle approach towards treatment or the introduction of solvents will reduce the risk of damage significantly, but the choice of solvent does have an impact. For instance, from this research it has become evident when considering dirt or adhesive removal with a cotton swab using ethanol brings a considerable risk of dissolving the polymeric ink binder, IRL binder, or affecting the OBAs in the print.

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Light Sensitivity of Contemporary Photographic Print Material

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Abstract

The following study investigates the light stability of typical contemporary photographic prints in narrow spectral regions. The results can be used to predict colorant degradation of print materials under different light sources.. The absorbance losses of the colorants per unit of exposure (1 kJ/cm^2) of the narrow band light represent the sensitivity of the colorants to the specific wavelength range.
The method was applied to a selection of six contemporary photographic print materials. The prediction was compared to direct fading of the same print materials with white light LED. The fading tests were done in a proprietary chamber with several types of LED lamps and ambient environmental conditions. The colorants in the prints exhibit different fading properties, but all colorants are most sensitive in the wavelength range 400 to 550 nm. The method assumes that light degradation is the only degradation mechanism and that the fading of the different colorants on the sample is independent of each other. The method predicts absorbance changes of most colorants well, except for the colorants in silver halide photographic prints. Silver halide prints have a UV protection layer which slowly degrades when exposed to short wavelength light. The fading of the colorants depends on the presence of this invisible compound. The method is most suitable for photographic print materials and is probably not applicable to very complex image structures such as paintings.

Keywords: contemporary print materials, light stability testing.

Introduction

Colour photographic prints are delicate objects and require particular care when on display (Beltran et al., 2021). Recently, LED (Light Emitting Diode) lighting has replaced fluorescent and tungsten lighting. There are very few light stability data of print materials available for exposure with LED and museums worry about the best light levels, duration and choice of relative spectral irradiance (RSI) for display. Luo et al.(2018) have attempted to predict photodegradation for classes of materials by looking at the total energy of the exposure light whereas Yoo at al.(2023) find that different materials have different fading characteristics under the same exposure. The prediction of absorbance losses under light exposure based on the chemical structure of the colorant is difficult (Ragauskas and Lucia, 1998). Photodegradation of print colorants is not a photolysis but a photoactivated chemical reaction that depends on the excitation energy but also on the presence of oxygen and other environmental gases and on their particular excitation states and photodegradation pathways (Groenevelt et al, 2023). Most authors agree that light with shorter wavelength is more destructive than light with longer wavelength (Lavédrine et al., 2003) at the same total exposure. Only few studies look at light stability under white light LED exposure and the effect of different RSI in LED. Ishizuka et al. (2019) find that the position of the blue emission maximum is important in fading experiment. One challenge for light stability tests with LED, is to find an RSI that is representative LED used in lighting.
Action spectra can be derived from exposing prints to narrow band light. An action spectrum describes which wavelength of absorbed light lead to chemical reactions in the print material (Van Ackere et al., 2001; Caulkins, 1982). Based on the sensitivity of colorants to different wavelength of light, it is possible to predict fading for different types of white light exposure, particularly white LED exposures. This could help to select LED lighting and filters that could reduce fading of colorants.

Experimental Part

The experimental set up was described before by Hofmann and Hofmann-Sievert (2022.). The exposures chamber consists of 18 narrow band LED and 6 white LED, two of which each had the same centre wavelength. All narrow band LED had a typical width at half maximum of 30 nm, Their centre wavelengths were 380, 395, 405 , 425, 485, 505, 523, 590 and 620 nm. The RSI of the LEDs was measured by an Ocean Optics 2000® spectrometer and the total irradiance at the sample plane with a Genetec XLP12–3S–H2–INT-D0® power meter. The chamber contained four different white LED with a correlated colour temperature (CCT) of 2700 K, 4000 K, 5000 K, and 6500 K. The samples were exposed at ambient conditions (24 °C ± 2 °C , 45% RH ± 7% RH) by cooling of the sample plate.

The samples were provided by participants of an ISO TC42, WG5 committee's Interlaboratory Test to validate a new version of a standard. The exact material types were not disclosed, but the samples are meant to represent a typical range of contemporary photographic print materials. The sample set consisted of a dye-based IJ print (IJD) on nanoporous RC paper, a fine art pigment inkjet (IJ) print on lustre RC paper (IJFA), two chromogenic photo papers (Photo A and Photo B), a dye diffusion thermal transfer print (D2T2) and a liquid toner electrophotographic pigment print (EP).

The print pattern was composed of medium light colour patches of yellow, magenta, cyan and black with a maximum absorbance of around 0.7. The coloured print patches consisted of only one colour (D2T2 and EP) or of a mixture of colours with one predominant colour (Photo A, Photo B, IJD, IJFA) as shown for cyan in Fig 1 a-c.

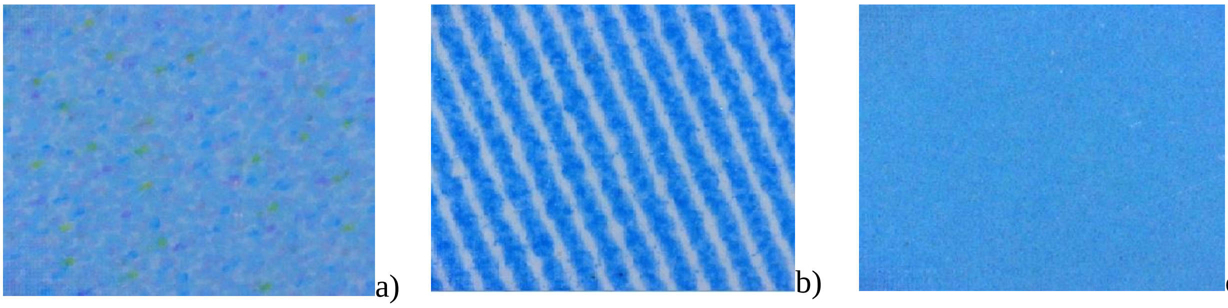


Fig. 1. Test pattern, enlargement of an original cyan spot of 0.4 mm a) IJFA b) EP, c) Photo A

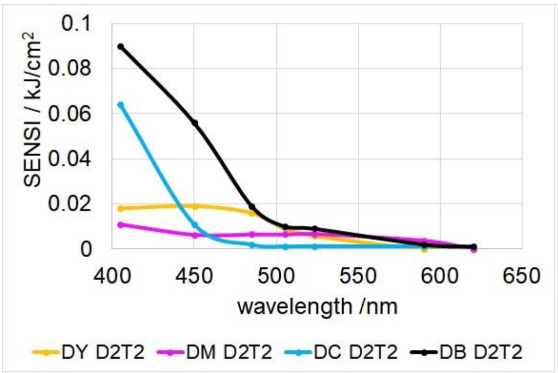
All test patches on a sample were measured before exposure. After each exposure interval, the sample was removed, measured and repositioned for the next interval. The intervals were adapted to the light stability of the sample. The test was continued until a significant change in A_{max} could be observed. The evaluation is done at the maximum absorbance of each colorant such that there is little spectral overlap from other colorants. The patches were measured with an iPro spectral densitometer, which has a fixed filter condition of 'no UV' M2 according to ISO 2009 with a white Melinex® backing. Colour coordinates are given for the D_{50} illuminant and the 2° observer. Colour differences are calculated in ΔE76 as recommended by Ishizuka et al.(2019b).

The absorbance after exposure with x kJ/cm^2 ($A_{max\ x}$) minus the absorbance before exposure ($A_{max\ 0}$), $\Delta A_{max\ x}$, plotted against the total exposure is the fading curve of a colorant for a particular narrow band exposure. In a typical fading curve, the signal stays below the noise level of the experiment at very small exposures. With further exposure, the absorbance loss becomes linear. Only this linear part is used in the evaluation. The negative slope of the linear part is the called the sensitivity (SENSI) of a colorant to a certain wavelength. The plot of SENSI against the different eposure wavelengths is called the action spectrum. For every wavelength it represents the absorbance loss incurred per 1 kJ/cm^2 of exposure at that wavelength.

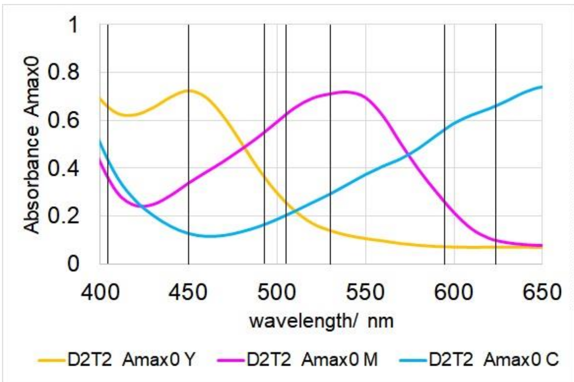
Results

The left side of Fig 2, a-f , shows the action spectra of the print mataerisl investigated. The right side of Fig 2, g-l , shows the corresponding absorbance spectra of the yellow (Y), magenta(M) and cyan (C) colorants of the various print materials, with the available LED center wavelengths shown as vertical black lines. The y-axis for the action spectra is a measure of the colorant light stability at a ccertain wavelength of light. Some colorants, particualrly yellows, are light sensitive over the whole range of their absorbance spectra, magentas and cyans are most sensitive in the shorter wavelength range of their absorbance spectra. For example, the cyan of IJD has very little light sensitivity in its maximum absorbance and mainly degrades upon exposure to short wavelength light below 450 nm, This behaviour was also observed in microfading studies for phtahlocyanins (Lerwill et al, 2015).

