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ANVUR Agenzia Nazionale Valutazione sistema Universitario e Ricerca
APeJ Academic Publications eJournal
BASE Bielefeld Academic Search Engine
DBH Database for statistikk om høyere utdanning
DOAJ Directory of Open Access Journals
EZB Elektronische Zeitschriftenbibliothek Regensburg
JURN Search tool for open access content
ROAD Directory of Open Access scholarly Resources

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PEER REVIEW PROCESS
All articles submitted to the Color Culture and Science Journal are peer-reviewed according to the following procedure:

First review level
The Associate Editors evaluate each article to determine if the topic and content are of interest to the journal. Once the article passes the initial review, the Associate Editors select several reviewers from the Editorial Board based on their expertise in a particular subject area or topic.

Second review level
Two or three experts review each article with a blind peer-review process where the reviewers are kept anonymous. Reviewers are asked to evaluate the manuscript based on the following criteria:

- Originality
- Relevance to journal's aims and scope
- Technical merit and/or validity
- Soundness of methodology
- Completeness of the reported work
- Conclusions supported by the data
- Correct acknowledgment of the work of others through reference
- Effectiveness of the manuscript (organization and writing)
- Clarity of tables, graphs, and illustrations
- Importance to color researchers
- Relevance to color practices

If the article is accepted with major revisions, the author(s) are asked to improve the article according to the reviewers' suggestions. The revised article will then be submitted for further review.
After collecting the reviewers' reports, the Associate Editors recommend the acceptability of the article to the Editor-in-Chief.

TOPICS
The CCSJ accept papers on a wide range of topics on color, including and not limited to the following:

1. Color and Measurement/Instrumentation. Colorimetry, photometry and color atlas: method, theory and instrumentation; quality control and food coloring, dyes, organic and sustainable color.
2. Color and Digital. Reproduction, management, digital color correction, image processing, graphics, photography, film and video production, printmaking and 3D print, artificial vision, virtual reality, multispectral imaging, data visualization. Light field imaging. Multi-sensor fusion. Color localization, recognition, HDR imaging, ADAS systems.
3. Color and Lighting. Metamerism, color rendering, adaptation, color constancy, appearance, illusions, color memory and perception, color in extra-atmospheric environments, lighting design, lighting technologies, visual comfort.
4. Color and Physiology. Mechanisms of vision in their experimental and theoretical aspects, color vision and color appearance, deficiencies, abnormalities, clinical and biological aspects, synesthesia, health, well-being.
5. Color and Psychology. Phenomenology of colors, color harmonies, color & form, perceptive, emotional, aesthetic, and diagnostic aspects.
6. Color and Production. Food and beverages, agriculture, textiles, plastic materials, ceramics, paints, gemology, color in the food industry.
7. Color and Restoration. Archaeometry, painting materials, diagnostics, and conservation techniques, restoration, and enhancement of cultural heritage.
8. Color and Environment. Representation and drawing, urban planning, the project of color, architecture, interior design, landscapes & horticulture, color and architectural syntax, territorial identities, biodiversity.
9. Color and Design. Furniture, CMF design, fashion, textiles, textures, cosmetics, food design, museography.
10. Color and Culture. Arts and crafts, history, philosophy, aesthetics, ethno-anthropology, graffiti, geology, sociology, lexicology, semantics, anthropology of vision, food culture and heritage, color naming.
11. Color and Education. Pedagogy, didactics of color, aesthetic education, artistic education.
12. Color and Communication/Marketing. Graphics, communication, packaging, lettering, exposure, advertising.

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Editorial

The Gruppo del Colore – Associazione Italiana del Colore (Color Group – Italian Color Association, https://gruppodelcolore.org/?lang=en), in collaboration with the *Istituto di Fisica Applicata "Nello Carrara" of the Consiglio Nazionale delle Ricerche (IFAC-CNR)* and the *Opificio delle Pietre Dure (OPD)*, organized the first edition of the international conference on "**Colour Photography and Film: sharing knowledge of analysis, preservation, conservation, migration of analogue and digital materials**" on 29th and 30th March 2021. Due to the pandemic, it was held online. The organization of the conference started in early 2020, while we were experiencing the lockdown because of Covid-19.

Although the idea to launch a conference on the state of art of contemporary photography was born within the Italian research project called Memoria Fotografica https://www.ifac.cnr.it/images/stories/libri/archivio/BOOK/Memoria-fotografica.pdf, which was active during 2018-19, a new situation emerged in 2020, therefore also a new involvement. The growing international interest in visual memory was a direct reaction to this change. Issues related to photo and film material's preservation, conservation, investigation, transmission and use became the topics of the conference.

Contributors were asked to share their recent research and experience on analogue and digital colour photographic and film materials. Highlights on preservation, conservation, restoration, digital migration of colour photographs and film were encouraged, including on the following topics: a) Historical and current technologies, materials, processes; b) Preservation issues and sustainability; c) Contemporary Photography Preservation Issues; d) Conservation treatments, experiences, case studies; e) Emergency preparedness and recovery; f) Digitization and digital recovery of photographic objects and film materials; g) Research, Technologies and New Tools in Film Restoration.

The scientific committee of the conference selected 30 oral presentations of 20 minutes each and 16 digital posters given as short presentations of 5 minutes. The conference counted around 140 attendees from 15 countries. The book *Colour Photography and Film: Sharing knowledge of analysis, preservation, conservation, migration of analogue and digital materials – 2021: Conference Proceedings*, published in August 2021, was a direct outcome of the convening. It came out as part of the open access Research Culture and Science Books (available here: https://www.rcasb.eu/index.php/RCASB/catalog/book/1).

The scientific committee, whose contribution had a great impact on the success of the event, was then invited to select the most significant papers in order to publish a special issue of the Colour Culture and Science Journal (CCSJ), where the extended contributions were submitted to a double blind peer reviewing process before their publication. The same process was applied to two additional papers, which were selected among the external submissions because they were found to be important to the advancement of the field.

The present special issue of the Journal covers the history of photographic process, their technicality and practise, nowadays nearly lost: Nayla Maaruf, Maria Kokkori, and Sylvie Pénichon investigated the principles of the Flexichrome color process; Laura Covarsì the Jos-Pe collection found at the Rijksmuseum of Amsterdam; while Nicholas Le Guern discussed the three colour Kodachrome, one of the most iconic and widely missed process; Nadezhda Stanulevich deepened the knowledge on the versatile additive process created by Prokudin-Gorskii.

The history of motion film processes was also investigated through the work of Paolo Tosini, who described and discussed the conservation of Prizma Color films found in the Mexican National Film archive; while Louisa Trott outlined the birth of the color motion photography for the amateurs.

Simone Venturini and Serena Bellotti, as well as David Pfluger, Lutz Garmsen and Giorgio Trumpy, presented two papers dedicated to the necessity of a wider view on the film and non-film material that are fundamental to achieve a philological restoration and the restoration and digital methods involved in the reconstruction of lenticular films, respectively.

Two extra conference papers were also admitted to the current special issue. They were by Sabrina Negri, who explored the conservation of the experimental hand painted films by Stan Brakhage, and Ivan Magrin-Chagnolleau, who presented a pedagogical approach to photo retouching and colour grading.

As editors of this Special Issue, we would like to remind you all that CCSJ is a double diamond publication and that all the contributors and scholars involved in the peer reviewing process act as volunteers, in the present case, for the empowerment of the preservation, conservation, restoration and science of the photography and film community.

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The Flexichrome: visual examination and scientific analysis of an overlooked color process.

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ABSTRACT

Flexichrome is the commercial name for a dye imbibition process where the color image is formed by hand coloring a gelatin relief with acid dyes, without the use of color separation negatives and with great creative freedom. Final prints resemble those made with other processes like carbro or hand-colored gelatin silver. The Flexichrome was first marketed by Jack Crawford as the 'Crawford Flexichrome' in the early 1940s. Kodak purchased the patent from Crawford and remarketed the product as the 'Kodak Flexichrome' from 1949 until 1961. This paper presents an overview of the Flexichrome process and, through the study of selected Flexichrome prints and historic dyes, investigates the technology and variations in the formulations available. Prints and dye samples were characterized using a complement of analytical techniques including visible and fluorescence light microscopy (VLM, FLM), Fourier transform infrared (FTIR) spectroscopy, and x-ray fluorescence (XRF) spectroscopy. A key goal of the study was to establish identification clues for Flexichromes, informed by results from invasive and non-invasive analytical techniques. Handheld XRF analysis showed both the absence of silver and chromium, supporting the ability to distinguish a hand colored gelatin silver print and carbro prints from the Flexichrome. Unaided visual examination and VLM provided the following visible characteristics specific to the Flexichrome: continuous tone with no misalignment or misregistration of superimposed color layers and the presence of fluid lines and visible brushstrokes depending on the skill of the colorist. A print can also exhibit differential gloss and fluorescence in the magenta colors when unobstructed by a finishing layer. FTIR analysis of multiple sets of dyes confirmed the nature of the dyes as being acid dyes as indicated in the literature. Color fading is therefore not uncommon in contrast to carbros which have a higher lightfastness.

KEYWORDS: Color photography, Photographic identification, Materials analysis, Flexichrome, Dye imbibition.

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1. Introduction

The Flexichrome (a dye imbibition process) is a photographic color process that has received limited attention in the historical and conservation literature (Sipley, 1951; Coe, 1978; Koshofer, 1981; Pénichon, 2013). It was however used by a wide range of photographers; from commercial, to artistic and novelty use. In the words of its inventor Jack Crawford, Flexichrome compared "favorably in quality with Wash-Off Relief, Chromatone, and Carbro," [1] and was "quite similar to the latter method in texture and physical appearance" (Crawford, c.1939).

Making a print with the Flexichrome was cheaper and faster than with other color processes available at the time; the process was praised for its color flexibility and high-quality color images hence its name 'FLEXI-chrome'. It clearly offered certain advantages, including the use of a regular black-and-white negative and the relative simplicity of the process. It takes, however, a significant number of steps and materials to create a Flexichrome. Although the process was widely distributed by Eastman Kodak when it relaunched it in 1949 (*Kodakery*, 1949; *Australasia Photo-Review*, 1949; *Austin American*, 1949), it was soon overshadowed by chromogenic processes and eventually taken off the market by Kodak.

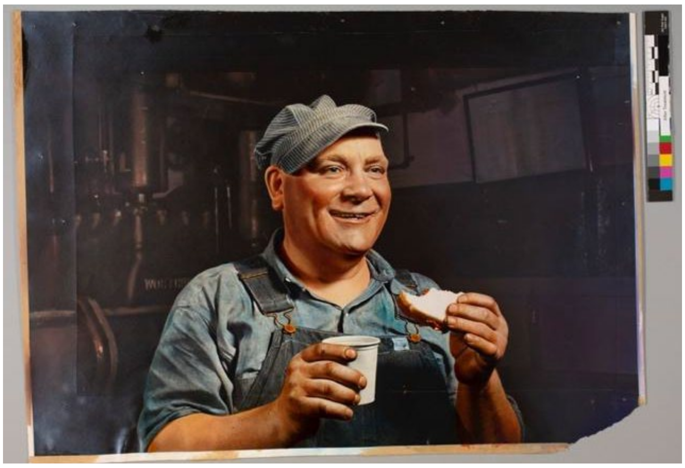

Figure 1: Herbert Lyman Emerson, Untitled, 1950's, Flexichrome, 37.1 × 49.2 cm (image); 37.9 × 50.2 cm (paper), Photography and Media, 2012.282, The Art Institute of Chicago. Courtesy of the Art Institute of Chicago.

This paper will highlight the historical development of the process and visual characteristics of the Flexichrome based on a print by Herbert Lyman Emerson in the collection of the Art Institute of Chicago (Figure 1) and reference prints from the Image Permanence Institute (IPI) and private collections. Secondly, we will report on findings of analysis performed on prints and sets of Crawford and Kodak original dyes, including visible and fluorescence light microscopy (VLM, FLM), Fourier transform infrared (FTIR) spectroscopy, and x-ray fluorescence (XRF) spectroscopy.

2. History of the Flexichrome Process

2.1 *The Crawford Flexichrome (1940-1942)*

In 1938 Jack Crawford, a New York photographer, filed a patent application for a new method of producing multicolored relief pictures (Crawford, 1941b). The following year, he filed a second patent with minor chemical changes to the process (Crawford, 1943). The patents describe the act of coloring a gelatin relief by hand to create a color photograph, and contain limited material information. The receiving layer is described as a gelatin silver bromide film in the first patent, and a 'wash-off relief emulsion' in the second one. While Crawford did not invent a new color photographic process, he creatively used the existing materials and knowledge of dye imbibition photography to make his own color prints from black-and-white negatives. His method eliminated the need for separation negatives, which were the more complicated aspect of the carbro and Wash-Off Relief processes.

The Crawford Flexichrome was brought to the market in 1940 by the Defender Photo Supply Company, an early leader in the manufacture of photographic materials located in Rochester, New York (Potter, 1940)[2]. Photographers could purchase Crawford Flexichrome materials individually or as a kit through the Crawford Flexichrome Company, Defender or select dealers—$6 for the complete outfit (Deschin, 1941) (Figure 2). Crawford promoted his process in popular magazines such as *Photo Technique, Minicam, The Camera* and *The Complete Photographer* (Dudley, 1940; Crawford, 1941a, 1942b, 1942a), and organized public demonstrations at various locations around the United States (Nevada State Journal, 1941; New York Times, 1941e; New York Times, 1941d) [3]. For those who wanted to color their own pictures but did not care to make the black-and-white Flexichrome print (i.e. the gelatin relief), Crawford Flexichrome Laboratories in New York City offered a printing service. Customers supplied original negatives, prints, or transparencies and size desired; they received their prints in the mail, ready to be colored (Crawford, 1941c). By 1941, the Crawford Flexichrome Company was busy enough to be looking for more employees to help cover the demand (New York

Times, 1941a; New York Times, 1941b; New York Times, 1941c). Commercial success was however short-lived.

Defender Photo Supply Company ended its collaboration with Crawford in 1942, when the United States entered the Second World War and supply for commercial use was deprioritized over military needs (Defender Trade Bulletin, 1942; Coe, 1978; Nadeau, 1989). Between the years 1942 and 1949, the authors could not find ads or articles on the Flexichrome, suggesting the product was commercially unavailable until it was re-introduced by the Eastman Kodak Company in 1949 as the ‘Kodak Flexichrome Process’. By 1943, Jack Crawford had sold his patents to Kodak; he eventually moved to Rochester, to direct the company’s Flexichrome studio and improve the process (Crawford, 1943; *Kodakery*, 1949; Lipton, 1949).

Figure 2: A Crawford Flexichrome kit comprised of a set of 11 Flexichrome colors, a reducer and a modeling agent (or black dye), a jar of liquid paper backing, a bottle of Flexilene quick drying varnish, chromic acid, ammonium dichromate, two brushes, lint-less paper blotter and an instruction booklet. Film and processing chemicals were purchased separately (Crawford, 1940). Courtesy of the George Eastman Museum.

2.2 *The Kodak Flexichrome (1949-1961)*

It was common practice of the Eastman Kodak Company to acquire promising photographic patents and hire their inventors to continue their work under the Kodak brand. The company had the resources to support research and development of the Flexichrome and the ability to advertise and market the product globally. It developed an entire new line of Kodak Flexichrome products with simplified ready-to-use sets of chemicals and instructions, an improved convenience over Crawford’s system where customers had to make the processing chemicals from scratch (Eastman Kodak Company, 1949).

In 1949, an extensive marketing campaign for the new Kodak Flexichrome began worldwide. Kodak emphasized the ease of making a color print using this process. The product was first introduced in New York City to commercial and professional photographers, dealers, artists, illustrators, and advertising agency representatives with an exhibit, a movie and demonstrations (Kodak, 1949) (Figure 3).

Figure 3: Jack Crawford at the launch event of the new Kodak Flexichrome (Kodakery, 1949).

The Flexichrome process was suitable to a myriad of uses, from studio portraiture to popular baseball cards, medical photography or artistic production. Commercial photographers such as Herbert Lyman Emerson likely used the process because it lent itself well to the production of originals that would be reproduced in magazines, while artists like Lyman Grey Fayman or Josep Masana created dramatic images of great artistic value (La Jolla Museum of Art, 1969; Galmes, 1984). In the industry, textile manufacturers, for example, favored the Flexichrome process for the illustration of their products because they could obtain closer matches to the colors of their original subjects than with other color processes available at the time (Varden, 1967).

Kodak discontinued the Kodak Flexichrome in 1961 but the dyes remained available until stock lasted (Nadeau, 1989). They were later marketed as Kodak Retouching Colors for color prints and transparencies and were especially well suited to retouch dye imbibition prints (Varden, 1967).

3. How to make a Flexichrome

The Flexichrome is a dye imbibition process. This means it uses the properties of a colloidal receiving layer to absorb or imbibe acid dyes and form a full color image. Making dye imbibition prints usually consists of successively transferring dyes from a yellow-, magenta- and cyan-dyed relief matrix onto a receiving sheet of paper coated with gelatin. With the Flexichrome, dyes are applied directly by hand onto a single positive gelatin relief image.

3.1 Making a gelatin relief

The making of a Flexichrome print started with a black-and-white negative, obtained directly in the camera or made from a color transparency. The negative was printed onto a sheet of Flexichrome film by projection or contact; exposure was performed through the film base (Dudley, 1940; Crawford, 1941a). Crawford Flexichrome Film, with a semi-matte surfaced celluloid base, was available in sizes from 5×7 inches to 20×24 inches (Crawford, 1941a; Lester, 1942; Deschin, 1941). Film in rolls 42 inches wide and 10 or 25 feet long was also available, for photomurals or commercial display (Crawford, 1941b; Crawford, 1942). Likewise, Kodak Flexichrome Stripping Film came in sizes from 5×7 to 20×24 inches and in rolls of 20 inches by 30 feet or 40 inches by 30 feet (Eastman Kodak Company, 1950).

Once exposed, the film was developed and then tanned in a dichromated solution to harden the gelatin surrounding the developed silver image. At that point, the film was immersed in warm water to wash away the unhardened or unexposed soft gelatin and create a relief where areas of thick gelatin correspond to the dark areas of the image. Next, the relief was bleached, fixed, and washed to eliminate its silver content [3]. The last step before coloring consisted in dying the relief in a black or 'modeling' dye bath. The gelatin relief absorbed the dye in proportion to its thickness resulting in a positive black-and-white image on a clear film base, which would be the outline to guide in the coloring of the image.

With Crawford Flexichrome, an opaque white paint or 'liquid paper' was applied to the back of the film to create a print. With Kodak Flexichrome, the dyed gelatin relief was stripped from its base and transferred onto a paper substrate [4].

3.2 Coloring the gelatin relief

The gelatin relief was then ready for coloring. During coloring, the dyes were absorbed by the gelatin proportionally to its thickness, i.e. the density of the image. Each new application of color displaced a portion of the black modeling dye. Dyes could be applied at will, until the desired color had been reached. Each print created was unique; multiple copies of an image required the printing and coloring of new reliefs (Figure 4).

Figure 4: The Process of hand coloring a Kodak Flexichrome (Eastman Kodak Company, 1950, pp. 20-21).