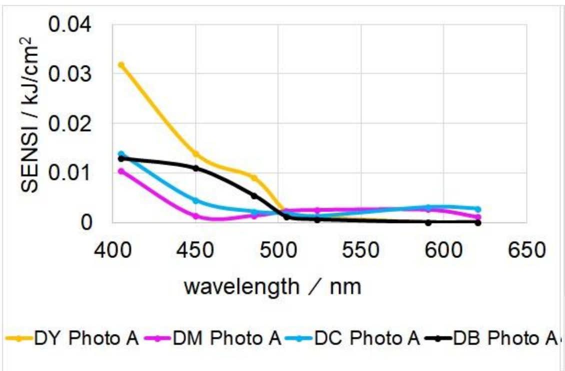
The y-axis scales of the action spectra in Fig 2 are adapted to the light stability of the different materails. For D2T2 and its least stable dye, black, SENSI at 400 nm equals $\Delta A_{max} = 0.09$ per kJ/cm^2, for the most stable material, EP; it is $\Delta A_{max} = 0.15$ per kJ/cm^2 for magenta, a factor of 1.4. At 450 nm D2T2 black fades at $\Delta A_{max} = 0.06$ per kJ/cm^{2,} whereas the EP magenta fades at $\Delta A_{max} = 0.005$ per kJ/cm$^{2.}$ A factor of ten. The fading rate difference of two materials depends on the wavelength range compared. The action spectra show that some colorants of a print fade considerably faster than others leading to a strong colour shift. An exaple is the D2T2 print which loses the cyan and black colorant, causing a reddish cast, whereas in the IJD print, all colorants fade at a similar rate, which is lightienig up the print and is less objectionable.



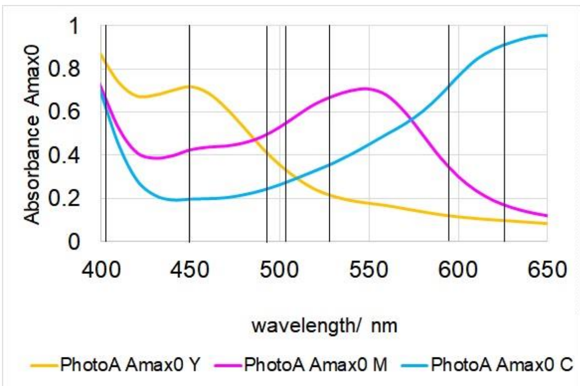
a)



g)



b)



h)

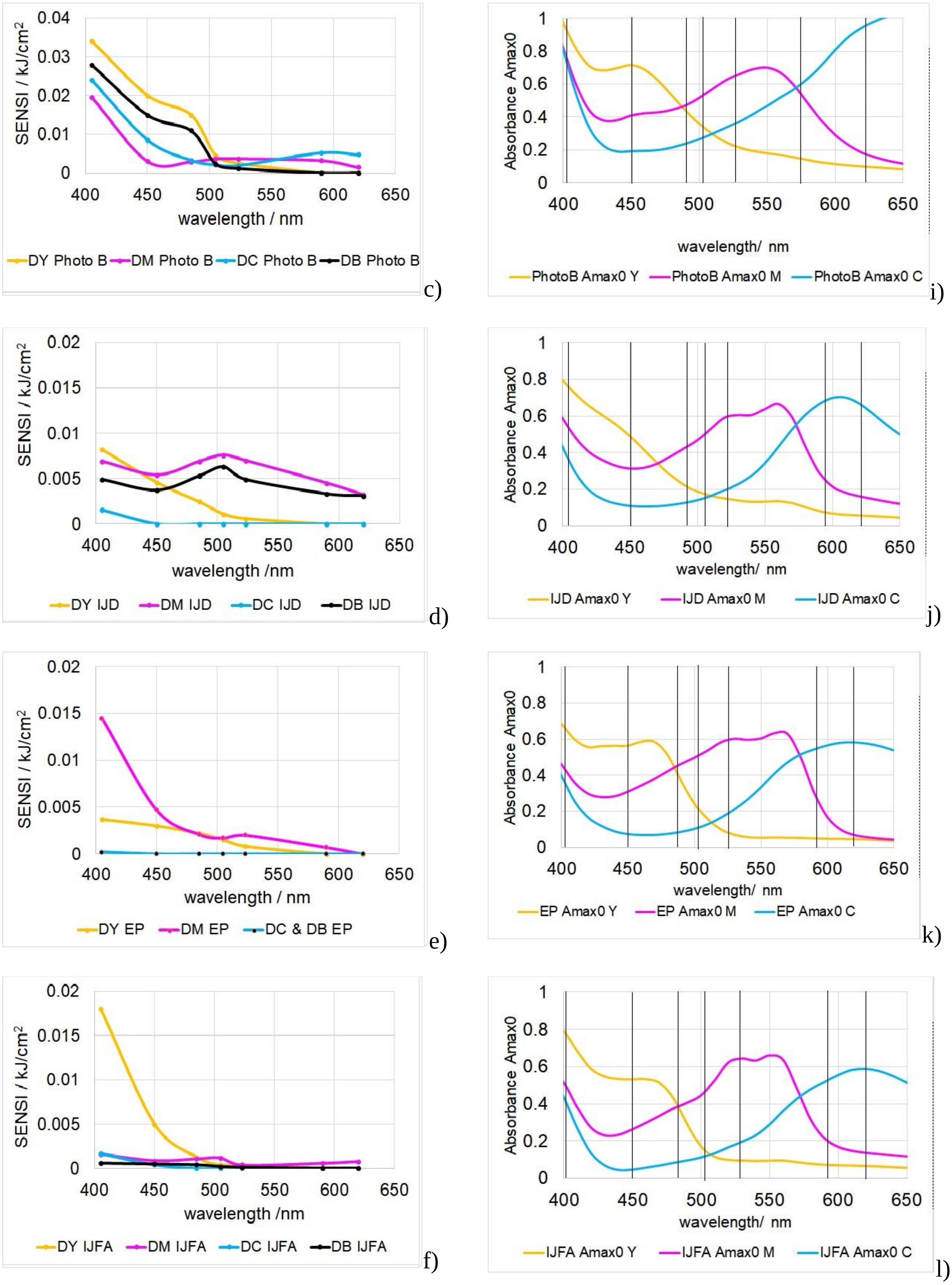


Fig. 2, left side (a-f) action spectra, right side (g-l) absorbance spectra of 6 print materials a) and , g) D2T2, b) and h) Photo B, c) and i) Photo B, d) and j) IJD, e) and k) EP, f) and l) IJFA. The black vertical lines indicate the maximum emission of the narrow band LED

Action spectra can be used to predict absorbance changes of print materials which are exposed by light sources with differet RSI. In a first step, the RSI of the exposure light source has to be matched by the exposure of the narrow band LED. This match does not need to be a good colourimetric spectral match, but needs to excite the same electronic states of the colorants as the expousure light (Groenevelt et al., 2023). Imaging colorants have broad absorption peaks (Aceto et al., 2014) as can also be seen in Fig 2g-l. As is known from laser flourescence spectroscopy (Zaffino et al., 2017), the exposure light does not have to illuminate the whole absorption range, or even the maximum absorbance to excite the colorants. The emission of the narrow band LED (black vertical lines) are suitable to excite all colorants investigated. The GRG nonlinear fit of the narrow band LED to the white LED provides for those narrow band LED that constitute the white ligth best as is shown in Fig 3 for the case of a 2700 K LED. The spectral intensity factors have to be weighted by the photon energy to better represent the excitation energy. Tab 1 shows the original spectral intensity factors in the left column and the photon energy weighted factors in the right column for the LED 2700 K shown in Fig 3.

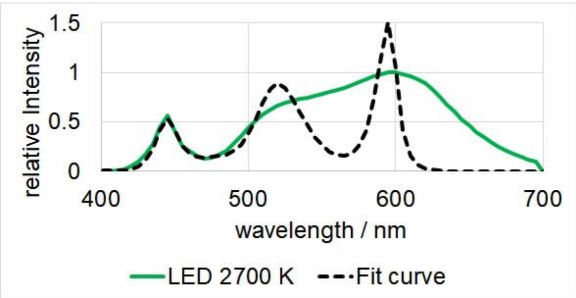


Fig 3: relative intensity spectrum of LED 2700 K and GRG nonlinear fit of the narrow band LED to the white LED 2700 K

Narrow band LED	spectral intensity factor LED 2700K	weighted by photon energy
385 nm	0.00	0.00
395 nm	0.00	0.00
405 nm	0.00	0.00
450 nm	0.53	0.47
485 nm	0.09	0.07
505 nm	0.00	0.00
523 nm	0.88	0.68
590 nm	1.50	1.01
620 nm	0.00	0.00

Tab. 1 Match narrow band to white light LED

The case of a LED with CCT 5000K was selected below to predict absorbance losses for certain exposure levels. The photon-energy weighted spectral intensity factors indicate the ratio of the narrow band wavelength which have to be multiplied with the total exposure at which the comparison is done. The linear range of the fading curve depends on the light stability of the print material is at different exposures for the differnt materials This is why the comparison is done at different exposure level for the six print materials. In the example below we have selected the total exposure of 50 or 55 kJ/cm^2 for silver halide photoA and B and IJD, 27 kJ/cm^2 for the D2T2 print and 70 or 77 kJ/cm^2 for the pigment based print matearisl (EP and IJFA).Table 2 compares those predicted absorbance changes with actual measurements after the expsoure with LED 5000K. The experimental errors of the prediction can be estimated from the exposures made with the two LED of the same RSI. Those errors were about ±0.02 for all colours.

ΔAmax x @ kJ/cm^2		50	55	50	27		70	77
		IJD	Photo A	Photo B	D2T2		EP	IJFA
Pred..	Y	0.11	0.36	**0.47**	0.27		0.11	0.18
Act.	Y	0.11	0.33	0.25	0.23		0.13	0.09
Pred..	M	0.28	0.12	0.17	0.16		0.2	0.05
Act.	M	0.3	0.18	0.13	0.19		0.14	0.04
Pred..	C	0	**0.17**	0.29	0.15		0	0.01
Act.	C	0.01	0.41	0.32	0.16		0	0.03

Tab. 2. Predicted vs. actual fading of print materials

The predictions works very well for most investigated print materials and most colorants but not for silver halide prints. Many silver halide colour prints materials have a sacrificial UV absorber which protects the colorants from fading under UV and short wavelength yellow light (Pénichon, 2013). When it is slowly destroyed by short wavelength light the protection is gradually lost and the fading speed of the colorants changes as well . In a white light exposure, both process, the slow destruction of the UV absorber and the degradation of the colorant run in parallel. This cannot be predicted by narrow band exposures that only affect one small wavelength range.

Conclusions

The method described is suitable to predict qualitatively and quantitatively the light fading of contemporary coloured print materials. However, several conditions have to be met. It assumes that light is the only factor that attacks the colorants. In real display conditions pollutants may attack the colorants and may speed up colorant destruction. The prediction can only be made for a specific colorant of a print and only applies to this specific material. It is thus of importance to unambiguously identify photographic print techniques (Cattaneo et al., 2022; Eom and Lee, 2023) and even colorant types of prints (Silva, 2022) to use it.

The method is particularly suited to print materials with thin layers and a limited number of colorants and less for very complex image structures such as paintings. As the exposure takes place at ambient conditions, very fragile and heat sensitive materials can be investigated.

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Style Transfer in Advanced Film Digitization and Rendering Workflows

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Abstract

This paper introduces *Multi-sourced Aesthetic Transfer* (MAT), a crucial feature in advanced film digitization and rendering workflows. It is essential when integrating various film elements—whether negatives or positives—and matching their differing material characteristics to produce an aesthetically coherent result.

In typical professional filmmaking of the analog era, the camera negative and exhibition prints represent the two material endpoints of the production process. The camera negative holds the original information from a film's primary shooting, preserving the full dynamic range of captured scenes and superior sharpness. Moreover, as negatives were generally stored safely and were never subjected to the wear and tear of projector use, they are typically more complete and remain in better condition. Exhibition prints, by contrast, serve as a better color reference, reflecting adjustments made during color timing for aesthetic or narrative reasons. However, it is important to note that exhibition prints often can vary due to differences in the film stock or processing technique. Additionally, if a print has faded over time, digital restoration may be required to recover its original appearance. When both a camera negative and a reference projection print are available, *Multi-sourced Aesthetic Transfer* (MAT) becomes invaluable. It allows for the integration of the structural integrity of the camera negative with the refined color palette of the projection print.

The combination of the camera element—negative or reversal—with exhibition prints is just one application of MAT. Other "non-final" elements, such as interpositives or internegatives can be the input source for MAT. This tool is also applicable to other film element sets, such as black-and-white color separations used in two-color and three-color processes, most notably in Technicolor's dye-transfer system. These processes often use arbitrary and idiosyncratic color components for printing and produce image textures distinct from the graininess of the black-and-white separations.

By integrating disparate film elements, MAT preserves the complete spectrum of color and spatial details, ideally captured through multispectral scanning. This enables digital recreations of a film's appearance as it would have been experienced in analog cinema. Through this process, MAT ensures that digital renderings retain both the aesthetic integrity and historical authenticity of original screenings.

Keywords: film scanning, multispectral imaging, style transfer, film aesthetics, film restoration.

Introduction

In discussing the surviving prints of a film, Paolo Cherchi Usai (1994) observed that "film is a multiple object".[10] This inherent multiplicity encompasses all the accessible elements that can contribute to the digitization and restoration of a film. Consequently, critical questions arise: which element should serve as the primary source material for scanning? Which should be used as the color

[10] "The 'original' version of a film is a multiple object fragmented into a number of different entities equal to the number of surviving copies." (Cherchi Usai 1994: 84)

reference? Furthermore, the so-called philological reconstruction of a film often requires restorers to combine various source materials into a final digital version, striving to include all available sequences from the film's original première. These questions have been central to debates in restoration ethics and practices for decades (Read and Meyer, 2000; Venturini, 2006) and have gained even greater importance with the advent of digital technologies (Catanese, 2013; Fossati, 2009).

These general observations highlight two key requirements that are addressed in this paper. *1) Accurate Digital Translation of the Color Reference Element*: Ensuring that the selected color reference element is translated into the digital domain with a physically accurate method is critical. This process requires high-quality imaging of its film frames combined with scientifically rigorous visual rendering. Ideally, a multispectral scanning approach is used, sampling the visible spectrum at evenly spaced intervals. The resulting images must exhibit sufficient spatial resolution, high bit depth, and an excellent signal-to-noise ratio. These high-quality spectral images are then processed to produce color-accurate images using standardized color matching functions (CIE, 2015) and the spectral power distribution of historical film projectors. *2) Precise Color Transfer to Source Material Scans*: Accurate transfer of these color values from the reference to scans of the optimal source material is essential. The source material should be selected based on its aesthetic integrity, its physical and mechanical condition, superior resolution, and the presence of a wider range of scene luminance levels—qualities typically found in earlier-generation film materials.

Source Materials for Scanning (MAT input)

While original camera negatives are often the best source materials for scanning due to their dynamic range and oftentimes pristine condition—not only are they not exposed to the wear and tear of film production, but they are often also more color-fast than prints—they do not contain the color adjustments and alterations made in post-production and color grading for aesthetic and narrative purposes. Therefore, for various reasons, different reference materials are required for the most convincing result that meets the core requirements of restoration ethics.

Understanding a film's history as an artwork, its aesthetic qualities, and the production and post-production technologies used is crucial, as different historical color processes are rooted in distinct technical and conceptual foundations. Therefore, selecting the right scanning materials requires not only knowledge of a film's specific history and context but also a thorough understanding of the color technologies applied. Chromogenic multilayer films that have become the standard for color film production in the mid-1950s were conceptualized with a comprehensive workflow consisting of a specialized film stock for shooting, adapted development and processing steps in the lab and a printing process on a positive film stock that was adjusted to these material requirements. Its foundation relies mostly on sophisticated chemistry to establish a working connection between the sensitization of the silver halides, the colored couplers of the correction mask (if present), and the image-forming dyes embedded in the layers of the film emulsion.

Earlier processes, such as the many two-color technologies and the three-strip dye-transfer Technicolor No. IV, were built on much more arbitrary connections between the recording stocks—black and white separations captured through color filters—and the result in the dye-transfer exhibition print. This arbitrary assignment of printing dyes to the representation of spectral characteristics in the taking stocks not only yielded highly idiosyncratic color renditions—for instance the typical Technicolor look—but, as we will show, it is also much more challenging for the transfer of color information present in exhibition prints onto scans of the black-and-white color separations.

Our study shows how modeling the relationship between the various film elements can change depending on the case at hand and the collection of film elements included in the process.

Reference Element for Aesthetic Appearance (MAT reference)

When correcting colors in film digitization, the ideal reference is an exhibition print, as it faithfully represents the visual presentation originally intended for audiences. To apply Multi-sourced Aesthetic Transfer (MAT) effectively, it is not necessary to scan the entire reference film element. Instead, it is sufficient to scan a selection of representative frames. These frames must encompass a diverse range of colors, adequately reflecting the overall color palette of their respective shots. Given that the chosen reference film element may be fragmentary, it is crucial to ensure that representative frames are available for each shot. Capturing these frames with high color accuracy is essential, and this can be achieved through appropriate color management workflows using standardized reference color targets or, ideally, by employing multispectral imaging techniques (Trumpy *et al.*, 2021).

Multi-sourced Aesthetic Transfer

Multi-sourced Aesthetic Transfer (MAT) employs an input image and a reference image to automatically generate look-up tables (LUT) that minimize the color difference between the processed input and the reference image. Leveraging LUT processing—a standard technique in video editing—MAT effectively harmonizes diverse film elements by aligning their differing material characteristics, producing an aesthetically cohesive result. An overview of the MAT workflow is presented in Table 1.

Overview of Multi-sourced Aesthetic Transfer Workflow	
1	Investigate and select pairs of matching scene frames from input and reference sources.
2	Use high-quality imaging systems with superior optics, advanced electronics, and robust software to scan and render the selected images. Ensure the input image has sufficient spatial resolution, while prioritizing high color accuracy for the reference image.
3	Crop images to remove the perforation area, focusing exclusively on the image region.
4	Perform image registration to precisely align the input and reference images, ensuring pixel-to-pixel correspondence of their features.
5	Generate a 1D LUT to minimize the color difference between the input image, processed via the look-up table, and the reference image.
6	If needed, create a 3D LUT to further reduce any residual differences.
7	Apply the generated look-up tables in color grading software to the input video file or image sequence, ensuring they are selectively applied to the specific shot corresponding to the representative frame.
8	Repeat steps 2 through 7 for each shot, using the input and reference images corresponding to the representative frame for that specific shot.

Table 1 - Workflow for Multi-sourced Aesthetic Transfer

When the input image is from a negative film element, step 5 includes a negative-to-positive conversion, followed by optimization to minimize the color difference with the reference. These transformations are combined in a single 1D LUT. For certain film sources, such as the Technicolor case study, a 1D LUT alone may not provide a satisfactory result, requiring the use of a 3D LUT (step 6) for a better match. The following case studies illustrate how the presented technology functions in practice.

Case study #1: ROTE OHREN FETZEN DURCH ASCHE, AUT 1991
Internegative to exhibition print (both chromogenic)

The film ROTE OHREN FETZEN DURCH ASCHE (English title FLAMING EARS) presents a typical example of how Multi-sourced Aesthetic Transfer (MAT) can adjust an input image to match the color aesthetic of a reference image using a one-dimensional look-up table (1D LUT). This experimental Austrian science-fiction punk film was directed by Ursula Pürrer, Dietmar Schipek, and Ashley Hans Scheirl (1991). It was originally shot on chromogenic Super-8 reversal, from which a blown up 16 mm internegative film was created. From the internegative, Atlantik-Film in Hamburg produced the prints for exhibition purposes. The Super-8 camera material was unfortunately lost. The negatives, cut into A and B rolls, were digitized using a *Kinetta* scanner equipped with an RGBW LED illumination chip and a *Lumenera* Lt16059H color camera. Reference frames from the original 16 mm print were selected from various scenes and captured using a prototype 25-band multispectral scanner developed as part of the "VeCoScan" research project (ERC Proof-of-Concept 812583). Accurate color renderings of these reference frames were calculated from the 25-band data, following the methodology outlined in a previous publication (Sec. 3 in Trumpy *et al.*, 2021). These rendered images served as the reference for MAT, while the input consisted of the corresponding frames from the scanned internegative.