4. General visual characteristics of a Flexichrome

Examples of Flexichrome prints and transparencies are not easy to find per se, partly because in many cases they might have been misidentified as carbro or hand-tinted photographs (Maaruf, 2021). Key characteristics of Flexichrome prints are as follows: Firstly, the color is distributed in a continuous tone, this means there is no delineation between color areas, and the shading or color transition is smooth.

Secondly, because the colors of Flexichrome prints are applied by hand with a brush, there is no misregistration or misalignment of color layers, contrary to color prints made with assembly processes such as dye imbibition or carbro. Depending on the skill of the colorist, the edges of colored areas might not display crisp color delineations, but rather fluid lines that sometimes overlap or run into each other (Figure 5).

Fine brushstrokes are usually visible in areas such as the eyelashes or lips (Figure 6). These brushstrokes can be confused with retouching but upon close inspection, it should be clear that the color is part of the gelatin layer.

When examined in specular light, Flexichrome prints typically display a differential gloss between light and dark areas of the image. The high-density or dark areas—where the gelatin layer is thicker—are glossier than the low-density or light areas of the image—where the gelatin is thinner. The differential gloss might not be visible if the print has received a thick application of varnish.

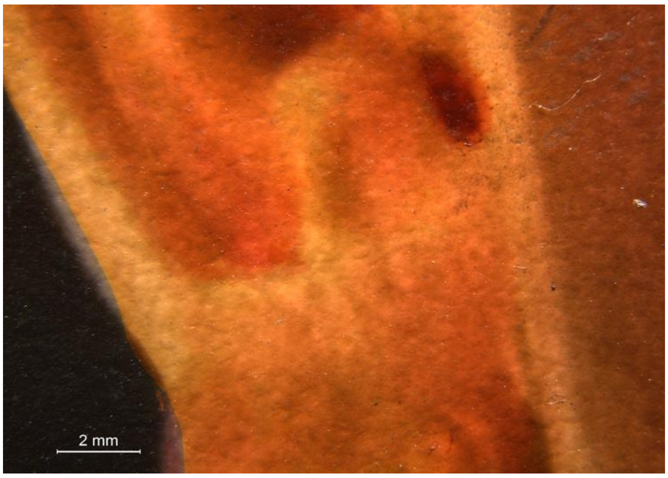

Figure 5: Detail of Emerson, Untitled, showing continuous tone and no delineation between color areas. Courtesy of the Art Institute of Chicago.

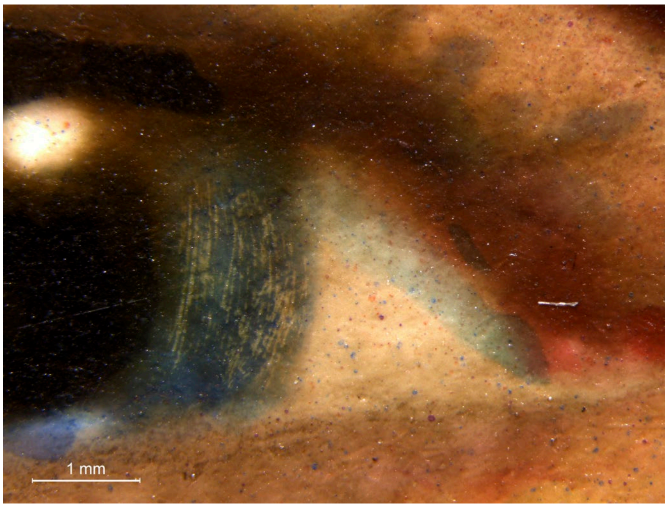

Figure 6: Detail of Emerson, Untitled, showing brushstroke color application visible in the detailed areas. Courtesy of the Art Institute of Chicago.

Under ultra-violet radiation, containers of magenta, red, and yellow reference dyes as well as the reducer fluoresced. Fluorescence in a print will however depend on the amount of dye present, the mixture of the dyes and the possible obstruction of a finishing varnish application.

In addition, the authors observed fading in several reference prints that had most likely been kept in frames and on view for an extended period of time. It would be worth investigating the light fastness of the Flexichrome dyes to inform display guidelines.

5. Analysis

5.1 *X-ray fluorescence (XRF) spectroscopy*

XRF analysis was performed on six Kodak Flexichromes: the Emerson print at the Art Institute, two reference prints from the IPI, and three prints from a private collection. Two carbro prints were also analyzed to provide comparative spectra.

No silver (Ag) was detected in the Flexichrome prints, which confirms that the Ag has been bleached out to the extent that it is not detectable with handheld XRF. This provides the ability to distinguish a hand-colored gelatin silver print from a Flexichrome [5].

Additionally, the elemental compositions of carbro and Flexichrome prints were compared, due to the visual similarities between these two types of print. Both processes make use of a dichromate to harden the gelatin and create a relief; however, chromium (Cr) was only detected by handheld XRF in the carbro prints but not in the Flexichromes (Figure 7).

Based on these analyses, the absence of both Ag and Cr appears to be an analytical marker for the Flexichrome, corroborating information derived from visual comparisons. Handheld XRF is limited in its ability to detect certain elements. The absence of both Ag and Cr in the XRF spectra does not mean they are not in any amount present in the prints, it only indicates that the amounts are non-detectable using this technique.

5.2 *Fourier transform infrared (FTIR) spectroscopy*

FTIR was used in the analysis of a set of Crawford Flexichrome dyes from the George Eastman Museum collection and three reference sets of Kodak Flexichrome dyes acquired for this project. The Crawford set contains a group of 12 dyes comprising blue, blue green, green, black, brown, flesh, lemon yellow, primary yellow, orange, red, scarlet, and violet. Two reference Kodak sets contain a slightly different group of 10 dyes (blue, cyan, brown, flesh basic, neutral, green, magenta, orange, purple, red, and yellow) and the third set contains 8 dyes (omitting the orange and purple).

According to contemporary sources, there were material differences between the iterations of the Flexichrome. Between the first and second patent by Crawford for example, there was a change in chemical processing of the prints, and meeting notes from the Kodak Research Laboratories made between 1947 and 1952 show a constant evolution in material composition to improve the tinting strength of dyes and lightfastness (Condax papers, 1947, 1950-1952).

While production of dyes was curtailed in the United States during World War II, the dyestuff industry expanded rapidly in the postwar years and Kodak Research Laboratories continued their explorations and embraced advances in technology.

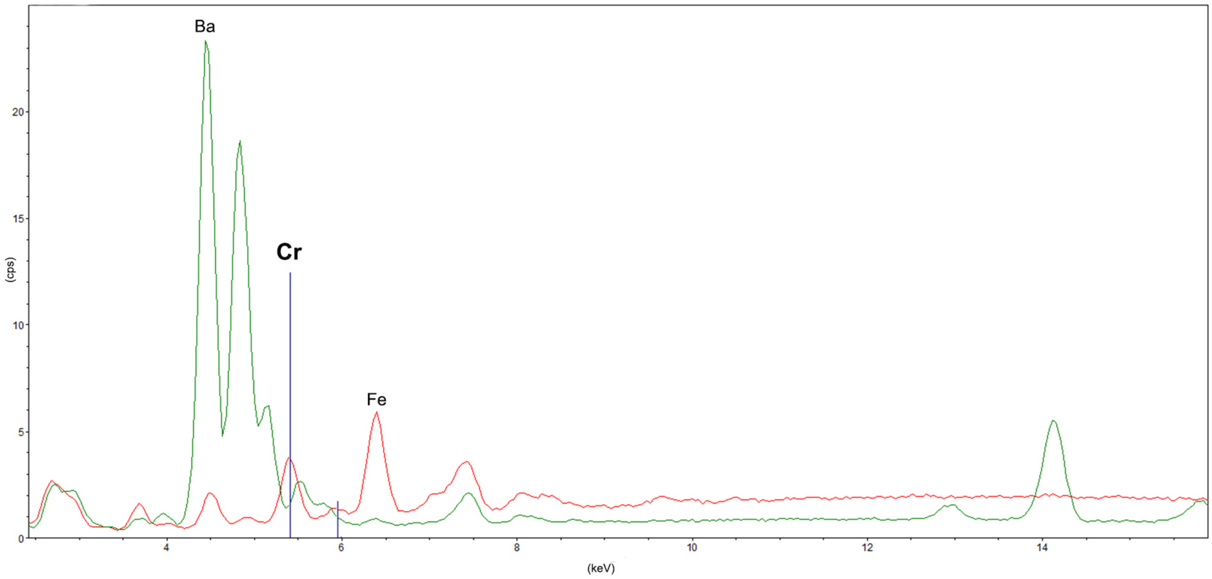

Figure 7: XRF spectra of a reference carbro (red) and a Kodak Flexichrome (green).

”Only 4 or 5 dyes will be necessary to cover all the range of colors needed,” wrote Kodak researcher Louis Condax in his meeting notes, ”However, Mr. Crawford feels that the mixtures should be incorporated in the set rather than to have the user mix them.” (Condax papers, 1947). The dyes used for dye imbibition processes fall under the family of acid dyes, which belong to the larger class of synthetic organic dyes (Colton and Thronson, 1940). The spectra collected from the Crawford dyes indicated the presence of acid- and azo-dyes. The spectra collected from the three Kodak sets showed close similarities to each other and, as suggested in the Condax papers, of the analyzed reference dyes there were only a few main types and the rest were mixtures of blue, magenta or red, and yellow dyes. Analysis indicated the presence of phthalocyanine blues, azo yellows, alizarin and anthraquinone reds (Figure 8 & Figure 9).

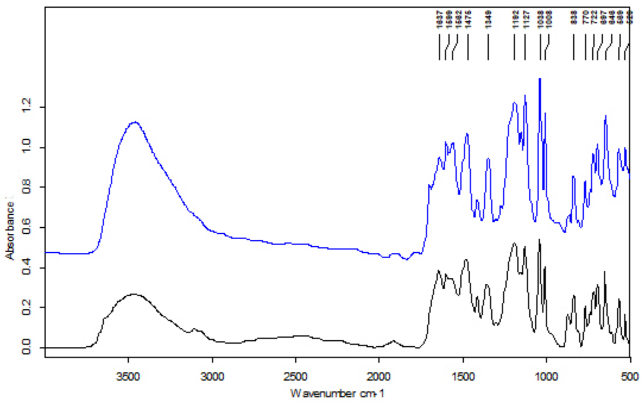

Figure 8: Infrared spectrum of Crawford Flexichrome primary yellow dye (blue) compared with the IRUG reference spectrum IOD00031 of Acid Yellow 23 (black).

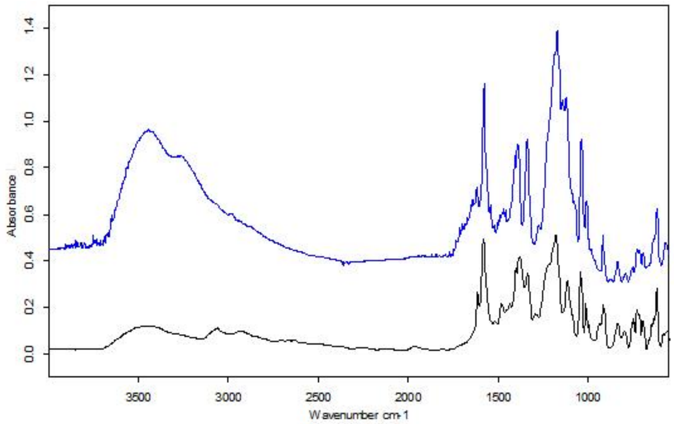

Figure 9: Infrared spectrum of Kodak Flexichrome green dye (blue) compared with the IRUG reference spectrum IOD00043 of Acid Green 6 (black).

FTIR was therefore useful for gaining information about the chemical classes of the Flexichrome dyes. There are often only minor chemical differences between individual colorants within the class, which, along with the presence of binders and extenders, complicates interpretation of the spectra (Lomax, Schilling and Learner, 2007). Therefore, complementary analytical techniques are required for a more definitive identification of these materials. This will also contribute to investigate further their lightfastness.

5.3 Cross-section

In collaboration with IPI, cross-sections were prepared to further understand the structure of Flexichrome prints. A sample from a Kodak print shows a paper substrate with a baryta layer and a gelatin coating on top, most likely a sheet of Kodak Dye Transfer paper, recommended by Kodak in the user manual. Above the gelatin layer of the paper substrate is the gelatin relief with imbibed dyes. The cross section shows that the coloring dyes did not penetrate all the way through the relief layer and that a portion of the modeling black dye is still present. Finally, there is the surface varnish layer (Figure 10). This correlates with the cross-section diagram published in the Kodak material data series (Figure 11), although the varnish and baryta layers are absent in the diagram (Eastman Kodak Company, 1950).

Together with XRF analysis and a close visual assessment, cross-sections can provide additional information. However, taking a cross-section is a destructive method and is not advised on collection items. The paper base and baryta layer may not be present in the cross-section if the relief was transferred onto a different substrate.

The layering structure of a Crawford Flexichrome will consist of a bottom paint layer—unless it is a transparency—followed by a celluloid layer, the gelatin relief with imbibed dyes, and a final varnish.

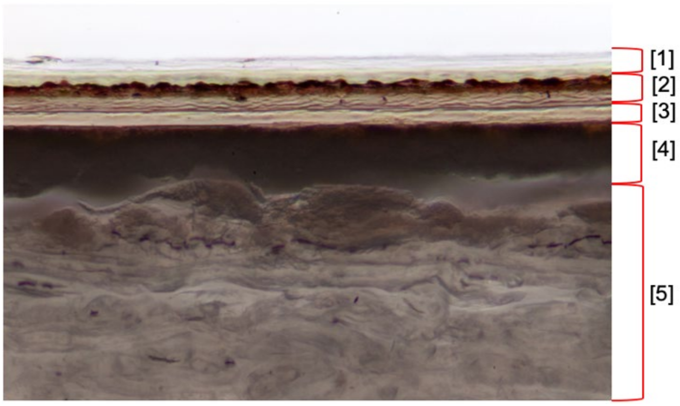

Figure 10: Cross-section of a Flexichrome in transmitted light. [1] varnish, [2] dyed gelatin relief, [3] gelatin coating, [4] baryta, [5] paper support. Courtesy of the Image Permanence Institute, Rochester Institute of Technology.

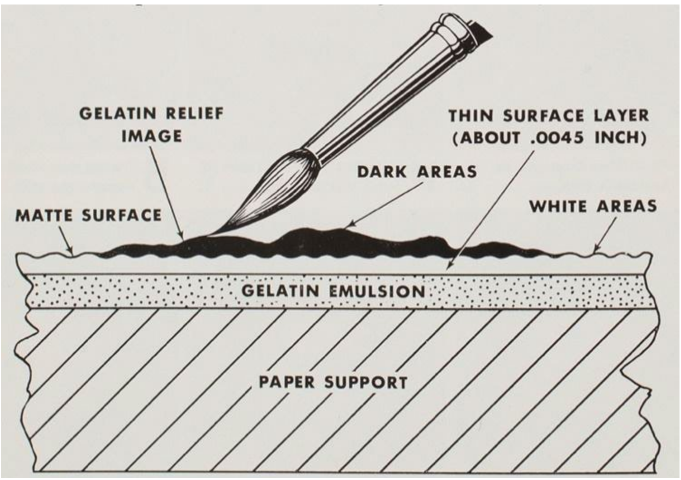

Figure 11: Cross-sectional diagram of a Flexichrome print, showing relief image greatly magnified (Eastman Kodak Company, 1950, pp. 22-23).

6. Conclusion

The Flexichrome process is a dye imbibition process that might be more prevalent in photographic collections than initially considered. Flexichrome prints share visual characteristics with carbro and hand-tinted gelatin silver prints, which has sometimes led to their misidentification. Due to misidentification and a lack of coverage in the historic and contemporary literature, the process is easily overlooked, even though it seems to have found commercial success under the Kodak branding, and was accessible and distributed worldwide.

Visual characteristics of a Flexichrome include a continuous tone, a lack of misregistration or misalignment of color layers, a brushed application of color, and non-delineated color transitions. There is the possibility of overall color fading and of UV-fluorescence of certain dyes. However, the mixing of colors and possible finishing layers may obstruct the fluorescence of the dyes. Lastly, because the final product is a gelatin relief, there is the possibility of differential gloss, which might not be detectable if a thick layer of varnish is present. A Crawford Flexichrome will be identifiable by its painted celluloid support.

XRF analysis indicated that silver and chromium were not present at detectable levels in a Flexichrome print. Elemental analysis complements the visual identification of the process, helping to distinguish it from a hand-colored gelatin silver print or a carbro.

FTIR supported the available literature by showing the dyes belong to the family of acid dyes. The dye sets were found to comprise of mixtures of a limited number of dyes. Due to the presence of additives and filler in the dye sets, complementary analysis is needed to further specify the individual dyes.

7. Conflict of interest declaration

The authors declare there is no conflict of interest concerning the research presented in this paper.

8. Funding source declaration

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Notes

[1] Wash-Off Relief was a dye imbibition process manufactured by the Eastman Kodak Company between 1935 and 1947. Chromatone was a silver toning process of the Defender Photo Supply Company, marketed from 1935 until 1942. The carbro process is a three-color pigment process where stacked layers of magenta-, yellow- and cyan-pigmented gelatin reliefs create a full color image.

[2] Defender and Crawford first exhibited the process in Chicago at the Combined Photographic Industry and Trade Show, August 19-23, 1940 (Defender Trade Bulletin, 1940, New York Times, 1941d).

[3] If a transparency was desired, the silver image was not bleached, to add density for the viewing in transmitted light or projection.

[4] Kodak recommended the use of Kodak dye transfer paper. However, the gelatin relief could be transferred to any type of paper or any other type of support desired.

[5] Does not apply to transparencies.

Experimental

1. *Visible and fluorescence light microscopy*

Print samples prepared as cross sections were examined using a Zeiss Axioplan 2 research microscope with reflected light and UV fluorescence illumination; images were captured using a Zeiss AxioCam MRc5 digital camera.

2. *X-ray fluorescence spectroscopy*

A Bruker/Keymaster TRACeR III-V handheld XRF spectrometer with Rhodium tube was used with voltage of 45kV and tunable beam current of 2-25μA.

3. *Fourier transform infrared spectroscopy*

A Bruker tensor 27 FTIR spectrophotometer coupled to Hyperion 2000 Automated FTIR microscope with nitrogen- cooled broadband MCT detector (covering the range 4000–450 cm^{-1}) was used. Samples were analyzed in transmission mode through the microscope after compression in a diamond cell; scans were acquired at a resolution of 4 cm^{-1}.

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The Jos-Pe process in the Jacob Merkelbach collection at the Rijksmuseum in Amsterdam

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ABSTRACT

The Rijksmuseum in Amsterdam holds a collection of 208 photographs from the Merkelbach Studio (1907-1961 in Amsterdam). At least 28 of them were made with the Jos-Pe technique, which was invented in Hamburg in 1924 and remained in use for 20 years. This dye imbibition process is part of the early history of commercial color photography. This research project began with the characterization and visual examination of Jos-Pe prints on paper and three-color printing matrices on glass that are part of the Rijksmuseum's Merkelbach collection. The Rijksmuseum Jos-Pe prints and plates, as well as (aged) mock-ups were analyzed with different techniques: specular light, UV fluorescence, microscopy, XRF and liquid chromatography UPLC. A cross section obtained from an unexposed Jos-Pe paper made it possible to determine the prints 'structure: a paper coated with a thin layer of barium sulfate, topped with a thin layer of gelatin. The analyzed glass plates revealed the use of dyes such as carmine, Induline Blue and Dianil Yellow 2R. Fading tests performed on mock-ups made of the red dye showed a Blue Wool Standard (BWS) lightfastness of 1-2. The fading tests of the other two dyes were not performed. The specialized literature points out the lightfastness of the blue dye as 4 and 2-3 BWS for the yellow dye.