MAT streamlined the color grading process, eliminating the subjectivity inherent in manual adjustments. The process employed a two-step workflow:

1. **Inversion to Positive (neg2pos)**: The negative input image was converted into a positive image with an adaptive, content-aware process (Diecke *et al.*, 2020).
2. **Color Optimization (pos2ref)**: A 1D LUT was optimized to minimize residual colorimetric differences between the processed positive image and the reference.

The look-up tables generated in steps (1) and (2) were then combined into a single 1D LUT for application. The resulting combined 1D LUT is compatible with standard color grading software, enabling efficient and consistent rendering of the restored film. In this specific case, the restoration achieved a remarkable visual alignment between the scanned internegative and the reference frames from the exhibition print, as illustrated in Figure 1. While director Ursula Pürrer expressed great satisfaction with the results, she requested subtle refinements to ensure the final version fully adhered to her creative intent.

Case study #2: LEA AUS DEM SÜDEN, GDR 1963
Camera Negative to Exhibition Print (both chromogenic)

Another compelling application of Multi-sourced Aesthetic Transfer (MAT) is the restoration of LEA AUS DEM SÜDEN, a short musical film shot in 1963 by Deutsche Film AG (DEFA), directed by Gottfried Kolditz and photographed by Erich Gusko. This film highlights the use of Agfacolor, a widely employed color process in German cinema of the era. Compared to FLAMING EARS, this case presented a greater challenge, as the materials used in the MAT workflow spanned three generations of duplication. The original camera negative, preserved in excellent condition, served as the input material for MAT. For the reference, an exhibition print—produced through three successive duplication steps from the camera negative—was selected to represent the intended color aesthetic. Despite the generational differences, MAT effectively created a unified 1D LUT, offering a streamlined workflow that revitalized the film's vibrant aesthetic while maintaining its historical authenticity. As shown in Figure 1, MAT's application to LEA AUS DEM SÜDEN demonstrates its ability to digitally emulate multiple photo-chemical film copying processes with a 1D LUT and successfully reconstruct the original Agfacolor palette. However, due to the extended duplication chain, some residual color differences remain more pronounced compared to the FLAMING EARS case.

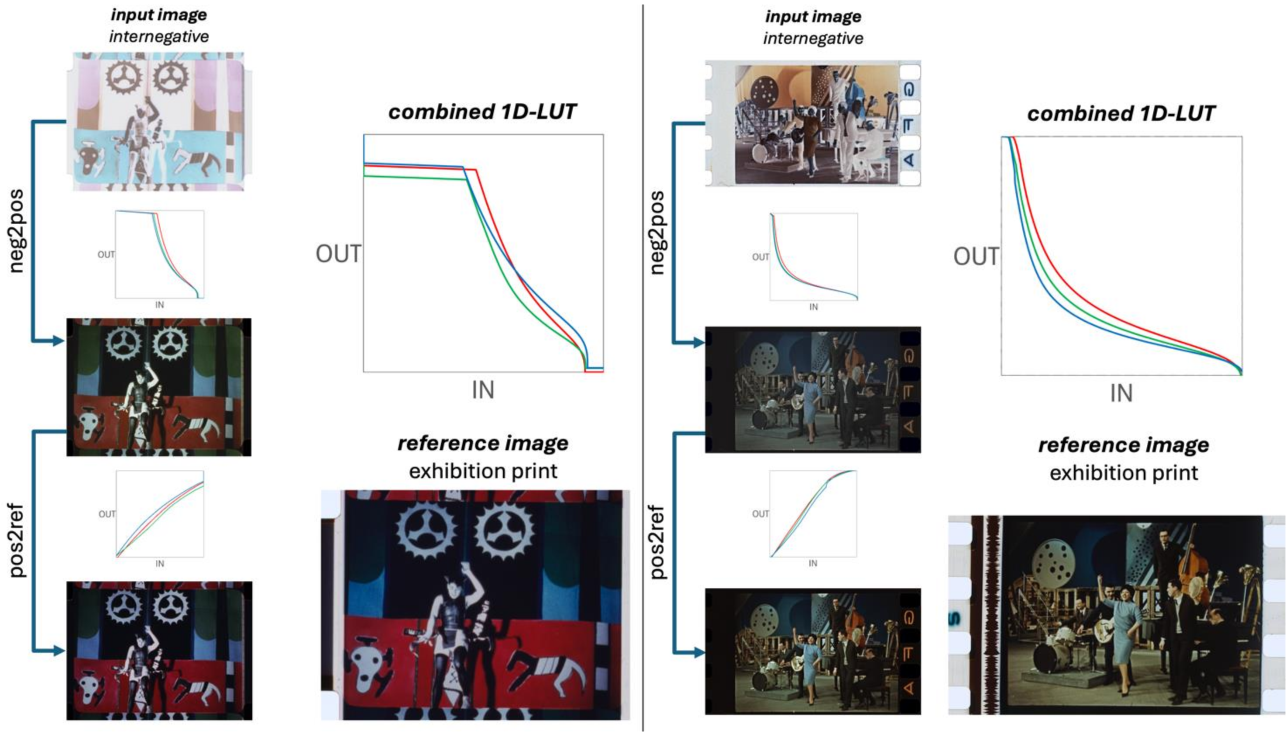

Figure 14 – MAT applied to ROTE OHREN FETZEN DURCH ASCHE (left) and LEA AUS DEM SÜDEN (right). In both cases, the result of pos2ref (bottom-left image in each part) well matches in color the reference image at its right.

Case study #3: HEIDI UND PETER, CH 1955
Black-and-white Separations to Technicolor Dye-transfer Print

In the 1950s, Technicolor transitioned from its cumbersome three-strip camera system to using chromogenic Eastmancolor negatives for filming. From these negatives, three black-and-white separations were created to produce the printing matrices for Technicolor's distinctive dye-transfer prints. HEIDI UND PETER, the first Swiss feature film shot in Technicolor, was based on Johanna Spyri's famous novel and produced by Lazar Wechsler / Praesens-Film, directed by Franz Schnyder. The film's chromogenic negative, the black-and-white separations, and three dye-transfer prints are preserved in the holdings of Swiss television SRF at the Cinémathèque suisse. These prints exhibit noticeable color variations, which are characteristic of Technicolor prints. The "German print" has cooler, more neutral hues, while the "French print" and the "SRF 2003" print display warmer tones.

In a previous research project (DIASTOR, Swiss Commission for Technology and Innovation), we were granted access to these film elements and documented them using a color-managed workflow based on a DSLR camera. For this case, the input is the color image obtained by merging the black-and-white separations for the cyan, magenta and yellow primaries into the R, G and B channels respectively. The reference used was one of the prints. Following the procedure described in previous case studies (neg2pos and pos2ref), the transformation found was condensed into a single 1D LUT. Despite the optimization process, the residual mismatch between the resulting positive image and the reference remained unacceptable. To address this, an additional 3D LUT was applied to map the colors of the 1D LUT-processed input to match the reference colors of the print. While a 1D LUT maps each dimension independently of the others, transforming input RGB values into corresponding output RGB values, a 3D LUT adjusts the mapping by considering the interdependencies between all three color dimensions. The 3D LUT is constructed from pixel data of both the input and reference images. Its size increases exponentially with the number of RGB table entries per dimension. Each output RGB value is calculated through standard triangular interpolation, using the input RGB and surrounding or intersecting RGB entries in the table. This approach ensures the interpolated output RGB values align closely with the reference data.

The earlier registration of the frame pairs provides sample correspondence between the input colors and the reference colors. These sample pairs of input colors and reference colors are assigned to one or more sets. When a 3D-LUT input RGB address used for triangular interpolation has no unique contributing RGB reference values, the nearest RGB input and reference values are used; when this occurs, these input reference RGB pairs contribute to more than one set. Each input RGB table entry is associated with a set of one or more input reference RGB pairs. A color difference metric is used to find a fit to map each pixel pair set from its input values to its 3D LUT interpolated output reference values. The CIE76 color difference is faster to compute than more recent color difference metrics, and it was therefore adopted. Optional adjustments local to specific input RGB neighborhoods to the color difference function weights can improve the calculation of table entries for colors with low luma or high chroma extent. Data quality and the amount of data of the sample pairs of input colors and reference colors will impact the quality of the 3D LUT.

For this case study, two different shots of HEIDI UND PETER were selected. The two Technicolor shots are shown in Figure 2; each shot (*a* on the left and *b* on the right) has four sub images. From the lower left clockwise, these sub images show the input negative, the result from applying the combined 1D LUT described in the previous case studies #1 and #2, the result from the following application of the 3D LUT, and the reference exhibition print.

a

b

Fig. 2 – Two test cases of HEIDI UND PETER (*a* and *b*) – for each case, bottom left represents the input; top left is the result of the combined 1D LUT; top right is output after applying 3D LUT; bottom right is reference positive.

Closing Remarks

The multi-sourced aesthetic transfer (MAT) case studies presented here illustrate how modeling the relationship between various film elements can vary significantly depending on the specific context and the combination of film elements involved. MAT harmonizes the differing material characteristics of these elements to achieve an aesthetically coherent result, even in complex transformations. An example is the Technicolor process, where the arbitrary connections between black-and-white separations and the dye-transfer print necessitate the use of 3D LUTs. The effectiveness of the MAT approach is evident when comparing the output to reference frames, as shown in Figure 1 (bottom) for the *ROTE OHREN FETZEN DURCH ASCHE* and *LEA AUS DEM SÜDEN* case studies, and in Figures 2a and 2b (right) for the *HEIDI UND PETER* case study.

Multispectral film scanning enhances film digitization by measuring the transmittance values of the film across each spectral band within the selected set. The possibility to select specific spectral bands for the visual rendering enables better digitization results tailored to the purpose of the digitization. This ensures either the physically accurate reproduction of color values (with the full set of spectral bands), ideal for well-preserved projection prints, or the enhancement of color information (with narrow RGB bands), which is particularly useful for negatives or films that have faded.

The combined use of MAT and multispectral film scanning, creating look-up tables from digital files generated through multispectral captures, provides a robust framework for producing aesthetically coherent results. This approach preserves both the aesthetic integrity and historical authenticity of the original screenings, ensuring a faithful representation of the cinematic experience.

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Understanding colors of Dufaycolor: Can we recover them using historical colorimetric and spectral data?

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Abstract
Dufaycolor, an additive color photography process produced from 1935 to the late 1950s, represents one of the most advanced iterations of this technique. This paper presents ongoing research and development of an open-source Color-Screen tool designed to reconstruct the original colors of additive color photographs. We discuss the incorporation of historical measurements of dyes used in the production of the color-screen filter (réseau) to achieve accurate color recovery.

Keywords: Dufaycolor, additive process of color photography, color-screen

Introduction

Additive color processes of early color photography employed a variety of techniques to filter light into its primary components – red, green, and blue – and then recombine them to create a full-color image. A common approach, proposed by Louis Ducos du Hauron in his seminal 1869 work "*Les Couleurs en Photographie, solution du problème*," involved the use of a fine screen or mosaic of color filters (referred to here as a *color-screen*) placed in front of a light-sensitive monochromatic emulsion. The first commercially available process based on this technique was introduced by John Joly in 1895. Number of improved processes followed (Pénichon, 2013), including the most widely known one, Autochrome Lumiére introduced in 1907 (Lavédrine and Gandolfo, 2013).

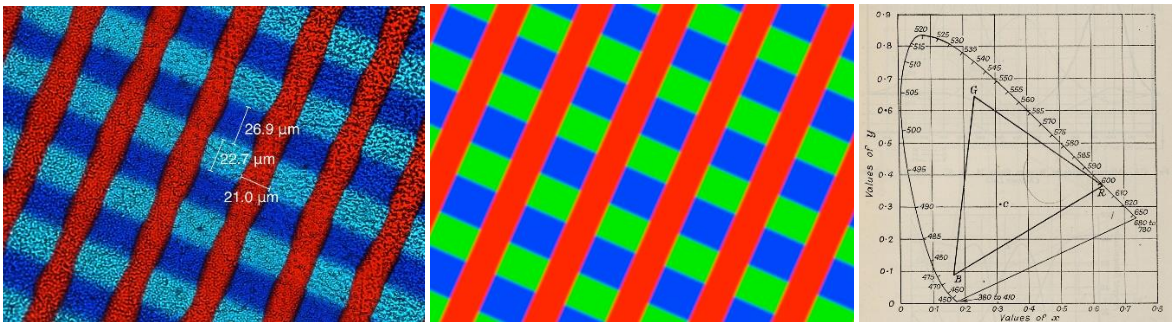

Fig. 1 – Dufaycolor réseau: (a) microscopic image[11], (b) digital simulation of original colors, (c) primaries on the chromaticity diagram (Cornwell-Clyne, 1951) p150.

Dufaycolor, introduced in 1935, was a relatively late example of an additive color process, but also among the most refined and best documented. The Dufaycolor film consisted of a transparent film base coated with a color-screen filter called a *réseau*. This réseau was a mosaic comprised of tiny, alternating green and blue squares, interleaved with red lines (Fig. 1). (We call those miniature filters *elements*.) A layer of protective varnish separated the réseau from a panchromatic photographic emulsion. The film was loaded into the camera with the base facing the lens, the reverse of conventional practice. During the exposure, light passed through the film base and then through the

[11] The Emulsion has been removed. The visible structures are not silver grain but the structure of the filter layers. From the Timeline of Historical Film Colors, image by David Pfluger, ERC Advanced Grant FilmColors. Imaging was performed with support of the Center for Microscopy and Image Analysis, University of Zurich.

colored réseau elements before reaching the panchromatic emulsion. Each element of the réseau acted as a tiny filter, allowing only its specific color of light to pass through. This resulted in a record of the color information behind each element being captured by the underlying panchromatic emulsion. This principle is conceptually similar to that used in modern digital cameras, where a Bayer filter, a modern color-screen, is placed over a monochromatic CMOS or CCD sensor. The réseau served a dual role in the Dufaycolor process. Firstly, it encoded the color information during the initial exposure, as described above. Secondly, after the photographic emulsion was developed into a high-contrast monochromatic transparency (an *image layer*), the réseau in combination with the image layer visually recreated the recorded colors.

The dyes used in the réseau were not particularly stable and lightfast, causing virtually all surviving Dufaycolor images to appear faded today. However, the silver-based image layer is significantly more stable. This allows for the possibility of digital restoration through infrared scanning: Capturing the color scene in image layer gave an analog variant of a RAW file from a modern digital camera. Once digitized (réseau superposing the image layer is transparent in the infrared light), identifying the individual color-screen elements within the scan becomes a critical yet challenging step due to factors like deformations caused by shrinking of the film base, and geometric distortions introduced during scanning. Nevertheless, with these challenges addressed, modern image processing techniques, such as demosaicing algorithms and color-space conversions, can be applied to reconstruct a full-color image from the recovered data with greater level of precision then possible from faded subtractive films (Barker *et al.*, 2022; Hubička *et al.*, 2023).

We are developing an open-source tool, Color-Screen[12], specifically designed for the analysis and color reconstruction of early color photographs captured using color-screen methods. This tool has successfully yielded well looking color reconstructions from a variety of processes, including *Paget*, *Dioptichrome*, *Finlay* color plates as well as Dufaycolor film. This paper focuses on the challenges encountered in achieving faithful color reconstruction, aiming to reproduce the colors as they appeared when the photographs were new, before the degradation of dyes within the color-screen filters. This task involves understanding numerous technical details. While the method is applicable to other color-screen processes, this paper will primarily examine Dufaycolor due to its comparatively extensive documentation, with plans to extend our research to other processes in the future. Because all Dufaycolor photographs are significantly faded today, we dive into historical records on Dufaycolor film to find data for the digital simulations.

Manufacturing Dufaycolor's réseau

Examining Dufaycolor film in a microscope reveals the surprisingly precise printing of the réseau, with individual color elements arranged without significant overlaps or gaps that could compromise color fidelity. While some variation in the uniformity of these elements exists, their high density effectively averages out these minor inconsistencies. Multiple types of réseau screens were produced across different production lines. The density of the lines ranged approximately from 19 to 25 lines per millimeter (480 to 635 lines per inch). This more than doubles the line density of modern high-quality halftone prints, which typically use around 200 lines per inch. The high density of the réseau's color elements is attributable to the process's original development for motion picture film, where such resolution was necessary for satisfactory image quality upon projection.

(Cornwell-Clyne, 1951), in pages 285–290, gives what we believe to be the most comprehensive description of the réseau's manufacturing process, including photographs of the printing machinery. We refer the interested reader to this publication for a detailed account and (Friedman, 1947) for a survey of many associated patents. In brief, the process involved first coating the acetate film base

[12] https://github.com/janhubicka/Color-Screen/wiki

with a layer of blue-dyed collodion. Subsequently, the color pattern of the réseau was created in a two-step process using a specialized machine similar to a halftone press. This machine was capable of printing fine lines of greasy ink, transferred from an engraved cylindrical roller.

The *first step* of the process involved printing a series of lines at an angle of approximately 23° to the film's edge. The areas of the blue-dyed collodion not covered by these lines were then bleached and dyed green. This created a pattern of alternating green and blue stripes. In the *second step*, a different engraved cylinder was used, featuring lines oriented roughly, but not precisely, orthogonal to the first set, and with a similar, but again not exact, line density. After this second printing, the remaining exposed blue- and green-dyed collodion was bleached and dyed red, resulting in the final, characteristic réseau pattern. This process is also apparent in microscope, since the blue lines appears closest to the film base, green lines in between and red lines most distant.[13] Final steps of production line involved application of the protection layer and finally coating by the photographic emulsion.

Research on Autochrome plates (Lavédrine, 1992) has revealed significant variations in the colors of starch grains producing Autochrome's color-screen and their different percentages across different production batches.[14] These inconsistencies yield doubts on the possibility of achieving reliable color reconstruction for Autochrome images. Dufaycolor, however, was designed for both still and motion picture film, with the latter imposing far stricter demands for reproducibility. Consequently, it is reasonable to expect that Dufaycolor réseau production exhibited greater uniformity. This hypothesis is further supported by the comparatively detailed quality control procedures (Cornwell-Clyne, 1951):

Following the first printing step, the film underwent quality control in a view-box illuminated by CIE Standard Illuminant B.[15] This inspection involved assessing the straightness, evenness, and number of breaks in the printed lines. Additionally, the degree of ink penetration and the frequency of printing anomalies were evaluated. After the second printing stage, the color accuracy of the réseau was measured using a colorimeter and compared against a set of tricolor filters. If the réseau's color deviated beyond a (regrettably unspecified) tolerance from a target chromaticity (also unfortunately unknown), the film was back-coated with a subtractive filter to adjust its color properties.

	x	**y**	**Y**	**Dom. Wavelength**
Red element	0.633	0.365	17.7	601.7
Green element	0.233	0.647	43	549.6
Blue element	0.14	0.089	3.7	466.0

Tab. 1 - Colorimetric specification of réseau elements, (Cornwell-Clyne, 1951) page 290.

The colorimetric specifications are given in Tab. 1. We find it remarkable that the 1931 CIE standard has been already applied in production of Dufaycolor. (Bonamico and Baker, 1933) also mentions: "*It is scarcely necessary to say that every new batch of dyes used has to be tested with the spectrophotometer, so that its concentration may be modified in accordance with requirements*."