KEYWORDS Jos-Pe, Jacob Merkelbach, Dye-imbibition, Rijksmuseum, Subtractive Color Photography, Three Color Photography

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1. Introduction

The Merkelbach collection held at the Rijksmuseum in Amsterdam offers an interesting corpus for studying the industry of photographic processes and its evolution; with 13 different photographic processes the collection presents a very good example of the commercial photography in use those days, between the 1920's and 1940's. The Jos-Pe prints in the collection are probably the most interesting objects in this group of photographs (Fig. 1). The general lack of technical data on the process and the materials creates challenges for the conservation of these photographs. The objective of the research carried out in 2018 and 2019 was to study the material components of the prints and to examine the sensitivity of the image-forming dyes to factors such as light and oxygen, in order to evaluate exposure levels for exhibitions and loans.

2. Jacob Merkelbach and the Studio Merkelbach

Jacob Merkelbach was born in Amsterdam in 1877. During the first years of his professional career, he worked in a business belonging to his father and his brother-in-law: M.H. Laddé & J.W. Merkelbach, a shop selling magic lanterns, film and photographic materials and also the first film studio in the Netherlands (Hegeman and Leijerzapf, 1985). For a short period, Merkelbach worked in the film industry until he opened his own studio, in 1913. It was located in a fashion house, on the fifth floor of the luxurious Hirsch & Cie in the Leidseplein building in Amsterdam. He worked mainly on commercial portraits, and his clients came from the high society of Amsterdam. Merkelbach also worked for the theatre and dance world, producing many of the promotional images of actors and dancers of the Dutch scene. His frequent collaboration with the commercial galleries where the studio was located could be seen in the showcases of the ground floor, where Merkelbach often showed fashion photographs.

The studio offered its clients numerous and diverse techniques, from bromide photographic papers to pigment processes such as carbon prints or Jos-Pe prints (which are the focus of this research). The negatives on glass were heavily manipulated by the retouchers of the studio, as in European studio photography at the time, which was a great inspiration for Jacob Merkelbach. It was one of the most important studios in Amsterdam in the period between the wars.

Jacob Merkelbach died in 1942 and his daughter Mies continued the business until the 1960's, when the studio was closed for good (Veen *et al.*, 2013). During the last years, Mies Merkelbach sold what was left of the collection (negatives and prints) to different buyers and institutions. In that period, the Dutch collector Bert Hartkamp bought a group of 200 prints on paper, a group that later became part of the Rijksmuseum Collection. Other artworks produced by Studio Merkelbach can be found in the Special Collections at the University of Leiden, the Amsterdam City Archives (Stadsarchief), the Dutch Institute for Theater in Amsterdam (Theater Instituut Nederland) and the Jewish Historical Museum in Amsterdam (Joods Historisch Museum).

Fig. 1. Portret van een vrouw in een rode jurk, Jacob Merkelbach, 1920-1930. RP-F-F03962 Rijksmuseum.

3. The Jos-Pe process

Jos-Pe is the name of a photographic process registered by a company of the same name in Munich, Germany, in 1924, founded by the photographer and inventor Gustav Koppmann and Josef-Peter Walker (from whom the process takes its name). In 1926 the company moves to Hamburg. After bankrupt in 1931, a fellow customer, Franz Vollmer, takes over the company from 1934 until 1943, when a bomb destroyed the factory on the 25th of July (Koshofer, 2013; Thiele, 2006).

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This technique is included in the group of the dye imbibition processes, together with other processes such as Sanger-Shepherd, Pinatype or Kodak Dye Transfer. It is a subtractive three-color process in which the print is made with three relief printing plates, blue, red and yellow, made from three color separation negatives (Pénichon, 2013). The process relies on the capacity of gelatin to absorb or release dyes when in contact with another layer of gelatin.

4. The special Jos-Pe camera

More than merely a photographic process, Jos-Pe was a complete printing system that offered the photographer all the necessary materials for printing in color. This included the special and advanced "Jos-Pe camera" which allowed the photographer to make the three-color separation negatives in one shot, avoiding the undesirable effect of time-parallax misalignments and allowing the photographer to take pictures of moving objects or portraits in color (Fig. 2). Until then, color separation negatives had been obtained in non-synchronized cameras or sledge-cameras such as the Dr. Miethe Three-color Camera, produced by Wilhelm Bermpohl since 1903, and also offered by the Jos-Pe company in its catalogue.

Fig. 2. Jos-Pe catalogue. ca. 1930

The camera was constructed in a trapezoidal shape, with a lens in the front, built by Zeiss, and two mirrors manufactured by Steinheil Sohne located behind the lens (Jos-Pe Farbenfoto, 1930). This group of mirrors split the incoming beam of light into three individual beams, which exposed the three negatives located in the back of the camera through the corresponding color filters: red (in front of the lens), green and violet-blue, made with dyed gelatin sheets sealed between glass and located exactly before the glass negatives, next to the plate holders. Focusing was done with the aid of a ring in the front of the camera, set under the lens, and checked on the ground glass of the back, where later the plate holders were placed. In this manner, three black-and-white negatives on glass were obtained.

The Jos-pe catalogue offered two cameras for two types of consumers: amateur and professional (Uka Type). The differences lay in the size of the negatives: 4.5x6 cm or 9x12 cm, and certain features like the speed of the shutter and the quality of the materials used to construct the camera. The price difference between one and the other was substantial: 950 RM or 3000 RM (Reichsmark).

The Jos-Pe camera was probably one of the greatest contributions made by the Jos-Pe company to the color photography industry. It was inspired by the camera patented by Frederic Eugene Ives in 1899 (Ives, 1899) in which mirrors were used to split the beam of light inside the body of the camera (Fig. 3).

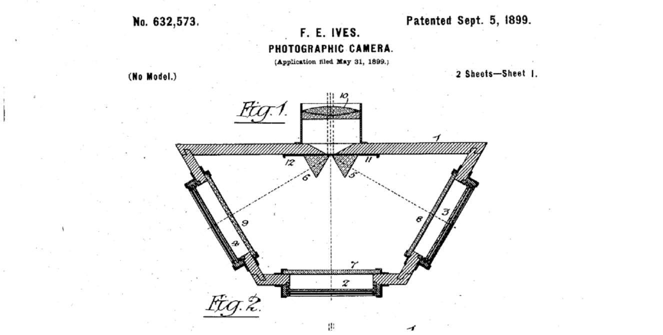

Fig. 3. Photographic Camera. F.E.Ives. 1899. US Patent.

5. The three-color Jos-Pe printing technology

In the Jos-Pe process, the three relief printing plates on glass used to obtain the final prints on paper were obtained from three black-and-white negatives made with the Jos-Pe camera. The glass negatives (Fig. 4) were coated with a bromide silver gelatin emulsion. Due to the division of light inside of the camera, the quantity of light received by each negative varied: 25% of the light reached the blue and yellow plates and 50% exposed the red one (Jos-Pe Farbenfoto, 1930). The sensitivity of the Jos-Pe glass negatives and the thickness of the color filters was adjusted to this. Some authors suggested that other panchromatic glass plates could be used, although the proprietary ones were specially fast (taking in account that the exposure was made through color filters that reduced the quantity of light reaching the negatives). Due to the high sensitivity of the emulsion, working under red light was not recommended. The development of the glass negatives must be done in complete darkness, unless a desensitizer was used in the process (Willekens, 1926).

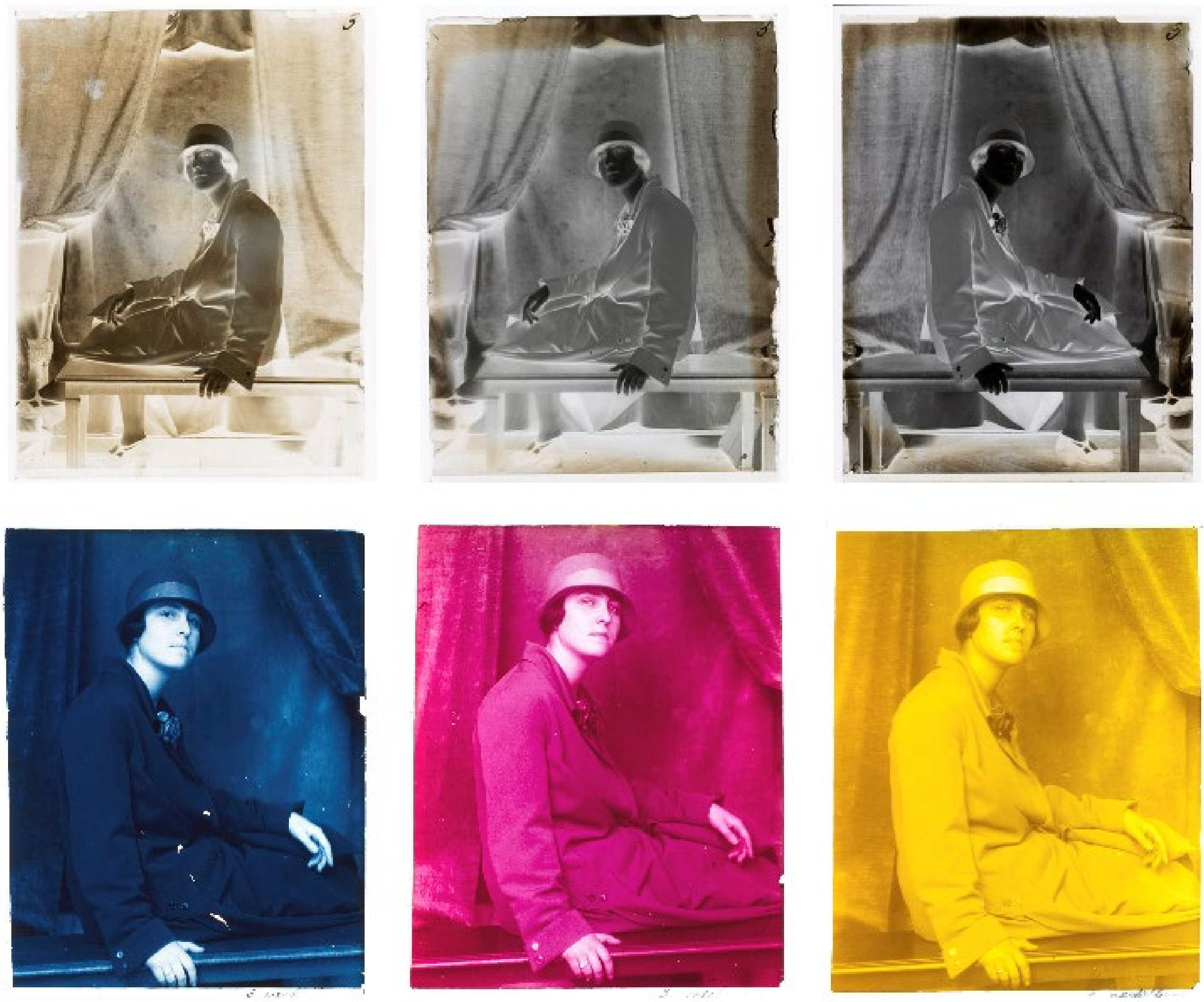

Fig. 4. Jos-Pe separation negatives and printing plates on glass. J. Merkelbach. RP-F-F26749-1/2/3 and RP-F-F26748-2/3/4. Rijksmuseum.

From the three negatives, the three printing plates (Fig. 4), or matrices, were enlarged to one of the common available formats (10x15 cm, 13x18 cm, 18x24 cm, 24x30 cm, 30x40 cm). The ensuing print would be made by contact. The matrices were manufactured on glass and also coated with a gelatin silver bromide emulsion.

The positive matrices were processed with a proprietary Jos-Pe tanning developer that probably included pyrocathecin with soda, caustic soda or ammonia (Willekens, 1926). The developer hardened the gelatin proportionally to the exposure to light and built up the necessary relief for printing. The unexposed areas (the non-hardened gelatin) would be removed under warm water (60 - 90º C). This method had already been described by Leon Warnerke in 1881, developed and applied by Gustav Koppmann in different patents, some of them under the name of the company Jos-Pe. The difference with non-relief processes was that there was no presence of gelatin in the white areas, which avoided dirty or blurry highlights.

To proceed with the printing process, each matrix was soaked in its corresponding Jos-Pe dye bath for 20 minutes for the first time and fewer minutes for the subsequent times. The dyes would be absorbed by the gelatin on the positive plate and remain in it until put in contact with a wet proprietary Jos-Pe paper. The dyes were sold in solid form but dissolved in water for this step. The manufacturer suggested using ammonia to dissolve the red dye in water. And citric acid was added to the blue and yellow dyes to facilitate the transfer of the dyes to the paper (Jos-Pe Farbenfoto, Patent No. DE000000421244A, 1924). The printing matrices could be used several times to produce multiple copies of the same image, until the relief looked deteriorated.

Fig. 5. Portret van Mies Rosenboom Merkelbach, Jacob Merkelbach, 1920-1930. RP-F-F26748-1. Rijksmuseum.

Here, the dyes transferred to the paper, in this manner forming the image there (Fig. 5). Users were recommended to start with the blue matrix and continue with either yellow or red. Thanks to the transparency of the printing plates, the superposition of the three images was easy if compared with other color printing processes with opaque matrices. However, this step was difficult and it is common to observe misregistrations in the final prints. According to Adrianus Antonius Marinus van Rietschoten, a retoucher at the Atelier Merkelbach, a Jos-Pe print would take a week to be finished (Veen *et al.*, 2013).

All the materials needed for the process were sold by the Jos-Pe company and distributed by licensed companies in different countries, for instance, Jos-Pe Trade Company Color Photo in Arnhem, for The Netherlands or Ibero Foto Color in Madrid, for Spain. Photographers interested in the process were kindly invited to attend workshops or events where the process was explained.

Most of the information collected on the process comes from the personal archive of the Catalan amateur photographer Mariano Ricart, interested in color printing processes, kept at the Institut de Estudis Fotogràfics de Catalunya, in Barcelona (Burgués and Belmonte, 2015) which includes numerous brochures, recipes, personal notes, study materials and correspondence between the photographer and the Jos-Pe Farbenfoto company. Another of the main sources for this research is the pamphlet published by Willekens in 1926 where the process is described at the same time as it is commented.

6. Characterization of the prints

Fortunately, the Rijksmuseum collection includes a complete set of the negatives, the printing plates and the final print of a photograph by Jacob Merkelbach (Fig. 4 and 5). This circumstance significantly aided our understanding of the process and gave us access to the original materials that could be analyzed for this research.

Under the microscope, Jos-Pe prints have a smooth continuous tone without any visible pattern. The dyes are shown in a soft tone, although sometimes individual particles are visible, perhaps due to their incomplete dissolution in water. Also small spots can be observed, probably produced during the printing process, when small bubbles in the gelatin were broken during the transfer of the image.

Another characteristic is the retouching process carried out by the photographer in order to improve the final image. Under specular light these corrections become visible, especially the ones created by scratching the surface of the print to make it lighter (Fig. 6). Retouching techniques also included adding media with a brush or with a pencil, to darken lighter areas or add details.

All of the prints in the Rijksmuseum collection have a matte surface, except one (RP-F-F03955) that shows a glossy coating on the surface. This coating did not fluoresce under UV irradiation, and no other analyses were carried out during this research project, so it could not be identified at this time.

Fig. 6. Retouching on a Jos-Pe print observed with specular light. RP-F-F03967. Rijksmuseum.

If the print is not trimmed, the superposition of the three colors can be observed at the borders. The pressure marks made by the edges of the glass printing plates during the printing process are also visible (Fig. 7).

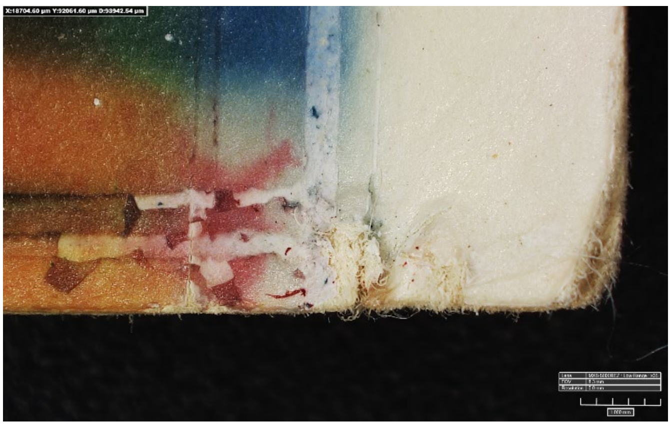

Fig. 7. Border of a Jos-pe print. Microscopy image (x35). RP-F-F04010. Rijksmuseum.

7. Instrumental analysis

To better identify the paper and media we used X-Ray Fluorescence analysis. The top layer of the support paper contains barium and sulfur, which indicates that the paper was coated with a baryta layer, used to isolate the fibers of the paper and create a white, uniform base for the image.

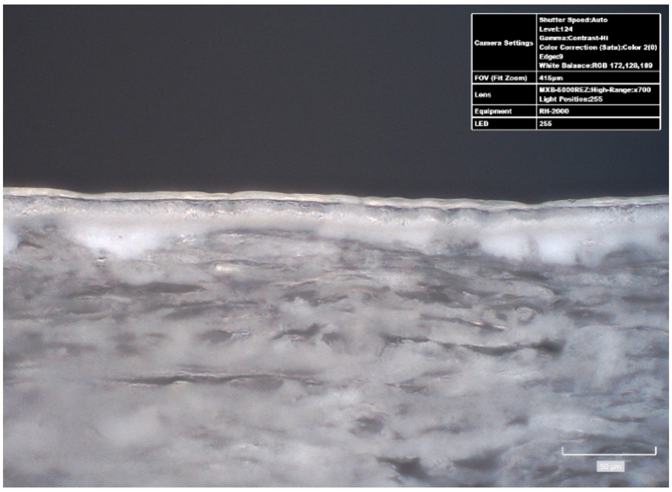

Fig. 8. Cross section of a Jos-Pe paper. Microscopy image (x700).

Thanks to the donation of a sample of Jos-Pe paper from Richart's archive from Institut de Estudis Fotogràfics de Catalunya (IEFC, Barcelona), we were able to perform a cross section. In this analysis we confirmed that the baryta layer had an extra top-coat of a thin gelatin layer, the image receiving layer (Fig. 8). This structure is observed under the microscope, specially at the borders (Fig. 9).

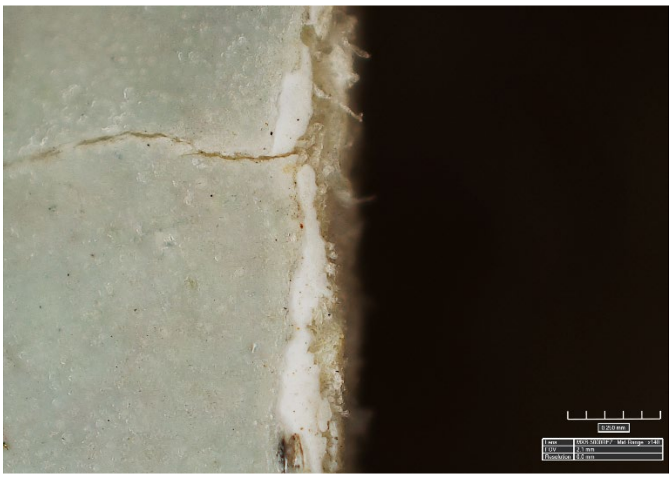

Fig. 9. Border of a Jos-pe print. Microscopy image (x35). RP-F-F03960. Rijksmuseum.

For the identification of the colorants we requested the expertise of Art Ness Proaño at the Rijksdienst voor het Cultureel Erfgoed (RCE). The dyes were sampled from the three printing plates, extracted from the gelatin and identified with liquid chromatography (UPLC). The red dye was identified as carmine (in ammonia), the blue dye was identified as Indulin B or Acid Blue 20 (sulphonated) and the yellow dye was identified as Dianil Yellow 2RI (Proaño and Neevel, 2020).

With this knowledge we proceeded to reconstruct the process in order to artificially light-fade mockups on paper to analyze the chemical stability of the dyes. The red sample was exposed for two, four and eight hours, and changes already became apparent in the first exposure period of two hours, indicating low lightfastness. The fading tests of the other two mockups have not been subjected to fading tests yet, however, the report from RCE suggests that, based on specialized literature, the lightfastness of the blue dye is BWS 4 and that of the yellow dye is 2-3.

8. Conclusion

This research shed light on this interesting process and its importance in the history of color photography. The Jos-Pe process, far from being a unique invention, benefitted from other inventions and patents. The basis of the printing system had already been described by Leon Warnerke, Leon Didier and Gustav Koppmann. The Jos-Pe camera was inspired by the Ives camera from 1899. The three Jos-Pe dyes are common in the literature of dye imbibition processes and were also used in the Pinatype. The Jos-Pe paper was a typical paper with a baryta layer and topcoat of gelatin. However, the Jos-Pe process made complex three-color photography available to a broader public, offering professional results to both amateurs and professional photographers. Our research indicates that the dyes are not very stable, although more research has to be performed in difference circumstances.

9. Conflict of interest declaration

The author states that no actual or potential conflicts of interest exist including financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, her work.

10. Funding source declaration

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12. Short biography of the author

Laura Covarsí Zafrilla is an independent conservator specialized in photographic heritage. She received her M.A. in Conservation from Instituto Politécnico de Tomar, Portugal, with an internship in the photographic archive of the Maritime Museum of Barcelona (Spain). She previously studied History of Art (University of Salamanca, Spain) and Photography (School of Arts of Huesca, Spain). She worked for public and private collections in Spain and at the Rijksmuseum of Amsterdam between 2017 and 2019, where this research was carried out.

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The long-term development of three-color Kodachrome. An odyssey from the additive to the subtractive method of color reproduction

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ABSTRACT

The introduction of three-color Kodachrome in 1935 was possible thanks to the long collaboration between the independent inventors Leopold Mannes and Leopold Godowsky and the managers of the Kodak Research Laboratory at Rochester, New York. This paper considers this long research work initiated in 1917 by examining the technological solutions Mannes and Godowsky progressively followed, in the historical context of the first cinematographic additive processes. Besides the technological context, the paper analyzes the evolution of Mannes and Godowsky position into Kodak research. Working independently at the beginning, the two young men were funded by their families first, then by the Eastman Kodak Company and Kuhn, Loeb & Co, experimenting in their personal laboratory. In a second step, Mannes and Godowsky were finally employed by Kodak in 1931 as consultant researchers and incorporated with the team of the Kodak Research Laboratory at Rochester. In the mid-1930s Mannes and Godowsky were able to develop a two-color cinematographic process, which finally evolved in the three-color Kodachrome process. This innovative process was announced in April 1935, despite the fact that the Kodak researchers did not succeed in finding a correct developing process for exposed films. An immense amount of work was done in the American laboratory to find a correct sequence of chromogenic development in the summer 1935. This long research odyssey ended when the Kodak research team managed to drastically simplify the developing process of exposed Kodachrome rolls in 1938, encouraged by the recent German competition and the Agfa Color Neu process.

KEYWORDS: Color photography, Kodachrome, Eastman Kodak, additive technology, subtractive technology, industrial research, Kodak Research Laboratory.

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1. Introduction

With the long-term research undertaken by Leopold Mannes and Leopold Godowsky for a three-color multi-layer process, a new form of innovation took place at the Eastman Kodak Company (mentioned below as Kodak). It was the alliance between independent research and the industrial research organization of one of the main film manufacturers of the period. Given the final result of the three-color Kodachrome released in 1935, this scientific collaboration can be judged as a positive, successful one. The Kodachrome was a three-color reversal film which produced a positive image on a transparent base, and which was originally available as a motion picture film and then as a still film. It was the first commercialized color film to use the subtractive method of color reproduction, that involved the selective analysis and absorption by at least three superimposed layers of the red, green and blue components of a filmed subject. Before Kodachrome, the additive method of color reproduction was favored by inventors. Using the theory of the trichromatic color vision of the human eye, this method implied the filming of separation views through at least two colored filters, and the reproduction of the natural colors of the subject in adding the separation films obtained by projecting them through the same filters. The full collaboration necessary for the development of the Kodachrome differed from the model of the lenticular Kodacolor's development, for which patent rights were purchased from a third-party company without a complete sharing of knowledge, and which was introduced in 1928. The lenticular Kodacolor was a three-color motion picture film made of a black and white reversal film coated on an embossed lenticular base, which requested 3 colored filters in red, green and blue during the exposure and the projection. It was quickly replaced by the Kodachrome from 1935 on. The research odyssey of Mannes and Godowsky for the Kodachrome between 1917 and 1935 has already been studied and partially documented by Friedman (1944), Collins (1990), Coote (1993), Brayer (1996) and Le Guern (2017, 2019). This paper will only point out some events and milestones of their research work and clarify how an important teamwork was necessary at Kodak to work out a correct development process in 1935, and to simplify it 3 years later.

2. Early attempts with the additive method of color reproduction

The legend indicating that Kodachrome was invented by two skilled musicians living far from science is wrong. Mannes and Godowsky were talented inventors who used a scientific background to transform the theory into a true process through experimentation. Godowsky studied chemistry, physics and mathematics at the University of California and Columbia University and Mannes received his Bachelor of Science degree in physics from Harvard in 1920 (Brayer, 1996, p.224; George Eastman House, 1964, p.15). The two men had met in high school in 1916 and became friends with a mutual interest in photography. The next year, Mannes and Godowsky saw in New York a film entitled *Our Navy* made with the Prizma I additive process. The color rendering was not good and they started to undertake some research work at their high school to develop a better additive process. Prizma I had been developed by William Van Doren Kelley with the collaboration of Charles Raleigh, one of the inventor of the Kinemacolor process. Briefly, Godowsky remembered in an interview in the 70s that *Our Navy* was a two-color process only. However, this additive process used a rotary filter made of 4 color filters combined in pairs of complementary colors, so we could also see this process as a 4-color one (Dorot Jewish Division, 1971, p.39-40; Layton and Pierce, 2015, p.52-53).

Mannes and Godowsky started by improving a parallax issue encountered with multiple lens systems. The effect of parallax occurred with color additive processes, when the spatial viewpoint of each lens to record a color was slightly offset from the viewpoints of the other lenses. Therefore, the superimposition of the images was not optimal. They continued their research work during their holidays and managed to conceive a viable two-color additive process. It consisted of side-by-side images on a single strip of film exposed in a double-lens prototype camera. An experimental film was made but upon failing to adapt the projection equipment to the two-color film Mannes and Godowsky gave up their first color process (Collins, 1990, p.206). When they graduated from university, they started to work full time as professional musicians but were still experimenting during their spare time on color processes. At the beginning of the 1920s, they progressively turned from the additive to the subtractive theory, considering rightfully that the multi-layer technology could be a better solution than a two-color or three-color additive process to develop a color motion picture film. In their makeshift laboratory at home, they managed to coat double-layered plates able to record part of the visible spectrum (Brayer, 1996, p.225). But they also worked on the theory of three-color photography and filed their first patent application in October 1921, to secure the making of a colored positive from a set of separation negatives (Mannes and Godowsky, 1925; Friedman, 1944, p.108-109).

Evidence of a research work by Mannes and Godowsky on three-color photography has been found by the American artist Matthew Gamber in 2018. Analyzing the industrial archive left by Godowsky at the George Eastman Museum, Gamber found photographic tests dated 1920 made with 3 separation negatives on black and white film using filters. He digitized each separation and combined the 3 files to create a final color photograph using an image processing software (Gamber, 2019). The first photographic result was a view of the Ansonia Hotel in New York from Mannes and Godowsky's apartment, where they installed a personal laboratory. The second image was a portrait of a young lady, identified by Gamber as a cousin-in-law of Mannes, the illustrator Helen Theresa Damrosch Tee-Van, daughter of Frank Damrosch (Fig. 1). This technique of three-color photography reminds us the process used by the Russian photographer Prokudine-Gorski. The knowledge of this research work is useful because it confirms that in 1920, Mannes and Godowsky had not fully decided yet between the additive and the subtractive method of color reproduction.

Fig. 1. Matthew Gamber, three-color separation composite of Helen Damrosch Tee-Van, from a set preserved at the George Eastman Museum of three black and white negatives made by Leopold Godowsky and Leopold Mannes in New York City, NY, circa 1920.

3. The issue of funding and the progressive collaboration with Kodak

In the early 1920s, Mannes and Godowsky faced an important constraint. They had to seek funds to significantly improve their research work and results, as their families decided to stop their financing. In 1922, they were able to meet George Eastman directly to present their work on color photography. Eastman was intrigued by their findings, but the meeting had no financial results (Brayer, 1996, p.225). Finally, the two researchers managed to contact the photochemist Kenneth Mees who was the first director of the Kodak Research department. During one trip to New York, the intrigued Mees met Mannes and Godowsky at the Chemist's Club and was impressed by the progress of their photographic work. From then on and during the following years Mees accepted to supply them with the materials they would need for their research, especially some experimental film coated with more than one emulsion layer on a transparent base, prepared according to their specifications, provided that the two Leopolds would keep him informed of their further developments (James, 1990, p.166; McCarthy, 1987, p.10; Brayer, 1996, p.225). The same year, Mannes had also approached Everett Somers, a secretary of the investment firm of Kuhn, Loeb and Company. The two inventors gave a demonstration of their experimental process and managed to get a twenty thousand dollar loan from the firm (Strauss, 1962, p.97-98).

The money was invested in the research and around one year later, Mannes and Godowsky filed another patent application for a two-color negative process (Mannes and Godowsky, 1924). A red-sensitive emulsion was coated on a transparent support, and an orthochromatic emulsion - blue and green-sensitive - was coated on the red-sensitive emulsion. After development and fixation this multi-layer film was treated with ferricyanide to convert metallic silver into silver ferrocyanide. The new feature of the patent consisted in the method used for the development of the ferrocyanide images: the diffusion into the gelatin of the solution used could be controlled at will. Thus, one could develop only one layer without polluting the other one. Mannes and Godowsky took care not to unveil any formula or detailed mechanisms of this controlled diffusion (Friedman, 1944, p.109-110). In 1925, the independent photochemist Edward J. Wall published his *History of Three-Color Photography* and Mannes and Godowsky knew that they were cited in the book for their 1924 patent (Wall, 1925, p.158). Wall's book was influential, because they learned for the first time the scientific narrative of the monopack film and the potential of color development from the use of color couplers, which were chemical substances able to form dyes (Coote, 1993, p. 139).

From 1925 on, Mannes and Godowsky decided to investigate the chemistry of color couplers and began working on a technology of *integral tripack* or *monopack*, which relates to a reversal multi-layer film made of three inseparable light-sensitive emulsion layers coated one on the other on a transparent flexible base. One such multi-layer film was different than their initial two-layer negative process, which requested two different toning after the development to form the color in each layer. With Wall's book they read that a young independent photochemist Karl Schinzel was the first to patent the use of a subtractive monopack for color reproduction in 1905. In his process called *Katachromie* Schinzel suggested using a coated plate with several layers of silver bromide emulsion separated by plain gelatin films. Each sensitive layer was colored complementary to its sensitivity. However, this innovative process was theoretical and the few dyes available were not satisfactory to allow its practical use (Coote, 1993, p.134-135; Friedman, 1944). In 1907, Benno Homolka from Hoechst simplified Schinzel's process by inventing the principle of color development. He found that it was possible to form colored images by the creation of dyes in combination with silver images (Coote, 1993, p.135). This discovery was finally patented by Rudolph Fischer and his colleague H. Siegrist in 1912 with their method of color development anticipating the manufacturing of a subtractive tripack. For this process three emulsion layers were also coated on top of one another, and in each layer chemical dye-forming substances called color or dye couplers were incorporated. These dye couplers were supposed to form a dye image together with reduced silver into each emulsion layer in the presence of a developing agent. However, like Schinzel or Homolka, Fischer was unable to realize his process in practice due to its complexity and to the poor stability of the dye-forming substances available in the 1910s. Another issue was the impossibility to prevent the dye couplers from wandering between layers (Coote, 1993, p. 139). From 1927 on, Mannes and Godowsky conceived a different strategy for the color development to get around this problem. Unlike other methods, they decided to include the dye couplers into the liquid developer instead of each emulsion layer. Thus, the wandering coupler problem would be solved, but not the similar issue of the wandering sensitizing dyes (James, 1990, p.166; Collins, 1990, p.211).

In 1928, the chemist of the Kodak synthetic chemistry division Leslie Brooker was able to synthesize new dyes, which were excellent sensitizers from Frances Hamer's research work (Mees, 1961, p.121-123). The problem of wandering sensitizers was almost solved. The pooling of Mannes, Godowsky and Brooker's research works eventually constituted innovation because from that stage the monopack concept could move from theory to practice. For Mees, the time to increase the scientific collaboration with Mannes and Godowsky had come:

In 1930, I realized that the new dyes that we could now make would solve the problem of making Mannes' and Godowsky's proposed color process work. […] So we asked Mannes and Godowsky to join us here, where they worked happily with us for ten years, and we all set to work and made the new color process work (Mees, 1955, p. 37).

The agreement seemed an easy one. Kodak offered to pay a lump sum of $30,000, annual salaries of $7,500 each and also agreed that Mannes and Godowsky would receive royalties on all patents filed before the collaboration with Kodak (Coote, 1993, p.139; Collins, 1990, p.211). The two independent researchers accepted the offer and became incorporated in the Kodak research organization in November 1930. First, they worked in a special laboratory at New York. After 1 June 1931, they started working at Kodak Park in Rochester (Kodak, 1930, p.4).

Finally employed by Kodak, Mannes and Godowsky had to adapt their research methods to the collaborative work with the Kodak Research Laboratory's staff, because they were also known as professional musicians and had to prove their skills in photochemistry at the same time (Kodak, 1989, p.51). However, this period is not well documented and it is difficult to ascertain the research work done and the practical terms of the collaboration. From 1930 on, the two inventors focused on processes involving mono-layer and mixed grain coatings to avoid the use of a multi-layer coating and its potential problems (Coote, 1993, p.140). As Mannes and Godowsky had a three-year contract terminating at the end of 1933, and as the results of their research were not visible enough, Mees had to insist with members of Kodak management that they should be given another chance for one more year. They finally developed a concrete two-color motion picture film in 1934, "working practically around the clock, day after day" (James, 1990, p.166-167). As the production of the new film was delayed due to some complications, Mannes and Godowsky were able to perform additional research and modified the two-color into a three-color process.

4. Market launch of a three-color film not yet finalized in 1935

Finally, the new Kodachrome process in its 16mm version for color movie was announced in April 1935. As the motion picture film consisted of five layers of emulsion and gelatin it was nicknamed the "quintuplet" film by Science magazine (Anon, 1935). Three layers were devoted to the recording of the blue, green and red spectrums. Between each sensitive layer a thin layer of clear gelatin was coated, used as a margin of safety during the development process and the use of the controlled diffusion bleach (Fig. 2). It was thus possible to bleach two layers and not the bottom layer. Nevertheless, the first development process was very long and involved in all 28 steps (Coote, 1993, p.142; Coe, 1978, p.128).

However, the correct development processing for the new Kodachrome film was not at all ready in April 1935. This situation was critical. It was possible to expose some 16mm Kodachrome reels but it was still impossible to get a neutral colorimetric rendering of the developed slides. Mees had to organize and supervise an exceptional program in extreme circumstances; the theoretical technology of Kodachrome had to confront the practical side of the laboratory (Le Guern, 2017, p.264-265).

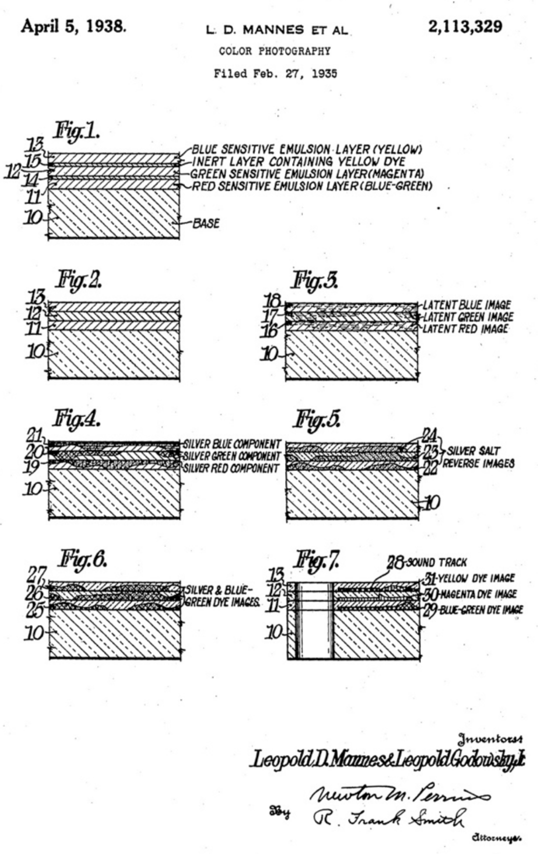

Fig. 2. Drawings from the American patent US 2113329A « Color photography » filed by Mannes and Godowsky on 27 February 1935 and granted on 5 April 1938 (Espacenet, European Patent Office).

In one of his notebooks, the researcher Franck B. Phillips detailed this critical period of intense research for a satisfactory development process. Phillips, a member of the Harrow Research Laboratory, was already visiting and working at Rochester in November 1934. He had probably been requested to help the American scientists and assist Mannes and Godowsky. In April and May 1935, he was testifying to the intensive work undertaken in the Research Laboratories. The teams were working nearly all day long with infrequent breaks in a desperate quest for better Kodachrome processing (Phillips, 1935). On May 10th, Phillips noted that “a man (Pringle) was sent to the Medical Dept having been made sick with fumes from acetone-alcohol mixture while cleaning racks from the b-g developer” (Phillips, 1935, p.71). One day, Phillips reported that the general tendency of the experimental work was the development of Kodachrome with green neutrals. The photochemists tested several solutions to reduce the color cast but, as the writer noted, the "results were very erratic" (14 May 1935, p.75). Some days later, the situation was better and the developed Kodachrome motion picture films at last reached a correct neutrality in the grey. The magenta bleach had been acidified with hydrochloric acid to reduce the residual blue-green dye. This acidification was criticized by Godowsky but Phillips disagreed in his notebook (Phillips, 1935, p.79). This evidence of research teamwork illustrates well the complexity of the new Kodachrome process.