Digital simulation of the réseau and problem in the published data

To simulate the réseau filter digitally, we combined data in Tab. 1 with measurements of the red, green, and blue elements' dimensions in Fig. 1 (a). While the width of the blue and green squares is not given, it can be estimated to be approx. 28.9 μm. Based on this we determined that red filter covers 42.1 % of area, green filter 26.5 % and blue 31.4 %. Simulated réseau is shown in Fig. 1 (b).

[13] Réseau printed with blue or green color last exists as well, those are used by earlier Spicer-Dufay motion film.
[14] Lavédrine, private communication.
[15] Illuminant B is an obsolete standard with tungsten light corrected to represent direct sunlight at intermediate and northern latitudes, with a correlated color temperature of approximately 4874 K. Later superseded by Illuminant D.

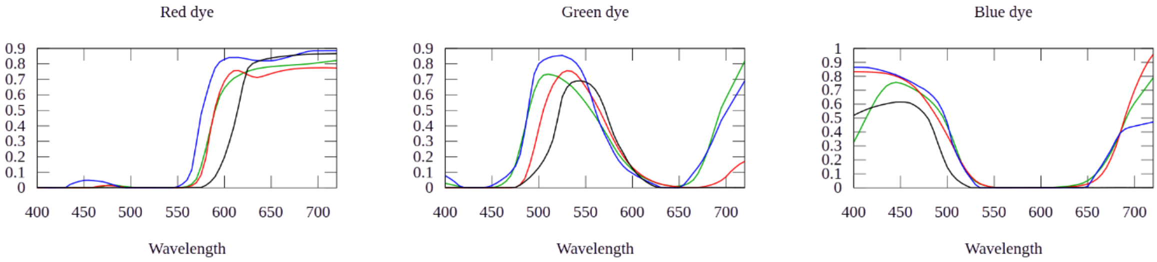

Fig. 2 – Transmission curves of primaries réseau from different publications. Green: (Harrison and Horner, 1939) p325, red: (Cornwell-Clyne, 1951) p149, blue: (Collins and Giles, 1952) p435 and black: (Neblette, 1952) p446.

Fig. 3 – Sample Dufaycolor 6×9 cm approx. 1937, Clachan Inn, Scotland: (a) color calibrated scan, (b) with color of réseau balanced to neutral using levels function in GIMP. Probably taken by J.B.S. Thubron and/or his wife Diana.

Fig. 4 – Color reconstructions using réseau primaries using xyY specification of primaries: (a) Tab. 1, (b) Tab. 2; and using spectra from Fig. 1: Harrison and Horner (c), Cornwell-Clyne (d), Collins-Giles (e), and Neblette (f).

Simulating color of our sample Dufaycolor scans using this réseau screen led to poor results, see Fig. 4 (a), with a relatively simple explanation. Additively combining the colors of the réseau elements in the proportions derived from their measured dimensions results in a greenish color. While Tab. 1 does not specify the illuminant used for the color measurements, it was likely either Illuminant B or C, both intended to simulate daylight conditions. Furthermore, the original color specification of the combined réseau is unknown but close to neutral grey. If réseau had a saturated overall color it would show in all over-exposed areas of photographs which would be undesirable (Harrison and

Horner, 1937; Neblette, 1952). This can be verified. Infrared imaging can be used to measure the visual density of the image layer in areas of a photograph we believe to be originally neutral grey and in these areas the densities are approximately the same whatever the colour of the reseau patch.

To verify Tab. 1 we recomputed dominant wavelengths (those are computed using chromaticity coordinates of the color and whitepoint). No whitepoint could reconcile the published values in Tab. 1. Examining other tables in the same source (Cornwell-Clyne, 1951) and tracing them back to their original sources revealed a relatively high frequency of typographical errors. This unfortunate fact can be attributed to the huge quantity of scientific data presented in the book.

Unfortunately, the original source of Tab. 1 could not be located. Luckily, page 150 of (Cornwell-Clyne, 1951), contains chromaticity diagram of the réseau elements, see Fig. 1 (c). Red and green primaries measured from this diagram align with the values in Tab. 1 (up to 0.005). The blue primary, however, suggests a missing digit in Tab. 1; specifically, that the x-coordinate of 0.14 should be 0.164 so all quantities are with 3 digit precision. Furthermore, to achieve a more neutral overall color when combining the réseau elements, we found it necessary to adjust the intensity of the blue primary from 3.7 % to 8.7 %. These corrections are summarized in Tab. 2 and corresponding rendering in Fig. 4 (b). Still, we failed to match the dominant wavelength of green element as indicated.

	x	**y**	**Y**	**Dom. Wavelength**
Red element	0.633	0.365	17.7	601.7
Green element	0.233	0.647	43	~~549.6~~ **534.8**
Blue element	~~0.14~~ **0.164**	0.089	~~3.7~~ **8**.7	466.0

Tab. 2 - Attempted correction to the colorimetric specification of réseau elements.
Dominant wavelengths are computed relative to Illuminant E (0.333 x, 0.333 y) which works well for red and blue.

Dyes used to print réseau

Motivated by the necessity to verify Tab. 2 we searched for information about dyes used in réseau. Fascinating insight into this area, given by (Bonamico and Baker, 1933), explains, among others, why the dyes used in réseau seems less stable than ones in Autochrome:

"The dye problem has been a difficult one. Owning to the chemical nature of the bleaching baths, it is necessary to use basic dyes throughout, and certain dyes, e.g. Methylene blue, will migrate through the protective layer to the photographic emulsion and cause innumerable small insensitive spots, which, on reversal, appear as black spots. A large amount of work has been carried out on the basis of trial and error because, although we can make up dye-baths to conform to any theoretical specification, we are obliged to employ dyes which will not migrate to emulsions. Moreover, they must be sufficiently soluble to obtain the very high concentrations necessary for efficient colouring to take place at the very rapid rate at which film passes through the machine. The dyes used must withstand also the repeated process to which the matrix is subjected. The thickness of cinematograph film is 5/1000 in., and the coating of green collodion has to be put on top of it[16], as well as the protective layer of gelatin, followed by a second protective layer of varnish, and finally the emulsion. It will be seen, therefore, that, unless these layers represent the absolute minimum of thickness, the film will be so unwieldy that it would not pass through the slender gate of the cine-camera and projector. Nevertheless, in this extremely thin film of collodion it is necessary to concentrate the requisite amount of all three dyes in order to give the required absorption within close physical limits. One way in which the colour chemist can help to improve the brilliancy of the pictures is to provide dyes, which are of the highest possible efficiency for the purpose under discussion, i.e. dyes which will give the necessary transmission of colour, but will not absorb a large proportion of the incident light. The fugitive character of the dyes is not of great importance, since the exposure of an individual picture frame in the projector only occupies 1/40th sec., and the life of average film is about 200 projections. The actual exposure of the colours, therefore, to the light of the arc lamp is of the order of 5 sec., so that the property of the permanence can be ignored."

[16] Published in 1933 this text refers to the pre-production variant of earlier Spicer-Dufay process or Dufaycolor. Spicer-Dufay réseau is printed with blue color last and Dufaycolor with red last. Also protection layer is likely synthetic resin.

We located four independent sources for spectral transmission curves of Dufaycolor primaries (summarized in Fig. 2). However, definitive information on the exact dye formulations proved elusive. While US patent 1,806,361 (filed 1931) describes a printing process using specific dye mixtures—*blue* dye (100 parts of alcohol, 4 parts of *malachite green*, 6.7 parts of *auramine)*, *red* dye (*basic red N Extra*, Kühlmann), *blue*/violet dye (80 parts 4% *crystal violet* 4% in alcohol, 20 parts 8% *malachite gre*en in alcohol)—these formulations, also cited in (Collins and Giles, 1952) and (Friedman, 1947), are examples rather than precise recipes, possibly altered to protect proprietary information. These described mixtures do not appear to correspond with the curves shown in Fig. 2.

Experimental results

Simulating the Dufaycolor réseau using spectral data requires selecting a backlight. (*The Dufaycolor Manual*. first edition, 1938) specifies that the réseau elements are balanced for viewing under normal daylight. Consequently, we used the D65 illuminant in our simulation. (Color-Screen allows selection of other color temperatures and applies a Bradford correction to the whitepoint of the output color space.) All additive transparencies appear dark without adequate backlighting. It was common practice to mount these transparencies in wide black mats or use specialized viewers that blocked all light not passing through the transparency. The results of our simulation are shown in Fig. 4 (c)–(f).

To evaluate significance of the data about réseau primaries we used sample Dufaycolor transparencies digitized using Nikon Coolscan 9000ED at 4000PPI in RGB and infrared channel. Color-Screen tool, using the RAW data obtained, performed later processing. First it analyzed the geometry of the scan (used RGB scan to identify individual color elements of réseau). Next it simulated the scanner scanning the réseau to determine dot spread functions at multiple spots of the scan. (This is necessary to compensate for variation of sharpness across the scan caused by film deformation). Next the infrared channel was used to determine intensities of each color element and image was demosaiced by bicubic interpolation. Using the information about dot spread function in multiple points of the scan the saturation loss is estimated and compensated for obtaining an RGB image in the color profile of Dufaycolor film. Finally, given primary colors are applied, and image is converted to XYZ. Overall brightness (exposure) was adjusted according to the simulated réseau has Y of 1.

	Tab. 1		**Tab. 2**		**Harrison and Horner**		**Cornwell-Clyne**		**Collins and Giles**	
	Avg	**Max**	**Avg**	**Max**	**Avg**	**Max**	**Avg**	**Max**	**Avg**	**Max**
Tab. 2	9.97	26.08								
Harrison and Horner	16.61	35.66	7.48	14.36						
Cornwell-Clyne	17.14	37.02	8.48	16.24	1.54	3.11				
Collins and Giles	15.37	33.64	6.62	12.97	1.27	2.79	2.19	3.62		
Neblette	17.60	38.66	8.99	17.41	2.40	4.90	1.16	2.54	3.04	5.50

Tab. 3 – ΔE (CIE 2000) between every pair of reconstructions in Fig. 4.