5. Chemical stability and color rendition of three -color Kodachrome version 1935-1938

Regarding this first version of Kodachrome film, it is challenging to estimate their photographic characteristic such as color rendition or stability of dyes owing to their scarcity in the early 2020s (Fig. 3). Sylvie Pénichon recently pointed out that original Kodachrome transparencies should not be projected due to their poor stability to light (Pénichon, 2013, p.204). Louis W. Sipley, a photographer and the creator of the American Museum of Photography in Philadelphia, included in his 1951 book valuable information about the stability of Kodachrome:

The dyes in this earliest Kodachromes were not very stable, with the result that pictures made on the 1935 film have degraded and no longer retain the full colors as originally made. Just as this book go to press [so we were in 1951] the American Museum of Photography has been presented with several rolls of 16mm Kodachrome motion pictures made in 1935 which show almost monochromatic pictures of a purple-magenta character (Sipley, 1951, p.142).

This clue points out that the yellow and cyan dyes in particular were less stable in the Kodachrome sandwich made and developed in 1935. Motion picture and still film rolls in color made during the period 1935-1938 are really rare or difficult to identify in the institutions preserving film heritage such as national or private archives and museums.

Fig. 3. The first version of three-color Kodachrome was introduced in 1935 as a 16mm movie film, and as a 35mm film for still cameras in 1936 (Eastman Kodak Company, 1971, p. 13).

However, a short film made in 1937 by the well-known photographer Man Ray provides some information about the nature of Kodachrome color rendering. According to Man Ray, he received a large quantity of Kodachrome rolls to test and a 16mm camera from the British subsidiary of Kodak in London (Man Ray, 1963, p.293-294). The result was a short film named “La Garoupe”, more than 10’ long, some portions of which were recently shown in a French documentary named “Un été à la Garoupe” (Knowles, 2012, p.239-240; Lévy-Kuentz, 2020).

The competition with Kodachrome was tough. In 1936, the I.G. Farbenindustrie A.G. at Wolfen in Germany managed to develop a technology of anchoring color couplers to individual emulsion layers, with the use of long-chain molecular structures. This way, a process of selective color development by controlled diffusion used by Mannes and Godowsky, was no longer necessary. The color couplers could be incorporated into the monopack film, and not during the developing process of the exposed film. Finally, after a satisfying selection of couplers for each of the three layers, Agfa introduced in October 1936 the Agfacolor Neu film including a simplified multi-layer reversal technology (Flueckiger, 2012). This innovation into the field of the monopack film led Mannes, Godowsky and their colleagues at the Kodak Research Laboratories to optimize the Kodachrome process.

6. The necessary simplification of the three-color Kodachrome developing process

For Kodak, the elegant solution of the Agfacolor Neu was a technological and economical threat even if the color rendering of the Kodachrome film was slightly better. The technology used by Agfa was far simpler and rendered the 28 steps necessary to the processing of Kodachrome films obsolete. The need of improving the stability of the chemical dyes used in the layers of Kodachrome was another important fact. Kodak’s first action was to develop a simpler processing for the Kodachrome films. It was not before 1938 that they released this new processing. The controlled diffusion bleach was replaced with selective re-exposure for each color-development step. In this way the total number of steps was reduced to 18 (Kodak, 1989, p.52).

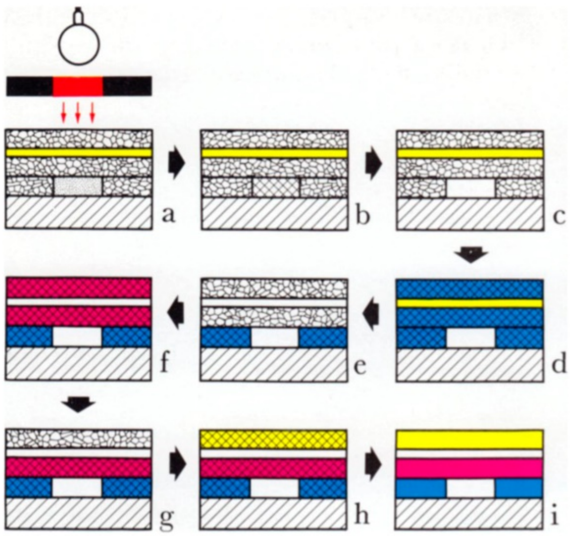

Fig. 14. Old Kodachrome processing: (a) exposure from red patch; (b) black-and-white negative development; (c) first bleach to remove metallic silver; (d) cyan development using residual silver halide in all layers; (e) bleach to remove dye and regenerate silver halide in top two layers; (f) magenta development using regenerated silver halide; (g) bleach to remove dye and regenerate silver halide in top layer; (h) yellow development using regenerated silver halide; (i) final bleach and fix to remove silver throughout.

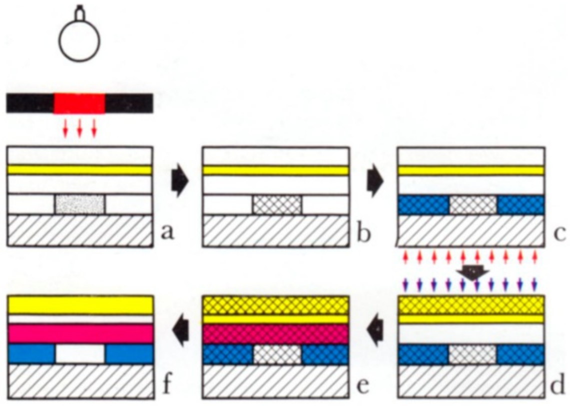

Fig. 15. New Kodachrome processing: (a) exposure from red patch; (b) black-and-white development; (c) red exposure (through base) and cyan development using newly exposed silver halide; (d) blue exposure (from top) and yellow development using newly exposed silver halide; (e) fogging magenta development using residual silver halide (which is left only in green-sensitive layer); (f) silver and yellow filter layer removed by bleach and fix.

Fig. 4. First Kodachrome developing process (1935-1938) compared with new Kodachrome developing process (from 1938) in Weissberger (1970).

Lot Spaulding Wilder, a researcher of the Rochester Laboratory, was the inventor of the Kodachrome processing simplification (James, 1990, p.169). After the release of the Kodachrome monopack, Mees decided to create an experimental department for color photography including Wilder, Ralph M. Evans and Wesley T. Hanson. Mannes and Godowsky also played an important role for scientific and patent work during the period up to the outbreak of the Second World War.

The final process was described by Friedman (1944, p.122). The new processing was equivalent up to the exposure with red light and the development in cyan developer (Fig. 4). The next step was to expose the blue sensitive layer from the top of the film with a blue light, and to develop with a yellow-coupler developer. Then the middle layer magenta sensitive was exposed to white light or treated by a fogging agent such as methylene blue or thiourea. This layer was developed with a magenta-coupler developer and the rest of the processing was similar to Wilder's experimental process of February 1938. The move from theory to production was unsurprisingly tough, as confirmed by Mees in 1944:

This process offered very considerable difficulties when it was first attempted but, in view of its advantages, they were overcome, and it is the method by which the Kodachrome film is now processed (Mees, 1944, p.234).

Following the successful simplification of the Kodachrome developing process, Mannes ceased his collaboration with Kodak in 1939. The same year, Godowsky left the Kodak Research Laboratory but still worked on color photography as a consultant in a small personal laboratory in Westport, Connecticut, nicknamed "Kodak Park Westport" (Kodak, 1989, p.54). After the Second World War, the knowledge produced and mastered on color technology would lead to other Kodak processes, such as Kodacolor negative film, Ektachrome reversal film and Eastman Color Negative.

7. Conclusion

This paper attempted to outline how the introduction of the 16mm version of Kodachrome in 1935 was only the beginning of Kodak research on color technology. It was only made possible with the long-term collaborative work with the atypical photochemists Mannes and Godowsky and the researchers of the Kodak Research Laboratories. In 1917, Mannes and Godowsky began studying independently the technology of color additive processes in the quest for a motion picture film in color. In the early 1920s, they managed to create a scientific collaboration with Kodak and be funded by Kuhn, Loeb and Company. Mannes and Godowsky gave up the additive method and investigated the concept of subtractive multi-layer film involving a color development from 1925 on. They were employed by Kodak and incorporated in the Research Laboratories in 1931, and managed to develop the three-color Kodachrome, a motion picture film in 1935. The introduction by Agfa of the three-color Agfacolor Neu film led Mannes, Godowsky and the Kodak researchers to simplify the Kodachrome developing process in 1938.

8. Conflict of interest declaration

The author declares that there is no conflict of interest related to this publication. There are no actual or potential conflicts of interest, including financial, personal or other relationships with other people or organizations.

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11. Short biography of the author

Nicolas Le Guern, Ph.D., is a technical manager in the photographic industry and a regular lecturer in French universities.

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Prokudin-Gorskii's technique of colour photography: colour separation, additive projection and pigment printing

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ABSTRACT

Russian scientist and photographer Sergei Prokudin-Gorskii studied the additive method of colour photography at Adolf Miethe's laboratory in Berlin at the beginning of the twentieth century. In December 1902, Prokudin-Gorskii gave the first colour presentation at the photography section of the Imperial Russian Technical Society. Prokudin-Gorskii photographed the Russian Empire between 1905 and 1915. Based on colour separation, he had successful optical colour projection and produced different types of colour prints. The Library of Congress purchased the main part of the negatives and reference print albums from his sons in 1948. Details of his technique contain in patents, articles and reports.

KEYWORDS Colour photography, Colour separation, Additive projection, Pigment printing, Prokudin-Gorskii, Additive technology

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1. Introduction

To record the word in colour was a mimetic dream shared by Russian photographer Sergei Prokudin-Gorskii (1863-1944). Prokudin-Gorskii's technique for producing colour images was an additive colour screen process. He took more than 3500 colour photographs and most of the colour separate glass negative preserved by the Library of Congress during his activity. Thanks to new digital technologies, Prokudin-Gorskii's photographic legacy is becoming known worldwide.

The photo historian Sergei Morozov (1955) was one of the first soviet researchers who mentioned the activities of Prokudin-Gorskii as a practical photographer. An important place in the study of the photographic heritage of Prokudin-Gorskii belongs to the works of the candidate of pedagogical sciences, Professor Svetlana Garanina. In her first paper about the photographer (Garanina, 1970), she told about the details of shooting the anniversary portrait of Leo Tolstoi in Iasnaia Poliana in May 1908 and Prokudin-Gorskii's note about the technique of colour photography. Professor Garanina published about ten articles with biographic details and descriptions of Prokudin-Gorskii's photographs.

The authors of the first foreign publications about Prokudin-Gorskii (Wall, 1925; Friedman, 1945) gave characteristics of the contribution of scientists from different countries to the development of colour photography, indicating the patents, including the information about Prokudin-Gorskii. The albums with the colour images printed by Prokudin-Gorskii's negatives from the Library of Congress Collection describing the photographer's biography and career are the primary publication type on a historical topic. One of the first English albums (Allshouse, 1980) also presented the research on the history of the development of colour photographic processes and, in particular, the additive method (Goldsmith, 1980). Some new facts from scientific biography photographer and analysis of his practical publications were published by Professor William Brumfield's cooperation research and Library of Congress staff (Brumfield, 1990). The Library of Congress annual newsletter describes the state of conservation of the collection, including glass negatives (Robb, 2001). A recital of various publications and projects that appeared after the digitization of Prokudin-Gorskii's collection can be found in the article (Leich, 2017). Still, most researches focused on the sampler of Russia's past in colour, not on the details of the photographic process. This is mainly because most sources exist only in Russian and have not been previously translated.

In this paper, the photographic articles, different reports and patents are analysed from the point of view of the scientific biography of the photographer and technical details of the additive colour process and further uncovered the history of the photographic heritage of Sergei Prokudin-Gorskii.

2. Prokudin-Gorskii science biography

Scientist, inventor, entrepreneur, and colour photographer Sergei Prokudin-Gorskii was born into a noble Russian family on 18 (30) August 1863 in Vladimirskaia province (Stanulevich, 2019). In October 1886, Prokudin-Gorskii enrolled as an irregular student at Saint Petersburg University. In the first semester, he listened to chemistry lectures by Dimitri Mendeleyev, inventor of the periodic table (Prokudin-Gorskii, 1886). Mendeleyev influenced the young Prokudin-Gorskii's interest in chemistry. Also, Prokudin-Gorskii attended a class in analytical chemistry in autumn 1887, and the following autumn, he stopped his education at University (Prokudin-Gorskii, 1888). Two months early, he started to be an irregular student at the Imperial Medical Army College. In the fall semester of 1889, he also stopped his education at College (*Certificate*, 1890). He did not complete the cycle of higher education, but the knowledge gained formed his main interests and skills: chemistry and photography.

In 1890 Prokudin-Gorskii married Anna Lavrova, daughter of an industrialist Alexander Lavrov, an active member of the Imperial Russian Technical Society (IRTS). Lavrov appointed his son-in-law director of the executive board of his steelworks, located in Gatchina near Saint Petersburg. In 1896 Prokudin-Gorskii started to be a member of the chemistry section of the IRTS. Two years later, he was a member of its photography section, presented an illustration report *On Photographing Meteor Showers*. In the same year, he was one of the exhibitors at the 5th Photographic Exhibition at the IRTS with 23 gold and platinum-toned celloidin prints. For this exhibition, he used isochromatic and panchromatic plates by Ilford and Lumière to make photographs of oil paintings from a private collection of I. Zabel'skogo (*Index for the 5th Photographic Exhibition organized by 5th department of IRTS*, 1898).

Prokudin-Gorskii maybe took his first photographs near summer 1892. He mentioned photographing in Yalta in one of his first photo articles (Prokudin-Gorskii, 1897). This could be due to professional interest and an increased interest in photography in everyday life. In addition, the birth of children in the family of Sergei Prokudin-Gorskii could serve as an appeal to photography - the eldest son Dmitry was born on 22nd January 1892 (Korlyakov, 2009).

Since 1898, Sergei Prokudin-Gorskii wrote reviews to international photographic news for the IRTS. I supposed that he concentrated his attention on colour photography by these researches. On 30th October 1898, he had a report at the IRTS about new Ives' magic lantern for the projection from three colour-separated slides. Prokudin-Gorskii emphasized the merits of colour reproduction, indicated the considerable labour input in production and long exposure that embarrassed the photographing animate objects (Prokudin-Gorskii, 1899). He mentioned more than twenty years later in the British Journal of Photography pages (Prokoudine Gorsky, 1920):

"Certainly, such an arrangement, i.e., exact superposing - on one and all - of three pictures through three coloured screens is a slow process, but if it is done at once it series continually, and therefore the most advantageous condition for such projection is a permanent hall where the apparatus is fixed and will not be moved. With such an optical apparatus colour projection was shown for the first time by Mr. F. E. Ives. This apparatus was modified by myself, and from the point of view of rapidity of arrangements and quality it gave better results, and, having shown my pictures in different parts of Russia by means of this apparatus. I had absolutely no competitors, not even Autochrome, which made its appearance long ago, and which remains within close limits of private circles. More than a hundred projections shown by myself playing convinced me of the great interest of audience, regardless of their composition. It is only necessary that the show be accompanied by verbal explanation; no lecture is essential, but just a simple explanation of what it being shown."

On 29th January 1899, Prokudin-Gorskii demonstrated John Joly's colour photography of a parrot to IRTS' members. Interestingly, this type of bird was a favourite subject for photographing by all scientists who created colour photography. For example, Alexandre-Edmond Becquerel (1820-1891) exhibited at the International Exhibition in Paris in 1855 one of his photographic plates depicting a parrot (Pénichon, 2013). One of the leading figures in three-colour photographic processes - Louis Ducos du Hauron (1837-1920) demonstrated at the Conservatoire national des arts et métiers in 1881 héliochrome depicting a parrot and a rooster, made in 1879 (Lécuyer, 1945). The photographers' choice for the shooting of the parrot was probably caused by the multi-coloured plumage, which made it possible to demonstrate success in obtaining colour images and the reliability of colour reproduction of one or another photographic method.

Two months later, on 19th March 1899, Sergei Prokudin-Gorskii showed at IRTS a stereoscopic photochromoscope by Lumière (*The photography section of the IRTS meeting journal on 19th March 1899*, 1899).

3. Colour separation, additive projection and pigment printing

In the early 1900s, Prokudin-Gorskii opened in Saint Petersburg a photographic laboratory called "Prokudin-Gorskii's Art Photomechanical Studio". At the first time, it produced photocopies from artworks, and then colour postcards and slides usually based on Prokudin-Gorskii's separate negatives. Also, Studio specialised in making photolithography and microphotography. At the beginning of the twentieth century, he studied an additive method of colour photography intensely from Adolf Miethe in Berlin. By analysing the dates, titles, and lists of participants of the IRTS' meetings, we understand that Prokudin-Gorskii's education in Berlin ended in December 1902. As mentioned in some articles, documents about his travel to Europe in the late 1880s (Adamson, 2002, p. 108; Allshouse, 1980, p. X) were not found during ten-year research. Maybe, he had some travels to Berlin in the late 1880s, but for the management of his father-in-law foundry, for the chemical and technical educational reasons.

As Adolf Miethe, Prokudin-Gorskii created his photographs using a camera that exposed one oblong glass negative plate three times in rapid succession through three colour filters. Prokudin-Gorskii photographed with shutter by Thornton-Pickard and different objectives by Steinheil or Voigtländer (Prokudin-Gorskii, 1906c) because the usage of colour filters extended the exposition time and demanded high lens speed.

In 1903 Prokudin-Gorskii published his results in booklet form, Isochromatic Photography with Instant Hand Cameras and recommended using isochromatic plates by Otto Perutz's factory-like a "perchromo" and "perorto platen" (Prokudin-Gorskii, 1903). The emulsion of these plates was made with the guidance of Adolf Miethe. As an analogue of Perutz's plates, Prokudin-Gorskii mentioned isochromatic products of different companies, for example, Aktien Gesellschaft fur Anilin Fabrikation, Edward's, Lumière, and Ilford.

His first known lecture on three-colour photography was delivered on 13th December 1902, reported on colour slides by Adolf Miethe (Adamson and Zinkham, 2002). Prokudin-Gorskii ordered the projector in a German factory. Later, this apparatus was destroyed after his leaving Russia in 1918 (Anon., 1932). A screen for projection was painted in white colour without blue pigment and then mounted to a black frame. A black drop-down curtain was lifted and closed for the projection of each image (*The photography section of the IRTS meeting journal on 4th February 1905*, 1905). Prokudin-Gorskii was one of the photographers who lectured about the regions he travelled, using the colour slides he had produced. His son Dmitry (1892-1963) often operated the lantern (Anon, 1910). Sergei Prokudin-Gorskii always had chosen a unique series of pictures that served the purpose of an action to viewers. It can be, for example, photographs of flowers (Fig. 1), which have an excellent appeal for Empress Alexandra in May 1909.