We compared each image pair using both average and maximum ΔE (CIE2000) values. To mitigate the influence of film damage and other anomalies, we excluded the 1 % of pixels with the largest ΔE values from this comparison. Results are summarized in Tab. 3. ΔE values range from 0 to 100, where $\Delta E < 1$ is barely perceptible; $1 \leq \Delta E < 2$ is visible only upon close inspection; $2 \leq \Delta E < 3$ represent slight (considered acceptable for commercial reproduction) differences; $3 \leq \Delta E < 5$ indicate obvious differences; $\Delta E \geq 5$ easily noticeable differences. The main difference between reconstructions is their overall color cast, caused by imbalances in the primary colors and their relative area in simulated réseau under D65. (Recall that réseau was neutral grey.) We added an option to Color-Screen to automatically adjust the intensities of primaries to obtain that. This correction is shown in Fig. 5 and Tab. 4 where we also tested a second image (Fig. 6) with more warm tones (skin tones and gray grass) to demonstrate the impact of image selection; the first image was chosen for its saturated greens.

Fig. 5 – Color reconstructions using the same primaries as in Fig. 4 with réseau white-balanced.

Fig. 6 – Second sample Dufaycolor 6×9 cm approx. 1937, Egypt: (a) color calibrated scan, (b) with color of réseau balanced to neutral using levels function in GIMP, (c) color reconstruction. Likely the same photographer as Fig. 3.

		Tab. 1		**Tab. 2**		**Harrison and Horner**		**Cornwell-Clyne**		**Collins and Giles**	
		Avg	**Max**	**Avg**	**Max**	**Avg**	**Max**	**Avg**	**Max**	**Avg**	**Max**
Tab. 2	**Fig. 3**	0.99	2.44								
	Fig. 6	1.46	2.87								
Harrison and Horner	**Fig. 3**	0.60	1.98	0.96	2.39						
	Fig. 6	0.92	2.05	1.42	2.63						
Cornwell-Clyne	**Fig. 3**	1.03	2.58	0.81	3.07	1.07	3.48				
	Fig. 6	1.54	2.80	0.58	1.93	1.30	2.49				
Collins and Giles	**Fig. 3**	0.76	2.65	0.81	2.45	0.38	1.12	1.16	4.18		
	Fig. 6	1.04	2.08	1.02	2.22	0.69	1.64	1.18	2.62		
Neblette	**Fig. 3**	2.03	4.79	1.48	4.84	2.00	5.26	1.01	2.28	2.05	5.92
	Fig. 6	2.97	5.49	1.66	4.22	2.62	4.66	1.44	2.70	2.46	4.72

Tab. 4 – ΔE (CIE 2000) between every pair of reconstructions in Fig. 5 and reconstructions of image in Fig. 6.

Conclusions

We compared color renderings based on five different historical measurements. Despite the inherent limitations of colorimetry and spectroscopy from the 1930s to 1950s, which resulted in significant differences between the raw measurements, we found a surprisingly good color match on sample images after white-balancing the réseau: mixing primaries together in real image reduces the differences. The agreement between all pairs of specifications in Harrison and Horner, Cornwell-Clyne, and Collins and Giles yields an average difference less than 1.18 ΔE and a maximum of less than 4.18 ΔE and they match well coloriometric measurements in Tab. 2. This makes the choice of historical measurement less significant than issues related to varying scan sharpness and accurately simulating light passing through the emulsion and réseau—topics we will address in a subsequent paper (with aim to mitigate differences in color reconstructions from scans of same Dufaycolor photograph using different scanners). Notably, even using sRGB primaries resulted in a reasonable average $\Delta E \leq 2.17$ and a maximal $\Delta E \leq 4.83$ in the same test as in Tab. 4, suggesting the possibility of reasonably accurate color reconstructions for other additive color processes. Reconstructions of Dufaycolor based on the infrared scan will probably need some manual white-balancing also due to the fact, that the film was back-coated by a corrective subtractive filter as part of the quality checking. Examining larger set of Dufaycolors will be necessary to evaulate importance of this. We note that even from RGB scans good reconstructions, up to white-balance, are possible using a technique estimating infrared channel using RGB values (Barker *et al.*, 2022). **Acknowledgement**: We thank to Bertrand Lavédrine for discussions that significantly improved this paper.

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The Scream (ca. 1910) through the Years: from Photographic Documentation to Digital Rejuvenation

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Abstract

Edvard Munch's *The Scream* (ca. 1910) captures the dramatic scene of a human shape overwhelmed by the vibrant sunset over the fjord, painted in oil and tempera on cardboard. Over time, the painting's appearance has inevitably changed, with previous studies highlighting the sensitivity of the yellow and dark red hues to moisture and light exposure. We utilized four colour photographs from 1971, 1989, 1993, and 2003 to digitally reconstruct the painting's appearance for those years. The method proposed in this paper addresses the challenges of film degradation by using stable areas of the painting as reference points for advanced colour correction. Our results demonstrate the effectiveness of this method in digitally rejuvenating *The Scream* offering a pluralistic glimpse into its potential past appearance.

Keywords: chromogenic film, transmittance spectral imaging, digital restoration, colour correction, polynomial modelling

Introduction

Digital rejuvenation (Berns, 2019) is the attempt to reconstruct the appearance of an artwork as it was in the past, and it is of high interest for a wide range of stakeholders: art historians, conservators, museum curators, educators and the general public. Very often, rejuvenation approaches start from accurate colour representations of the artwork based on spectrophotometric measurements of its current status (Kirchner *et al.*, 2018). This is combined with knowledge about the constituent materials and their colour change behaviour, which is usually assessed with accelerated aging experiments (Kirchner *et al.*, 2018). In some cases, valuable information about a painting's original composition and appearance can be found in documentary sources (e.g. descriptions of the artist's work in letters, diaries, newspapers) (Stańska, 2024) and/or archival records such as analogue photographs (Tsaftaris *et al.*, 2014; Stenger *et al.*, 2016).

Our research introduces a new method to digitally rejuvenate the painting *The Scream* (ca. 1910) from the Munch Museum in Oslo (Norway), by placing analogue archival records in conjunction with analytical data that informs the process of deterioration in the painting. Four analogue colour photographs of the painting were recorded in 1971, 1989, 1993, and 2003. Our aim is to restore the artwork's colours to how they appeared when the photos were taken. The challenge is that some of these records are themselves subject to colour degradation due to the photo-chemical nature of the chromogenic dyes used in films. We overcome this challenge by using scientific data about the materials in the painting and their aging behaviour to draw a correspondence between the optical properties of the films and that of the painting, as captured in colour images.

The current article further elaborates on our previously outlined proof-of-concept (Ciortan *et al.*, 2023), by showing the results of employing the stable areas in the painting as reference to obtain correct the colours of the film records. Technically, to obtain a film-to-painting transformation, we use the same mathematical implementations featuring polynomial models presented in one of our previous works (Ciortan and Trumpy, 2024), just that in the current article, we gather the reference or anchor points from the surface of the painting itself, whereas in (Ciortan and Trumpy, 2024) we extract these anchor points from the colour control patches captured in the photographs.

Method

The earliest known analogue colour photograph of *The Scream* (ca. 1910) was captured on large format Kodak Ektrachrome film in 1971. This was followed by two large format Agfa films taken in 1989 and 1993, and a 35 mm Fuji film shot in 2003. These photographs collectively document the painting over a span of four decades. Fig.1 presents the series of these existing reversal films. The degradation of the 1971 record is evident, as it is governed by a red cast, provoked by the fading of the cyan dye in the Kodak Ektachrome film.

Fig. 5: The analogue photographs of The Scream (ca. 1910) in 1971 (Kodak Ektachrome), 1989 (Agfa), 1993 (Agfa), and 2003 (Fuji).

After 2003, the digital transition began, meaning that the painting was documented with colour images. At the start of the current study, the most recent colour image of the painting was one acquired in 2017, shown in Fig.2. The idea underlying this work is to use analogue films to access the past colours of the painting, while at the same time, the non-fugitive materials and stable zones in the painting are used as reference for correcting the colours of the films, that withstood dye degradation in their turn as well.

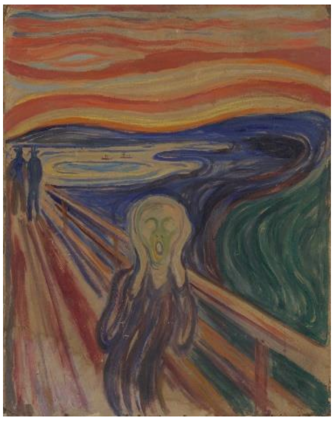

Fig. 6: Digital colour image of the painting captured in 2017, rendered in sRGB space.

In order to accurately capture the optical densities of the films, we designed a transmittance imaging setup, made of a hyperspectral scanner HySpex VNIR-1800 (Norsk Elektro Optikk AS, no date) that collects 186 spectral bands in the 400 nm - 1000 nm range, a glass translation table covered with a thin translucent white diffuser sheet, where the photographs were placed, and a broadband halogen lamp that backlights the scene. Due to the difference in format between the films, two different lenses were coupled to the hyperspectral camera to achieve comparable resolution. More precisely, the large-format films (shot on Ektachrome and Agfa) were scanned with a 30mm lens, while the 35 mm Fuji was captured with a 10 mm lens.

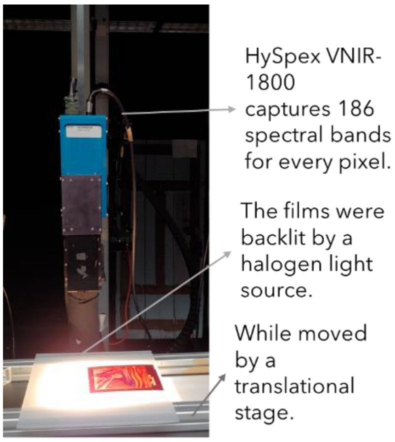

Fig. 7: The transmittance hyperspectral imaging setup designed for scanning the reversal films of The Scream (ca. 1910).