Fig. 1. Apricot flowers (dried apricots). Samarkand. 1905-1915. Sergei Prokudin-Gorskii. Digital colour rendering from digital files from glass negatives. Prokudin-Gorskiĭ Collection (Library of Congress). LC-DIG-ppem-02155.

At the first shows, Prokudin-Gorskii, probably, used a magic lantern with three lenses with attached colour filters that matched the red-green-blue separations on the glass slide. They formed a single, full-colour image when projected on a white screen in perfect registration. Later he tried to create a system with one beam and multilayer transparencies. As he mentioned in The British Journal of Photography publication (Prokoudine Gorsky, 1920):

The methods for the producing of transparency for the projection colour images existing at present can be divided into three groups:

1. Autochrome and other similar methods [...]
2. Different methods of gluing together films to films or to a glass […]
3. Colouring of the diapositives, even if made sometimes with very transparent colours [...]

After 1904 Prokudin-Gorskii began to develop a colour-sensitive photographic plates. He had perfected a new method that gave equal sensitivity throughout the spectrum within a year. Commenting on his colour images published in the journal Fotograf-Liubitel', Prokudin-Gorskii mentioned that he processed a special emulsion that hypersensitised the Ilford "red label" plates (Prokudin-Gorskii, 1906c). We found the same information (Evdokimov, 1914) on paper about trichromatic prints by Alexander Evdokimov, Prokudin-Gorskii's partner, between 1902 and 1914. Prokudin-Gorskii described drying the plates after sensitisation in his report at VI International Congress of Pure and Applied Chemistry in Rome in 1906 (Prokudin-Gorskii, 1906a) and one of the articles on colour photography (Prokudin-Gorskii, 1906b). The patent for the process of sensitisation of the emulsion was not detected in different databases and archives.

Sergei Prokudin-Gorskii started to obtain patents in Great Britain, the USA, France and Russia before the First World War for production of coloured slides, improvements in and relating to optical systems for the photographic camera, making multiple copies of colour slides etc. Some of them are mentioned in books like History of three-color photography (Wall, 1925) and History of colour photography (Friedman, 1945). From the Russian patent (*Patent #27542 was issued on 30th October 1914*, 1914), we can derive that he started to use colour separate negatives exposed through red, green and blue filters for printing two autotype clichés (for magenta and yellow inks) instead of making a glass slide like a "sandwich". Through gelatin solution, magenta and yellow images were transferred from paper support to one glass plate. The third part was a cyan slide printed from a halftone negative that had been exposed through a red filter. The last step was mounting both-glass slides - the magenta and yellow on one and the cyan slide on the other – together so that its result is one lantern slide. Sergei Prokudin-Gorskii wrote that the slides looked like a pigment colour image in projection.

The process of making clichés for colour printing described by Alexander Evdokimov in the first decade of the twentieth century contained the following steps: colour separation by the photographed through the three colour filters; contact printing of transparencies from each separated negatives; shooting from the scales; printing autotype negatives and then making clichés on copper or zinc (Evdokimov, 1914). In 1905 and 1906, Prokudin-Gorskii mentioned that Frankenstein-London Company dyes were used in his studio in Saint Petersburg. For the best results, masters printed on paper four colours (yellow, red, blue and black) one after with a difference like 24 hours (Fig. 2, 3). Prokudin-Gorskii started repeating the halftone process for each subtractive colour to make postcards with his colour-separated negatives since the same year.

Fig. 2. Yellow, red, blue and yellow plus red parts of colour prints. Prokudin-Gorskii, S. (1905) Photomechanical work. Saint Petersburg: Printing House "Public Benefit".

Fig. 3. No title. Postcard from oil painting. 1903-1905. Photographer Sergei Prokudin-Gorskii. Nadezhda Stanulevich private collection.

The Prokudin-Gorskii's Studio was a typical printing enterprise before showing colour slides for Emperor Nicolas II in May 1909. After the audience, the number of government orders increased. For example, Prokudin-Gorskii photographed the different objects for the government to publish historical albums for the centenary of the Patriotic War 1812 and the three hundred anniversary of the House of Romanov in 1913. He would also like to shoot the Emperor's ceremonial exits during the last celebration to colour cinematography. Sergei Prokudin-Gorskii began to develop different technological stages of producing colour cinematography in 1910.

Continuing his scientific activity, Sergei Prokudin-Gorskii participated in creating the Higher Institute of Photography and Photo Technique in Petrograd after the October Revolution. Realising the position of Russian industry by the end of the First World War, he decided to do business abroad. In August 1918, he left Petrograd for production colour cinema in Norway. He moved to England in 1919 and then France in 1921. Prokudin-Gorskii, with his sons, Dmitry and Mikhail, founded a company, "Societé de Photochimie Elka" named Sergei Prokudin-Gorskii's youngest daughter Helena (later a company renamed to "Gorsky Frères") in Nice in 1924.

Prokudin-Gorskii's photographs were demonstrated at the lectures Russia in Images in the different Parisian organisations in the 1930s. All pictures were black and white because an additive magic lantern had been left in Russia (Stanulevich, 2020).

Since the second part of the 1920s, the photographer started to use film in his processes. Prokudin-Gorskii mentioned that fact in his notebooks. Copy of these notes from the family collection in Paris was presented by Svetlana Garanina, the first Russian biographer of Sergei Prokudin-Gorskii, to the Polytechnic Museum in Moscow in 1995 (Danilina, 1995). These documents show the history of Prokudin-Gorskii's patent usage, describing his photographic processes' modifications during the 1920s.

On 18th December 1926, Prokudin-Gorskii had a report at the French Photography Society about making natural-colour prints on paper. In the photographer's opinion, the photomechanical property of the Elka paper was the possibility of the image being transferred to any desired surface. The image was transferred to a metallic surface and developed in hot water to remove all soluble gelatin at describing a process. The metallic silver of the films transformed into halide salt. Finally, the plates are rinsed very briefly, merely to remove the excess of the solution, and each is immersed in a dye solution, orange-red, yellow and blue. When the three dyed images have thus been produced, all that remains is transferring one of the prints to the final support and superposing the other two upon it (*Colour Photography on Paper*, 1926).

In addition, notes contributed information about the contract between Prokudin-Gorskii and Lumière's label for the making film with Prokudin-Gorskii's label – Elka. Despite the active popularisation of his photographic paper, Prokudin-Gorskii mentioned that he preferred to experiment with Kodak transferotype paper for making slides since 1927 (Prokudin-Gorskii, no date, p. 16). Kodak produced this paper to make enlarged negatives, glass positives or lanternslides, and prints upon opal glass, wood, metal tinted or other drawing paper, silk, satin, sateen, and other suitable support. In his notes, Prokudin-Gorskii explained the transition to Kodak paper because Elka paper, made at the Lumière factory by 1927, was not the best quality. The disadvantages were uneven emulsion, dirt, excessive paper relief (Prokudin-Gorskii, no date, p. 12).

Before the 1950s, "Gorsky Frères" specialized in commercial printing for Nestlé, Fléchet, L'Illustration and Figaro. Also, they partly realised an idea of creating a collection of French ethnographic types (one copy of prints was preserved by Mikhail's son Serge Procoudine Gorsky (1932-2005) in Paris). The colour prints with French views by "Gorsky Frères" are sometimes found on The Delcampe website [1].

4. Heritage of Sergei Prokudin-Gorskii

The Library of Congress purchased Prokudin-Gorskii's collection the photographer's sons in 1948, after his death in 1944. The entire collection of glass negatives and albums with sepia-tone prints was digitised in 1999 and is available worldwide on the Internet. In a 1995 interview, Anna Béraud (1930-1996), the granddaughter of Prokudin-Gorskii, said that the collection was kept in the basement (two or three square meters for each apartment) of a house at 69 rue de la Tomb Issoire, where the family lived since 1938. They were all afraid that the photographs would be spoiled without special preservation conditions (Minachin, 2003).

The Library of Congress collection includes 1902 black and white glass negatives and more than 3100 sepia-tone prints (Fig. 4) without any colour or black and white slides. The size of the glass negatives is 9 x 24 cm. The dimensions of each image frame are 8.5 cm. wide and from 7.5 cm. to 8 cm. tall. Prokudin-Gorskii mentioned in his emigrant memoirs that he printed copies of images and collected them to the album after shooting. In this way, the albums from the Library of Congress Collection were made. The author's numbering and titling were photographic prints from red filter glass negatives. Although sometimes Prokudin-Gorskii wrote this information from memory and made mistakes, researchers determine now. The sepia-tone prints with size 8 x 8 cm. mounted on fourteen albums (usually six photos on each page of the album).

Not all materials of Prokudin-Gorskii are kept in the Library of Congress and other officially declared collections. It is known from archival documents that as of 1913, the photographer shot 3350 negatives and made 1000 slides (Anon, 1913). In the case of the same subject, the Library of Congress collection may contain a set 'negative and sepia-tone print', or images are represented by only one type of material. And in the case of only having a sepia-tone print, we can see the colour image only thanks to the finds of colour prints from various publications, for example, early twentieth-century books published in cooperation with Prokudin-Gorskii's studio (Fig. 4, 5).

Fifteen black and white slides of Leo Tolstoi's Estate in Iasnaia Poliana with the size of 8 x 8 cm are preserved at the Institute of Russian Literature Collection. Twenty-four colour slides made in the 1930s on film are part of a private collection of Prokudin-Gorskii's grandson, Michelle Soussaline.

Colour postcards, posters, illustrations for publications printed by Prokudin-Gorskii based on his separated negatives are part of the collections of archives and libraries in different countries.

Fig. 4. Vyborg castle. 1904. Sergei Prokudin-Gorskii. Photographic print. Prokudin-Gorskiĭ Collection (Library of Congress). LOT 10333, no. 91.

Fig. 5. Vyborg castle. Example of colour printing. Prokudin-Gorskii, S. (1905) Photomechanucal work. Saint Petersburg: Printing House "Public Benefit".

5. Conclusion

Sergei Prokudin-Gorskii was a talented inventor who used his scientific background. The main interest of the additive process is that a black and white image is used directly as the base of the colour image. Prokudin-Gorskii wrote in emigration (Prokoudine Gorsky, 1920) that having been occupied with the problem of colour cinematograph since 1912; he concluded that the principle of three separate negatives was the most advantageous because it allowed large amplitude in the ratio of exposures. Moreover, in his opinion, these negatives can be utilised for another very useful purpose: optical colour projection and producing colour prints typographically.

In my opinion, the main contribution of Prokudin-Gorskii to the development of the additive method is the refinement of the emulsion for the plates, development of technology for creating colour slides with a transition to attempts to develop colour cinematography. Also, he selected shooting parameters for various weather conditions on the territory of the Russian Empire, created a series of surveys that included at least 3500 negatives, arranged the use of colour-separated negatives for printing colour illustrations and trained masters in his studio.

6. Conflict of interest declaration

The author declares that nothing affected their objectivity or independence and original work. Therefore, no conflict of interest exists.

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8. Short biography of the author

Nadezhda Stanulevich is a photo historian. She defended her Candidate of Science dissertation entitled *Sergei Prokudin-Gorskii and his contribution to the development of colour photography* in 2019. Most of her peer-reviewed articles focus on the history of photographic techniques or museums collections. Since September 2019, she has been a Researcher at Peter the Great Museum of Anthropology and Ethnography (the Kunstkamera).

Notes

[1] https://www.delcampe.net/en_US/collectibles/engravings/lot-de-3-tableaux-province-de-france-sous-verre-45-x-54-cm-photos-gorsky-1947-1948-voir-7-photos-159030833.html

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Two Prizma Color films, a curious finding in the Mexican National Film Archive

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ABSTRACT

Few years ago an important collection of silent movies was found in the National Mexican film archive. The collection did not contain any Mexican movie, unfortunately, but it was rich in terms of coloring techniques of the silent era; two findings were particularly interesting, the first on the Apache trail in the United States (around 1921) and the second on the clay making in Ohio (probably 1920s). The added value of both titles is that they were shot using the Prizma Color technique, a very original color-processing invented around 1913 by William Van Doren Kelley and Charles Raleigh. This color system was an additive color technique that eventually evolved into a bi-pack system. Even if a complete restoration is not yet completed, the films were a particular challenge for a proper conservation and film restoration. The paper will examine the research on the film, the color process and suggest some possible restoration techniques.

KEYWORDS Prizma, Prizma Color, Color Restoration, Film, Digital Restoration, Mexico

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1. Introduction

In 2011, while working at the Mexican National Film Archive, I discovered a collection of short films from the 1910's created with unique coloring techniques. My quest to find out more about these films led me on an interesting path of discovery. Two of the shorts used a lesser-known technology called the Prizma Color system, which was introduced in 1913 and disappeared in the 1920's. In this paper, I will discuss this unique coloring system and describe the challenges in restoring this particular kind of technology. Even if -regrettably - none of these materials are Mexican, they give us a glimpse into what the Mexican audience used to watch in the '10s.

2. The Prizma color origins

Cinema is a constant process of innovation; in any era of film history, we can find new systems, technologies or novelties. They all were invented to surprise the audience but also to push the boundaries - and therefore the form - of the movies. We live in a time where digital tools continue to expand the possibility of moviemaking, but technology has always shaped the way of making movies. Since the beginning of cinema, producers, directors and cinema "inventors" were finding ways to add colors to movies; at the beginning with hand painted techniques, tinting, toning and -later on- with more complex mechanical techniques, before the era of multiple layer film material [1].

For the purpose of this research, we will examine one specific technique, known as Prizma Color. Prizma color was a coloring technique invented by the Prizma Company, a company created by William van Doren Kelley, in the '10s. Van Doren Kelley (Fig.1) fathered many original techniques (e.g. Kesdacolor, Kelleycolor). The Prizmas (Prizma I and Prizma II) were the results of many attempts carried out in the 1910's and 1920's to reproduce colors in the most efficient way.

The first experiment of the Prizma system was made in 1917 with "Our Navy", a movie presented in the American A first experiment was carried out in 1913 with a more ambitious system, the Panchromotion [2] a four color filter (red-orange, blue-green, blue-violet, yellow) technology that was meant to challenge the "Kinemacolor"; the result was not successful especially resulting in color "fringing" (and optical aberration that occurs at the border of the image) and lack of projection brilliance.

Museum of Natural History. "Our Navy" was made using a three-disk system which resulted in instability and flicker when projected, an issue true of many of the disk technologies used during that era. These required upgrading all the projectors and training the staff to achieve the perfect speed required by the system.

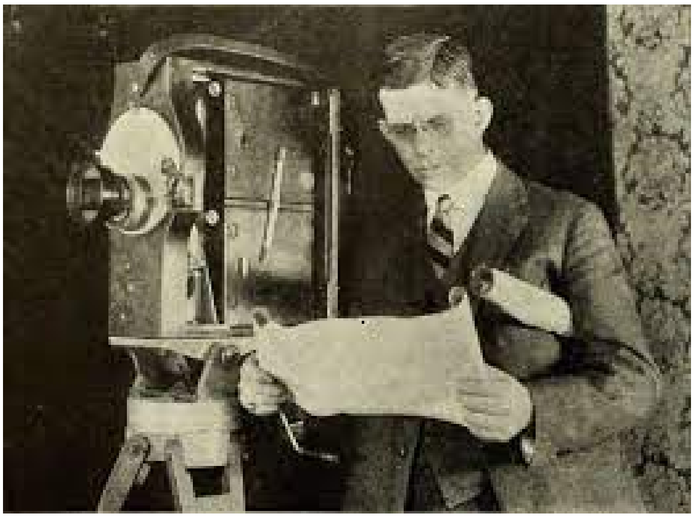

Fig. 1. William van Doren Kelley

3. Prizma I

As a result of these previous experiments, the Prizma I system was developed by combining two techniques. A first frame was colored in red and orange and a second one in blue and green with an additive system. They were then combined with a color wheel. Despite the fact that it was a combination of two different technologies, it continued to have fringing and synchronization problems, and van Doren Kelley was convinced that a subtractive coloring system would help to solve these issues. The visual result of these problems was called "bleeding" colors as the colors of the image were sometime "bleeding" out of the image; van Doren Kelley's quest to solve this instability led him to create a new subtractive system – which resulted in having the colored "captured" on the material rather than adding color directly to the material.

We must add that, in general, companies devoted to innovation in film production were devoted to more than one project, working on multiple levels to eventually achieve a goal, in this case to develop a more stable coloring system.

In this case we have to mention that another coloring system was experimented by Prizma, the Kesdacolor. This coloring technique was first used on "Our American flag" (1918). Tt was also a two additive system but used a filter made with a lens and a prism to achieve a diffused light and compose the image [3].

4. Prizma II

After few years of testing, on April 4th,1922 the Prizma Company patented a new system; the Prizma II, a complete shift in the previous projects of the company. Prizma II was a subtractive system to be projected on regular projector (vs. Kinemacolor) anticipating "bipack" system.

Two films were shot simultaneously (Fig. 2). One strip was sensitive to red-orange, the other to blue-green. Both negatives were processed and printed on "duplitized film" (film material with emulsion coating on each side) and then each emulsion was toned its complementary color, blue-green by an iron solution, and the opposite side red-orange with uranium.

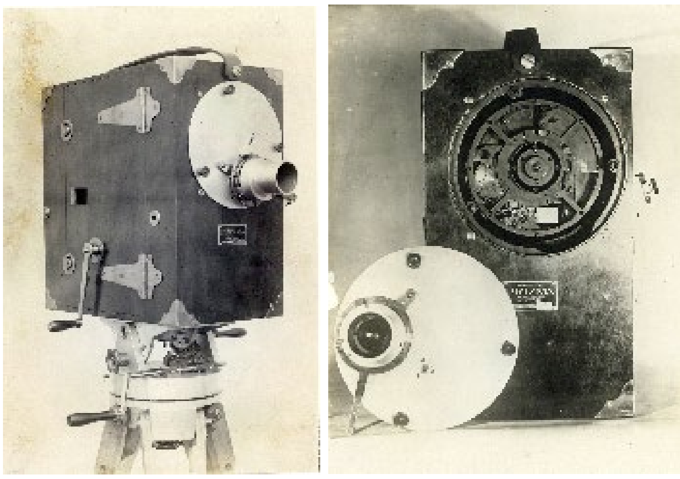

Fig. 2. Prizma II camera (Jonathan Silent Film Collection)

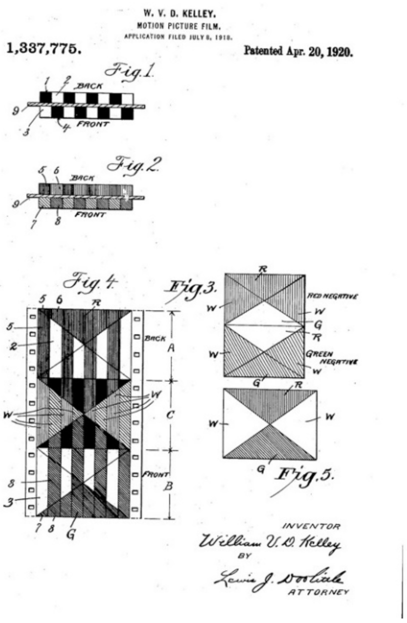

Fig. 3. Prizma II patent

Looking at the original patent (Figs. 3-4) we can better understand how the original object was considered as decomposed by two negatives (a red and a green one), and printed on a positive, then dyed blue-green and red-orange in a final complete positive copy. In this way, Prizma II was "imbedding" the color information in two negatives and untimely in one positive, so that could be projected in any venue, with no need for further technological upgrades.