Our approach to digital rejuvenation starts with a first pre-processing step, needed only for the heavily aged 1971 film, shot on Kodak Ektachrome. In this step, we adjust the spectral densities of the cyan, magenta, and yellow dyes so that they match the original concentrations, taking the black level in the film as reference (Chatterjee, Trumpy and Ruedel, 2023). This way, we obtain a less faded film record.

Fig. 8: The colour image of the reversal film from 1971, as it looks now (left) and after the pre-processing step (right) involving a spectral adjustment of the cyan, magenta and yellow dyes to make the black in the top part look darker and more neutral, without a red colour cast.

In the second step, we develop a film-to-painting transformation, where we correct the colours of the film record using the painting as reference. From prior investigations, we are aware of which areas in the painting are stable and have not changed during the last decades. Monico et al. (Monico *et al.*, 2020) identified that the yellow brushstrokes in the sky and the main figure's throat have faded because of the chemical reaction between cadmium sulfide pigment and humidity. Additionally, Chan et al. (Chan *et al.*, 2022) employed microfadeometric measurements to assess the lightfastness of various coloured areas in the painting, revealing that the red hues in the sky, painted with vermilion, are particularly sensitive to light exposure. These two sensitive pigments can be mapped thanks to previously processed Macro-XRF scans (Cardinali *et al.*, 2022), where the distribution of mercury (Hg) and the cadmium (Cd) elements indicate where vermilion and cadmium yellow were applied in the painting either as pure strokes or mixed. In addition, a water damage is known to have occurred in the bottom left corner during the theft of the painting that took place between 2004 and 2006. Thus, all these areas combined charter the substantial changes in the painting, as displayed in Fig.4. We assume that excepting these areas, the rest of the painting is stable and has not changed (see Fig.5). The stable areas become anchor points to define a transformation from the colours of the slides to the actual colours of the painting. Although each image of the film was geometrically aligned with the image of painting, there are still minor registration artifacts, so that a pixel-by-pixel film-to-painting transformation would be inaccurate. Instead, we summarized the anchor points into 60 meaningful patches, which are the centres of the clusters after k-means segmentation was applied. The number of clusters, 60, was decided following the recommendation of (Hong, Luo and Rhodes, 2001) as being the optimal number for polynomial modelling in digital colour management applications.

Fig. 9: The areas in the painting where significant change has occurred. In order from left to right: MA-XRF map of the mercury (Hg) element showing the distribution of the vermilion pigmen; Macro-XRF map of the cadmium (Cd) element, showing the distribution of cadmium yellow pigment; the localization of the water damage in the bottom left corner following the theft of the painting between 2004 and 2006; all the changing points, segmented in the digital colour image of the painting from 2017.

Film 1971 after pre-processing   Painting 2017

Fig. 10: The film-to-painting transformation exemplified for the case of the 1971 film. First, a correspondence is drawn based on the stable areas (what is not masked by white), between the film and the painting in its current state (2017). These areas are further summarized into 60 clusters, to avoid bias for a certain colour group.

Mathematically, we formalize the film-to-painting correction with least-squares regression of polynomial models and neural network fitting, respectively, same as (Ciortan and Trumpy, 2024). The four correction methods minimize the difference between reference and film colours. The first method (baseline) generates a first-order polynomial model (basically a 3x3 colour correction matrix) and three lookup tables for each colour channel, optimized with the Nelder-Mead simplex algorithm (Nelder and Mead, 1965). The second method fits a second-order polynomial with quadratic terms in the CIELAB space, while the third method fits a third-order polynomial with cubic terms. The fourth method employs a shallow feed-forward neural network with one hidden layer and an output layer, optimized using Levenberg-Marquardt (Marquardt, 1963) and Bayesian regularization for better generalization. We choose the best model according to the mean absolute error given a train-test split of the data of 80%-20%, i.e. 48 points out of the 60 cluster centres are used for training and 12 points are used for test. Finaly, we apply the resulting transformation to each film, which ultimately enables us to peek into the painting's past with improved colour accuracy.

Results and discussion

Fig. 6 shows the four films in their current state, as captured with the transmittance hyperspectral imaging setup, and rendered colorimetrically for the CIE D65 standard illuminant and CIE 1931 2° observer. Fig. 7, Fig. 8, Fig. 9, and Fig. 10 show the colours of the films after correction with the four methods: baseline (first-order polynomial and look-up table), second-order polynomial, third-order polynomial and neural network, respectively. Numerically, the neural network method yields the lowest error when comparing the stable areas (Fig. 6) between each colour corrected film and the version of the painting in 2017 (Fig.2). It is difficult to quantify the performance of the methods in the non-stable/fugitive areas, corresponding to vermilion or cadmium colours, as we do not know with precision the extent of change with respect to the current colours of the painting.

Fig. 11: Colour images of the four reversal films, as they are in their current state. In order from left to right: 1971 (Kodak Ektachrome), 1989 (Agfa), 1993 (Agfa), 2003 (Fuji).

Fig. 12: The colour corrected films with the baseline method: 1971 (Kodak Ektachrome), 1989 (Agfa), 1993 (Agfa), 2003 (Fuji).

Fig. 13: The colour corrected films with the neural network method: 1971 (Kodak Ektachrome), 1989 (Agfa), 1993 (Agfa), 2003 (Fuji).

Fig. 14: The colour corrected films with the second-order polynomial: 1971 (Kodak Ektachrome), 1989 (Agfa), 1993 (Agfa), 2003 (Fuji).

Fig. 15: The colour corrected films with the third-order polynomial: 1971 (Kodak Ektachrome), 1989 (Agfa), 1993 (Agfa), 2003 (Fuji).

Generally, one of the challenges of digital restoration approaches is given by the lack of ground truth. A way to cope with this is to check the consistency of well-known colour change behaviours of some pigments. For instance, vermilion is known to darken with the passing of time, and this is perceivable in our results in the sky region, where the vermilion brushstrokes become darker in the 2003 colour-corrected film with respect to the 1971, as displayed in Fig. 10.

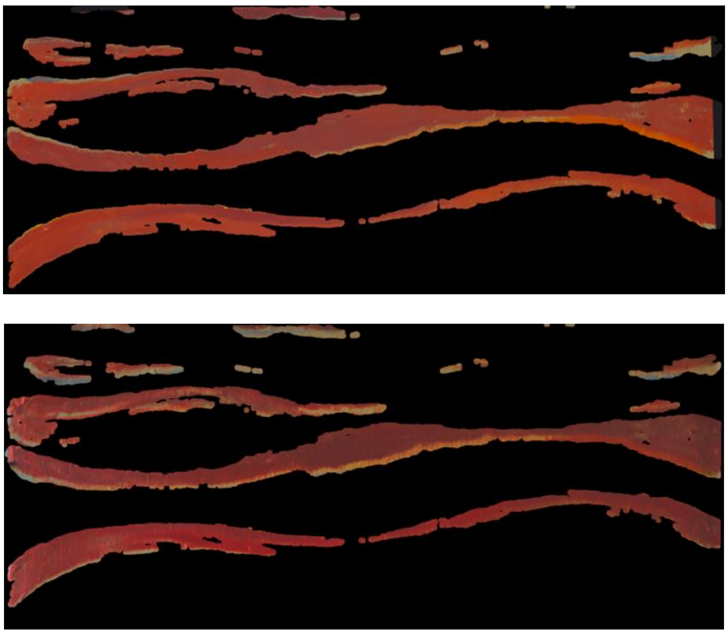

Fig. 16: Details corresponding to the vermilion brushstrokes in the sky of The Scream, taken from the colour corrected film records (with the neural network approach) from 1971 (top) and 2003 (bottom). The darkening effect typical to vermilion is obvious, which supports the fact that the corrected film records can be used as evidence to retrieve the past appearance of the paintings.

Another way to cope with the lack of ground-truth of the digital restorations is to consult documentary sources. In this regard, there is a description of the scene depicted in *The Scream* motif by the artist Edvard Munch himself, that mentions a dramatic sunset, where the red looked like "blood" and the yellow like "tongues of fires", as follows: "I was walking along the road with two friends – the sun was setting – suddenly the sky turned blood red – I paused, feeling exhausted, and leaned on the fence – there was blood and tongues of fire above the blue-black fjord and the city – my friends walked on, and I stood there trembling with anxiety – and I sensed an infinite scream passing through nature." *(Stańska, 2024)*. According to artist's description, we would expect a very intense, vivid and saturated red in the sky, as well as a high contrast between the red and the yellow tones. The method that achieves best this dramatic sunset effect is the third-order polynomial, as can be seen in Fig. 11. Nonetheless, the restorations for the 1993 and 2003 with the same method yield somehow unnatural colours in the face area and add a bit of black in the sky area that is unlikely to have been there method. Furthermore, the method that restores the dullest and desaturated colours for the sky is the baseline, followed by the second-order polynomial, while the neural network attains a good balance between realism and level of vividness of the sunset effect.

It is important to stress that every digital restoration is speculative in nature albeit our effort to root the process in a comprehensive set of scientific data from multiple sources—elemental mapping, colour and spectral imaging, artificial aging experiments, and documentary sources. One of the advantages of our work is that it offers multiple possibilities to showcase the painting's past appearance depending on a certain choice of method and parameters, without issuing a final judgement on which result, if any, is the undeniable truth. The choice of the most probable restoration is a complex process, and the verdict needs to be discussed and debated by a panel of experts, which we plan to fulfil in the future.

Conclusions

This research presents a comprehensive approach to digitally rejuvenating *The Scream* (ca. 1910) by leveraging analogue archival photographs and scientific data on the painting's material degradation. By addressing the challenges of chromogenic dye degradation in film photographs, we developed a film-to-painting transformation method that uses stable areas of the painting as reference points. Our comparative analysis of polynomial models and neural network fitting revealed that the neural network method yielded the lowest error in the colour correction of the film records. The results highlight the potential of our method to provide pluralistic representations of the painting's historical appearance, contributing to its understanding, interpretation and preservation. Future work will focus on further evaluation of the various restoration results by experts in the fields of art history, curatorship, conservation and conservation science.

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