Here is a very brief filmography of movies that were created with the Prizma company systems and screened:

- Way down easy (1920)
- The Gilded Lily (1921)
- Broadway Rose (1922)
- The Glorious adventure (1921)

Also, 26 shorts (or more) were produced and released to demonstrate the Prizma II and in 1925 Robert Flaherty took a Prizma II camera to the set of "Moana" (1926) but he was not able to shoot any material. The reasons for this are unclear.

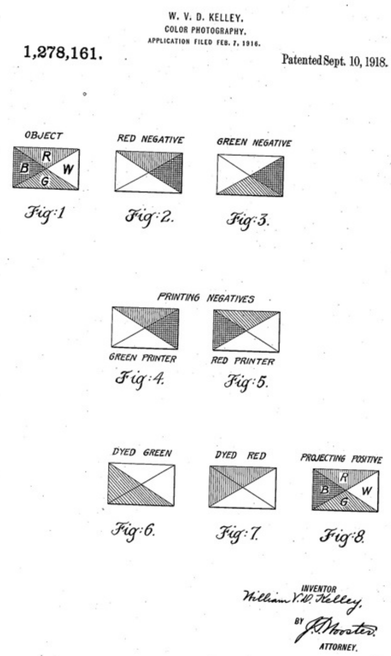

Fig. 4. Prizma II patent

As a conclusion to this very limited chronology of the Prizma Company, van Doren Kelley's last project was the Kelleycolor, which was unsuccessful. In 1928 all the patents belonging to the Prizma Company were acquired by the Consolidated Film Industries - part of Republic Pictures - and were re-branded as Magnacolor.

5. Two findings

The Mexican National Film Archive includes an interesting collection of Nitrate materials. It is still unclear how much of the collection was destroyed in the fire of 1982 but since then there has been a big effort reconstruct what was lost. It is likely that a collection of 25 silent film were donated to the archive, although it was not possible to trace the original donor. These materials survived because in the 1940s this selection of silent films were used by a teacher as visual illustration for his geography and history classes. All of these titles are either travelogues (the non-fictional one) or historical films (the fiction ones) but they all have some particularly original coloring techniques.

This research project was born when we found the first title “La senda de los apaches de Arizona” or “The Apache trail” (1919 ? [4]) (Fig. 5), not the positive original copy but a a ’90 dupe negative copy of this short movie, meant to show scenes from the Apache trail, taking advantage of the Prizma II system in big scenery shots. Even if the collection had not been studied or restored at the moment of the finding, the ’90 dupe negative (as for some of the titles) clearly indicate that there was an intent to preserve the materials. By reading the edgemark on the positive, one could clearly see that the film had been made using the Prizma system, and from there we began on our journey to discover the origins of this unique coloring technique.

Fig. 5. A frame of “The Apache trail”

Another Prizma title we found in the collection was “La industria ceramica” (1920?)(Fig. 6), a movie that begins as sort of industrial documentary, but then moves more to a peculiar and imaginative creation as the beauties of the ceramic industry in Ohio are shown by an exotic magician. The positive copy of the movie was also marked with the Prizma brand and had the same color effects as well as the same problems.

Fig. 6. A frame of “La industria ceramica”

6. An attempt at restoration

When dealing with such unique materials, the first concern was to understand as much as we could of the technique, including the desired color effects as well as the aberrations resulting from the failures of the of the Prizma technique. As we first approached the dupe negative material of “The Apache trail” we realized that the copying system (on Eastman material) was actually quite accurate, but it was definitely lacking the brightness of the original. This idea was confirmed as soon as we find the original positive copy.

After a complete inspection and reparation, we followed our regular scanning procedure of the Laboratorio de Restauracion Digital Elena Sanchez Valenzuela, the digital facility of the Cineteca Nacional: the three copies were scanned in a 3K resolution selecting accurate LUT for each material. It became clear that three main problems we would face in the image and color restoration process would be heavy flickering, color instability, and “Fringing” or “Bleeding”.

All three problems were created by the Prizma system itself, which resulted in a color that was not always centered, a heavier than usual image flickering and an instability of colors in the image (and in the same frames) which caused a “Fringing” or “Bleeding” effect (Fig. 7). It is probable that these defects were the main reasons why Prizma was not widely used in its time.

It must be noted that the system was mostly effective for scenes with limited camera movement (such as scenery shots) but definitely less effective in scenes that involved more action.

We decided to apply a minimal stabilization to the image and, after many attempts, a minimal color correction was successfully applied to match the two original positives.

Fig. 7. A frame with a "Bleeding effect"

7. Conclusion

Finding a new collection is often the impulse for new research and can ultimately lead to significantly broadening the field itself, especially when there is little that is already known about techniques used to create them. The finding of two Prizma color movies in a more complex collection in Mexico reaffirmed that film history can be changed from any part of the world. While a final solution to correcting the "Bleeding" problem was not found, we have hope that digital technology may, in the near future, be able to resolve it, perhaps with a digital division of color layers (maybe in a three-dimensional space, decomposing film material as complex object more than the result on the screen) or even without any intervention.

8. Conflict of interest declaration

The author declare that no financial/personal interests have affected the author's objectivity. Therefore, no conflicts of interest exist.

9. Funding source declaration

This research has received no grant or funding from public institution, for profit or not-for-profit companies or agencies.

10. Short biography of the author

Paolo Tosini has studied Film Restoration in Udine and Berlin. He has been the founder and director fo the digital restoration lab in the Mexican National Film Archive. He is currently the coordinator of the Film heritage conservation school for the CSC and teaches Film History at the Università del Salento, Lecce

Notes

[1] For example, Technicolor, Eastman color, Agfacolor, Ferraniacolor but also Dufaycolor, Kinemacolor and Gasparcolor among many others.
[2] For more information: Nowotny, R. A. (1983): "The Way of All Flesh Tones. A History of Color Motion Picture Processes, 1895-1929" Garland Pub., pp. 154-156
[3] For more information: Ryan, R. T. (1977): "A History of Motion Picture Color Technology", Focal Press, pp. 34-35.
[4] We estimated the year from the edge code of the stock material.

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The Start of the Rainbow: Possibilities of Color Motion Photography for the Amateur [1]

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ABSTRACT

This paper provides a chronology and summary of amateur cinematography's early color history. Drawing primarily on articles and advertisements in amateur movie makers' publications and the popular press in the United States and Europe, it summarizes the additive color motion picture processes, effects, and equipment available to amateur cinematographers in the 1920s and '30s. The paper concludes that while these additive processes might appear primitive and flawed in comparison to later processes and technologies, they are worthy of celebration and appreciation for their ingenuity and unique characteristics.

KEYWORDS Color motion picture film, Amateur motion picture film, Additive color processes, Historical color processes

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1. Introduction

The earliest era of amateur movie making offered an inventive array of color possibilities for the film enthusiast. From the simple addition of colored filters on a projector to the delicate hues of lenticular Kodacolor, and later the accessory-free magic of Dufaycolor's réseau [2]. The market for amateur movie-making quickly flourished after the introduction of 9.5mm and 16mm gauges in 1922 and 1923, respectively. New publications emerged dedicated to the amateur filmmaker, and industry and professional journals introduced amateur sections, providing advice to the more serious amateur, keeping them informed of the latest and forthcoming technological developments. The quest for color - particularly "natural color" [3] - was eagerly anticipated by most writers in these publications, stoking readers' excitement with articles about what to expect: "Do you want natural color motion-pictures? Yes, you do! Color, good color, is obtainable!" (s.n., Photo Era, 1929) Some even recognized the role that the rapidly-growing amateur market had played in the development of the new color technologies: "… industry has found amateur markets a sufficient spur to evoke invention and evolution designed for amateurs alone." (Maxim, 1928) In contrast, there were detractors and doubters too, for reasons of both practicality and cost, but also aesthetics. Some writers just did not consider color necessary for the amateur. For example, in Photo Era's amateur column, Herbert McKay, asserted that the amateur cinematographer did not need color, concluding, "let us be content to accept the monochromatic film [...] as our standard." (McKay, 1926) Others asserted that amateur filmmakers were very much the pioneers and that they had the power to drive the market and even influence the professional industry. For example, Carl Oswald was confident that, "… the efforts of the amateur […] lead to advances which the commercial organizations cannot afford to anticipate by the establishment of experimental laboratories." (Oswald, 1928)

2. A Chronology of Color in Early Amateur Moviemaking

The earliest (pre-1935) methods for producing color in amateur motion picture film were all additive processes, wherein colors in the image are created by the addition of colored light sources, such as filters or dyes, located either on the film stock itself or attached to the camera and/or projector. These early amateur motion picture color processes can be categorized into four broad groups (Fig. 1): 1. the application of color to the film or projected image (either applied directly to the film or through filters on the projector), 2. lenticular processes, 3. rotating, alternating filter mechanisms used to produce natural color, and 4. Dufaycolor's unique réseau. The dates in the table indicate the introduction of a process and its approximate obsolescence.

	Date	Process	Type
1	1920s	Hand-coloring	Manually applied directly to film
1	1920s – 1930s	Tinting / toning	Processed by filmmaker or sent to vendor
1	1927 - 1929	Filter projector attachments	Projector attachment
2	1928 - 1935	Kodacolor	Lenticular
3	1928 - 1932	DuPont Vitacolor	Rotating filter on camera and projector
3	1931	Mroz-farbenfilm	Rotating filter on camera; color applied to film base
3	1931 - 1933	Morgana Color	Rotating filter on camera and projector
2	1932?	Agfacolor	Lenticular
4	1934 - 1951	Dufaycolor	Three-color réseau inherent in film base

Fig. 1. A chronology of motion picture color processes available to the amateur filmmaker, pre-1935

2.1. *Direct Application of Color to the Film or Projected Image*

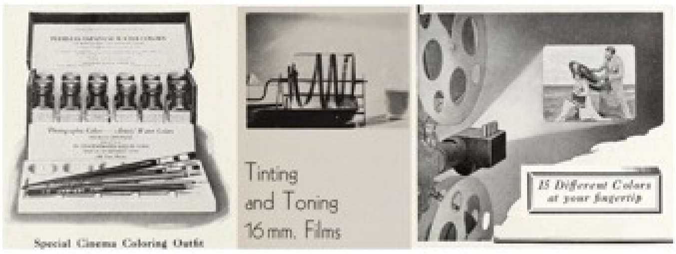

Fig. 2. Advertisements and an article in amateur movie publications. Special Cinema Coloring Outfit ad, Movie Makers, 1928, p. 476; Tinting and Toning 16mm Films, William Stull, American Cinematographer, 1933, p. 18; Automatic Colorator ad, Movie Makers, 1927, p. 65

Several techniques were available to the amateur who wanted to introduce color to the image, either directly to the film or to the projected image through colored filters attached to the projector. These techniques allowed the amateur to use color to interpret a subject or evoke a mood. For example, red for fire or danger, blue for a seascape or night scene.

To apply color directly to the film, filmmakers could hand-paint dyes onto the film, either covering the whole frame with one color or by intricately coloring specific parts of the image on each individual frame in an attempt to replicate natural color. Advertisements in the press (Fig. 2) show that hand-coloring equipment was available to the amateur filmmaker. Many amateurs would have been aware of hand-coloring techniques from seeing films such as those from the Edison and Pathé studios. The technique of hand-coloring individual frames was painstaking, immensely time-consuming, and the results did not live up to the ultimate quest for “natural color”. Nevertheless, professional hand-colorist, Gustav Brock, strongly advocated for – and practiced - the use of hand-coloring in theatrical prints into the 1930s. (Brock, 1930) He regarded it as an aesthetic choice, even when “natural color” was a possibility, Brock enthused about hand-coloring’s appeal and how aesthetically effective it could be.

While hand-coloring was an intricate and time-consuming process, tinting and toning was more easily achievable for the keen amateur. Tinting was a technique used to color the highlights of the image by immersing the film in a dye bath, and provided an overall color to the whole, or sections, of the film. Toning converted the black and white silver parts of the image to another metal, resulting in a different color depending on the metal. Tinting and toning techniques were advertised in the early amateur movie makers press – both for home processing and as a lab service. The amateur press ran several articles detailing methods and techniques for the keen amateur movie maker to try at home. [4] As early as 1925, Herbert McKay’s series on practical kinematography in Photo Era magazine (McKay, 1925) recognized the value of tinting and toning for amateur movie makers but he advised that it should be left for the labs to do. In contrast, later articles in the British Amateur Cine World and the American Movie Makers encouraged the more experienced amateur to experiment with tinting and toning techniques at home. (Abbott, 1934; Kerst, 1927)

Fig. 3. Advertisement for color filter attachment for Bell & Howell Filmo projectors (Movie Makers, January 1928, p41)

Color filter attachments which could be fixed in front of the film projector’s lens were a non-intrusive method of introducing color to the *projected* image. Some projector models (for example, within the Pathé 9.5mm and Keystone 16mm series) had color filter attachments fitted as standard. Filter attachments were advertised regularly in the amateur press throughout 1927-29. Manufacturers included American Cine Products who made the Automatic Colorator, Beckley and Church, Inc., makers of the Koloray, and Bell & Howell’s Filmo projector attachment with four color filter discs [5]. The Automatic Colorator attachment provided “15 different colors at your fingertips” which could be “individually or collectively interchanged simultaneously at the touch of a button”. (s.n., *Amateur Movie Makers,* 1927) The Koloray was a circular attachment that could be rotated to select a variety of colored filters, and also allowed for two-color combinations by aligning two of the filters in front of the projector lens simultaneously. This might be used, for example, in a landscape scene to achieve blue for the sky and green for the land. One Koloray advertisement (s.n., *Movie Makers,* September 1928) carried a letter of recommendation from Herbert McKay, who apparently embraced the use of color filters (and tinting/toning, see above) but also cautioned the amateur about the burgeoning natural color processes available to professionals, “Color is a source of infinite pleasure—but only when presented properly” (McKay, 1926). Manufacturers emphasized the devices’ ease of use and their ability to add color “without the necessity of tinting or toning” (s.n., *Movie Makers,* April 1928), as well as the benefit of “toning down the glaring white of the screen to save the over-exposed scenes which otherwise would be worthless.” (s.n., *Movie Makers,* April 1928) As with tinting and toning, the color filters provided emphasis to a scene or created a mood. The projectionist’s interaction and interpretation of the scenes also introduced an air of performance to the home movie experience.[6]

2.2. *Lenticular Processes*

Fig. 4. Kodacolor box and Kodacolor filter (Chicago Film Archives); Agfacolor filters (Leitz Photographica Auction)

The launch of Kodacolor 16mm film in the United States in September 1928 was met with palpable joy by Amateur Cine League president Hiram Percy Maxim, declaring that “Kodacolor has made a dream come true” (Maxim, 1928). In a lengthy and enthusiastic article recounting the inaugural demonstration of Kodacolor at George Eastman House, Maxim recounted an explanation of the lenticular technology employed in the Kodacolor process, and reveled in the visual pleasure of the natural color that it produced, in particular, "the startling effect of seeing living, breathing flesh and blood". Maxim professed that he found the experience "very stirring". (Maxim, 1928)

Kodacolor's technology was based on a process originally proposed by Frenchman R. Berthon in 1909, and further developed by A. Keller-Dorian. It required a special red, green, and blue striped filter (Fig. 4) to be attached to the camera lens when shooting, and to the projector lens when projecting the film. The lenticular process utilized black and white reversal film, which had been embossed with miniscule lenticules (lenses) running lengthwise, covering the surface of the film's base. Maxim's article quotes a fuller explanation given by Dr C.E.K. Mees, head of Research Department at Eastman Kodak, "The function of the lenses embossed on the film is to guide the rays of light falling upon each tiny area and lay them on the sensitive emulsion as three distinct impressions corresponding to the three filter areas, so that the three colors covering the lens are imaged behind each tiny cylindrical lens as three parallel vertical strips, because the tiny cylindrical lenses are parallel to the stripes of color on the filter." (Maxim, 1928)

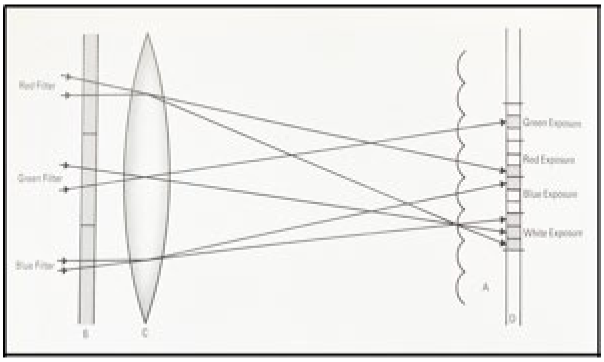

Fig. 5 – Diagram illustrating the lenticular process (Coe, 1981)

When the film was projected through the same three-color filter, a natural color image was achieved. This was "a novel and exciting capacity for the amateur cinematographer, one that put his or her craft ahead of even theatrical motion pictures, which still had limited color processes with which to work." (Gordon, 2013) In concluding his report of the inaugural demonstration, Maxim fired up his readers with the promise of the new technology for amateurs: "… what is nothing short of epoch making, we amateurs are given the means by which we may render immortal our loved ones, for portraits made with Kodacolor bring the living person directly before us." (Maxim, 1928)

Although the technology had its drawbacks, in particular, the need for additional accessories and the necessity for brighter lighting conditions, its ease of use and pleasing, natural colors meant that it was embraced by the keen amateurs who could afford it (the multipage Kodacolor ad provides a detailed breakdown of costs, Movie Makers, August 1928), making it a relative commercial success. With this burgeoning success, Kodak introduced additional accessories such as special projection screens to increase reflection and boost the loss of luminance due to the colored filter, and by the following year, rival manufacturer Bell & Howell was producing camera lenses and projectors equipped to shoot and project Kodacolor (s.n., *Movie Makers,* May1929). Due to its relatively widespread commercial success, several film archives in the USA have preserved examples of Kodacolor.

While there were reports of lenticular Agfacolor 16mm film being demonstrated in Germany and Britain in 1931 and 1932 respectively (s.n., *The International Photographer*, November 1931; s.n., *The Amateur Photographer and Cinematographer,* 1932), and an extensive description of the principles behind the process in the *Journal of the Society of Motion Picture Engineers* (Weil, 1933), it is not known if lenticular Agfacolor for amateur movie makers was ever manufactured for commercial sale [7]. The filter in Fig. 4 was likely for a stills camera using lenticular film.

2.3. *Rotating, Alternating Color Filters – Natural Color*

Based on processes available to professional filmmakers such as Kinemacolor and Biocolour in the 1900s and 1910s, a number of attempts were made to replicate the principle of an alternating color filter for the amateur market. Vitacolor was the most commercially successful of these.

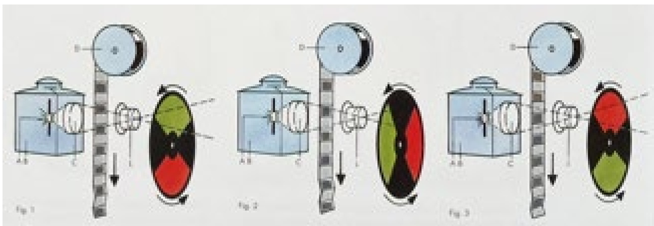

Fig. 6 – Vitacolor used the same principle as the earlier Kinemacolor process, illustrated here (Coote, 1993)

Invented by cinematographer, Max B. Du Pont (not related to the family of chemical and film stock manufacturers), a

Frenchman who emigrated to the USA in the early 1900s to work in the motion picture industry, and whose "desire to improve motion pictures with natural color came to him one day while examining some Pathé hand-colored film" (Anthony, 1928).

The process, which he developed over 10 years, used 16mm [8] black and white negative stock, which was exposed in the camera through a rotating filter, alternating between red and green so that alternate frames were exposed through either the red or green filter. After processing, a positive print was made, which was then projected through a rotating, alternating red and green filter attached to the projector, producing a natural color image. (Fig. 6).

Fig. 7. Vitacolor advertisement (Movie Makers, May 1929, pp. 282-283)

Throughout the latter part of 1928, numerous demonstrations were presented across the USA, and Vitacolor was launched onto the market the following year. Articles in the amateur cine press described and praised the new technology. Full page advertisements (Fig. 7) - sometimes double-page spread and illustrated - appeared in the amateur press. As was common at the time, a woman modelled the camera in order to emphasize the technology's ease of use. The 'Vitacolor Girl' – Mary Mabery - featured heavily in its promotion. Formerly "... a Sennett Girl […] from the University of California, where she was specializing in a course of athletics for a career of athletic instruction in high schools and universities" (s.n., 1927), she became the face of Vitacolor's print advertisements and featured in some of the demonstration films.

As with the lenticular process, Vitacolor's colored filters reduced the amount of light reaching the film's emulsion, so brighter lighting conditions were necessary. There was also an issue with "fringing" – the separation of the red and green projected images – particularly when the filmed subject was in motion. Despite this, the process was well-received by those who attended the demonstration screenings, even by those who had previously been skeptical about color. Natural color skeptic, Herbert McKay heralded Vitacolor to be superior to "old" Kinemacolor, and declared, "Every amateur owes it to himself to make films in natural color" (McKay, 1929) While there are no exact figures available, some amateurs--albeit *wealthy* amateurs who could afford the initial cost of the hardware - over $2,500 in 2022's money—did invest in the technology. The Yale Film Archive holds some examples of Vitacolor in its S.W. Childs collection.

In Austria, several years after Vitacolor was launched in the USA, Ukrainian-born Josef Mroz, experimented with a similar process for 9.5mm film. Comparable to Friese-Greene's Biocolour, the process exposed panchromatic black and white stock through a rotating, alternating green and red filter, then after processing, the film's alternate frames were colored red and green by the application of dyes directly onto the film. Mroz probably used a machine to apply the color to the film but the coverage was inconsistent, resulting in dense patches of color in some areas of the frame and thinner in other areas. Because the color was applied directly to the film, there was no need for a rotating filter on the projector. The process was never made commercially available (Zingl, 2018).

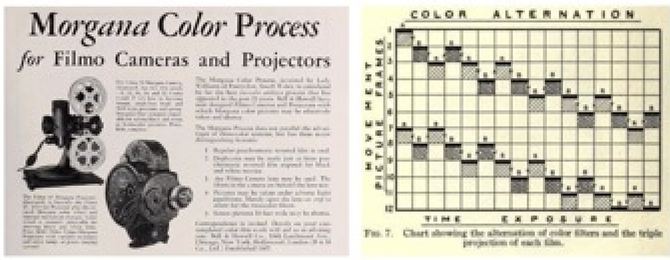

Fig. 8. Morgana Color/Bell & Howell advertisement (Movie Makers, July 1932, p. 285); Color alternation chart (SMPE Journal, 1933, pp. 403-412)

The Morgana Color [9] process refined the alternating red and green filter technique by attempting to eliminate excessive flicker and fringing during projection. This was achieved by a complex projection mechanism devised by Lady Juliet Williams of Pontyclun, south Wales [10] - a politician and advocate for social reform, with a strong interest in motion pictures. She was inspired to develop a practical color process after spending time on a film set in 1924 with her mother, the author, screenwriter, director/producer Elinor Glyn. Over several years, Lady

Williams worked with co-inventor George Short to create a mechanism that advanced the film two successive frames forward and one backward and thus (reportedly) eliminated flicker. According to Bell & Howell employee Joseph Dubray's detailed article in the *Journal of the Society of Motion Picture Engineers*, this was achieved by a quasi-increased film speed: "… although the film is running at a linear speed of 24 frames per second, 72 frames are alternating at the aperture during the same length of time, each picture frame being projected three times on the screen." (Dubray, 1932, p. 410) The diagram in *Fig. 8* illustrates this.

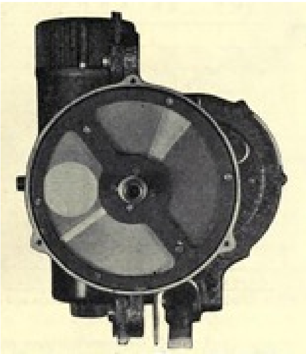

Fig. 9. Morgana color filter wheel on the projector (Dubray, 1933)

In December 1931, the Morgana Color process was backed by Bell & Howell, and in 1932 they began promoting it for use with their 16mm Filmo cameras and projectors. In the March 1933 issue of *The International Photographer* a short article describes a 350ft film made by a Bell & Howell employee (Dubray) of the 1933 Tournament of Roses, Pasadena, USA (s.n., 1933). It is reported that the film was shown to an audience of 300 as well as at a private screening for the parade's grand marshal, Mary Pickford, and Douglas Fairbanks. Later that year, the amateur section of *American Cinematographer* reported that Comte de Janze of Paris would be experimenting with Morgana Color on his forthcoming game-shooting trip to Africa. (s.n., *American Cinematographer,* 1933). Despite these references to Morgana Color films being made, and Bell & Howell's promotion of the process, no extant films or equipment are known to exist (with the exception of a few sample frames in the Theisen Film Frame Collection at the Seaver Center for Western History, Los Angeles). With the onset of the Great Depression in the USA and other, more practical and affordable color processes on the horizon, there is little evidence that the equipment was ever sold commercially. Simon Brown notes that, "The registrar was informed to dissolve the [Morgana Color] company in February 1937 and it was noted at this point that the Morgana patents had been allowed to lapse and that the agreement will Bell and Howell was therefore valueless." (Brown, 2012, p.277)

2.4. *Dufaycolor Réseau*

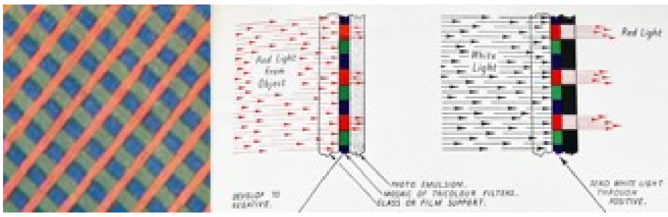

Fig. 10. Dufaycolor réseau (The Dufaycolor Process, 1935); Dufaycolor schematic (Spencer, 1948)

Launched in the United Kingdom in September 1934, Dufaycolor 16mm was the first motion picture color process available to amateurs that did not require additional accessories to produce a color image. Based on the 'screen plate' principle, and drastically refined from Louis Dufay's original process for stills photography in the early 1900s, the complex mechanical manufacturing process added a minute regular pattern of red, green, and blue dyes - the réseau - to the base of a black and white reversal film. The film was exposed in the camera with the its base facing the subject so that light passed through the réseau's colored dyes before exposing the black and white emulsion. After processing, the film was projected with the emulsion facing the projection screen, so that light from the projector lamp passed through the colored base first and created a natural color image on the screen. When viewed at an optimal distance, the pattern of the réseau was barely discernible.

Fig. 11 – Advertisements for Dufaycolor movie film (Amateur Cine World, Sept 1934, p. 156; Movie Makers, June 1935, p. 232)

Karl A. Barleben's article in *The International Photographer* in April 1935 excitedly pronounced that, "DuFayColor [sic] Is Here With a Bang!" (Barleben, 1935)

He observed that the numerous attempts to achieve natural color over the last few years had "not been a particularly successful venture, technically or financially. […] At the present time, there exists a most practical and worthy natural process – The DuFay Color [sic] process." Its benefits he noted, were that, "It has speed galore, requires no special adjustments or accessories, and reproduces color in a manner which is nothing short of amazing, considering that it is a one-film process." (Barleben, 1935) Because of its ease of use and, contrary to Barleben's claim of "speed galore", the brighter lighting conditions needed for optimum exposure, Dufaycolor enjoyed reasonable commercial success up to the 1950s (in stills photography, too).

Dufaycolor's USA launch in spring/summer 1935, however, coincided with the introduction of Kodachrome 16mm film, which offered the amateur even greater ease of use (although not accurate natural color for the first three years). Nevertheless, Dufaycolor introduced 9.5mm reels and cartridges in 1937, and the process remained on the amateur market until around 1950. The possibility of producing 8mm Dufaycolor was considered by its manufacturers (Hercock, 1979), but apparently never realized, possibly because the réseau would be too visible and intrusive. There is mention of 8mm Dufaycolor in some amateur movie magazines, and a few sample frames exist at the Theisen Film Frame Collection at the Seaver Center for Western History, Los Angeles, but otherwise it was not known to have been commercially produced. However, a reel of poorly-slit 8mm Dufaycolor was discovered a few years ago by the author of this paper, and has been donated to the University of Southern California's Hugh M. Hefner Moving Image Archive. The history and provenance of this reel is yet to be determined. Examples of 16mm and 9.5mm Dufaycolor can be found in many regional film archives, particularly in the UK.

3. Conclusion

In 1933, writing in the *Journal of the Society of Motion Picture Engineers,* F. Weil (Weil, 1933) outlined what he believed to be the principal requirements to make motion pictures in natural colors practically and technically successful:

1. The photographic manipulation and apparatus must be simple
2. The process must provide sufficient color saturation and resolution; that is, the color elements must be small enough to be unobjectionable
3. It must be possible to make prints from an original exposure
4. The process must make efficient use of the available light, both in making camera exposures and in projecting the pictures on the screen

These requirements echoed the predominant prescriptive approach of the majority of those writing about and making photographs and movies at the time. With the arrival of Kodachrome in 1935 - and its ability to fulfill the above criteria (at least post-1938) - the path was set for subtractive processes to dominate the markets, both amateur and professional. But while the impracticalities of accessories and slow film speed, as well as poor cost-effectiveness, meant that early additive color processes were short-lived and achieved relatively low commercial success, they should not be dismissed because of their inherent 'flaws' and relative lack of success. Instead, their inventors' ingenuity and each process's unique characteristics and aesthetic qualities should be considered worthy of our appreciation and duly celebrated.

4. Conflict of interest declaration

The author declares that no actual or potential conflict of interest exists including financial, personal, or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, their work or objectivity.

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6. Short biography of the author(s)

Louisa Trott has worked with amateur film collections at regional and national film archives in the UK and USA. She holds an MA in film archiving from the University of East Anglia, and is co-founder of the Tennessee Archive of Moving Image and Sound. She is currently Liaison Librarian for Cinema Studies and Theatre at the University of Tennessee, Knoxville.

Notes

[1] The title of this paper is adapted from Carl Oswald's article, "The End of the Rainbow – Possibilities of Color Motion Photography for the Amateur" (Oswald, 1928) in which he considers the feasibility of color motion pictures for the amateur. Published in January 1928, marginally pre-dating the introduction of lenticular Kodacolor, the article weighs the eager anticipation of color for the amateur filmmaker against the practical considerations of cost and the limitations of technology. Oswald was an authority on photographic processes and was a regular contributor to

Movie Makers magazine. For a brief biography of Oswald, see Movie Makers, June 1928, page 422.

[2] Réseau is the French word for "grid" or "network", and refers to the "screen" formed by the three colored dyes applied to the film's base.

[3] "Natural color" referred to a photographic image whose colors closely replicated the original scene, in contrast to the color-block effects of tinting or hand-coloring.

[4] A few examples of this technique can be found in the Amateur Movie Database (www.amateurcinema.org/), but generally, examples of hand-coloring and tinting/toning in amateur films seem to be fairly rare.

[5] The author has yet to locate any extant examples of the Automatic Colorator, the Koloray, or the Bell & Howell filter attachments.

[6] The author has been unable to locate any examples of these filter attachments in museums, archives, or private collections, but at the Northeast Historic Film symposium in 2019, the effect was replicated in a presentation, and proved to be quite satisfying - producing an audible gasp from the audience in spite of the primitive, low-tech process.

[7] The name Agfacolor was later used for other color processes made by Agfa. The Timeline of Historical Film Colors has some sample frames of lenticular Agfacolor.

[8] In addition to 16mm, Vitacolor was originally trialed in 35mm for the professional market, but Du Pont decided to focus on the amateur market alone.

[9] The author has not yet found an explanation for why the name Morgana Color was chosen. An informed guess might be that the name is a reference to the county of Glamorgan, where Lady Williams lived, and/or possibly a reference to the character of Arthurian legend, Morgan le Fay (aka Morgana), whose origins lie in Welsh/Celtic mythology.

[10] Pontyclun, south Wales (pronounced Pont-uh-clean) – in recent literature about Morgana Color, the name of this town has sometimes been misspelled as Pontyclud, probably originating from a typographical error in Brian Coe's History of Movie Photography (1981). Also originating from south Wales, the author of this paper has a personal interest in the history of Morgana Color and its inventor, and is currently working on a more detailed biographical piece about Lady Williams.

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Digital Struggles for Film Restoration: La battaglia dall’Astico al Piave

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ABSTRACT

Our contribution is focused on the ongoing reconstruction and restoration of *La battaglia dall'Astico al Piave* (1918, 35mm, tinted and toned, mt 1255), by the University of Udine in collaboration with La Cineteca del Friuli, Istituto LUCE and Cineteca Italiana, and supported by MiC. To date, three versions are documented: the 1918 Italian and French versions, both realized by the Italian Royal Army Film Department, and a further version released in 1927 which was probably re-edited by Istituto LUCE. Archival prints collected after a first survey of the film archives have been used to reconstruct the text on proxies, with the help of edge-to-edge and “repro-set” documentation and the other non-film materials. The restoration is being carried out through the digital intermediate route, using witness from Kinoatelje (“K”) as the main reference to reconstruct the order of the scenes and the colour palette for the digital Desmet procedure. The aim of our contribution is twofold: on one hand, we highlight specific restoration and reconstruction issues; on the other hand, we focus on the reloading and reframing of the long-standing and sensitive field of digital research and the educational-oriented critical edition of films, in order to document the restoration and reconstruction process and give a wider account of the material, visual and cultural history of film as a set of apparatus, discourses and practices, proposed here through an innovative digital design and environment and following new interdisciplinary approaches.

KEYWORDS Italian WWI Film Heritage, Film Restoration, Film Reconstruction, Film Philology, Critical Editions of Film

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1. Introduction

La battaglia dall'Astico al Piave [1] was made by the Italian Royal Army Film Department in 1918. The film testifies the days between 15 and 29 June 1918 and shows many important moments of the battle, from the attack on Montello to the recapture of the village of Nervesa.

Three versions have been documented to date: the 1918 Italian and French versions, both made by the military film department, and a further version, renamed *Ta Pum*, released in 1927 and still in circulation around 1930–33 at least, which was probably re-edited by Istituto LUCE.

Starting from archival prints, the project aims to make a textual reconstruction of the first Italian edition of 1918 with the help of edge-to-edge, "repro-set" recordings and other non-film materials. The restoration is being carried out through the digital intermediate route, and the result will then be recorded back on film to reproduce the tinting and toning through the Desmet method and using witness preserved by Associazione Kinoatelje (from now, simply called "K") as the main reference (see Table 1 above). According to the philology of texts, "witnesses" are "all the facts and objects that have transmitted the work through time, from its origin to us" (Chiesa, 2020). Then the 35mm colour print will be scanned so that there is conformity at least between the photochemical and digital theatrical copies, which could not be achieved otherwise. At the same time, we will give an historical and visual account of the other versions, especially the 1927 re-release, through the digital environment we are designing for a digital critical edition of the film.

The aim of the project is to reconstruct the first Italian edition of 1918 and at the same time to give an historical and visual account of the other versions, especially the 1927 re-release.

2. Objective

"A (film) restorer according to the contemporary definition of the term has always relied on and been involved in philology. And the final aim of the philologist is the critical edition" (Marotto, 2008). Therefore, we will present our approach to film reconstruction, showing the numerous similarities with the methodological instrument with which philologists critically edit texts and manuscripts. In the first part, we present a survey of the primary film and non-film sources collected for the purpose of the reconstruction and restoration process which are also at the basis of the digital critical apparatus and their *examinatio*; in the second part, we focus on the actual restoration and reconstruction methodologies, practices and issues we are working on at the present moment while making a morphological and qualitative evaluation and discussing some of the interesting *loci critici* we have found during the process. In conclusion, we hypothesize the creation of a single object that contains the restored edition plus documentation that puts the apparatus on view, in a very raw concept of the digital environment under construction.

3. Method

Our theorical background is based on a long film restoration tradition (Canosa, Farinelli, Mazzanti, 1997) with a philological approach deriving from the philology of printed texts, mainly focused on the analytical description of a book's physical characteristics and modes of production (Tanselle, 2020). Our methodological work involves disciplinary areas sharing common attention towards material culture and the relationship and inextricable links between formal and material artefacts (Fossati, 2018) that inspired the well-known historical evidential paradigm framed by Ginzburg (Ginzburg, 1986) and the pioneering application of this paradigm to film inspection by "excavator" Harold Brown (Brown and Bolt-Wellens, 2020). Furthermore, an effort to frame the relationship between formal and material artefacts was made recently in digital media studies in the shape of the forensic approach proposed by Kirschenbaum (Kirschenbaum, 2008).

In this perspective, to apply the philological method, the first step is to collect all the survived witnesses, and then to gain an adequate familiarity with them (Macé, 2015), that is the *recensio.* The next one is to describe and analyze them (that is the *examinatio*) and then to compare the texts they contain (*lectio*): this process is called *collatio* (Macé, 2015). The next and last phase is the *textual reconstruction*, made by editing and combining shots and sequences from different witnesses, according to the version chosen (in our case, the 1918 Italian version). The following paragraphs therefore describe the reconstruction process, according to the methodological steps just summarised.

Recensio. Table 1 sums up all the film elements found during the initial survey, carried out among several film archives, museum, and collections.

Witness "K" from Associazione Kinoatelje is a 35mm nitrate print on three reels, which is approximately 900 m long; it witnesses the 1918 Italian version and is the main reference for our reconstruction since it is a first-generation print, as attested by the edge codes and other clues; in addition, it includes handwritten information on the film edge about the colour palette. It retains most of the narrative order, the original Italian intertitles and the tinting and toning colours.

Witness	Title	Version	Format	Element	Support	Reels	Length	Colour
K Associazione Kinoatelje)	[La battaglia dall'Astico al Piave]	IT (1918)	35mm	Positive	Nitrate	3	913 m	Tinted and toned
G1 – G2 (Cineteca del Friuli/Lobster Films)	*La bataille sur le Piave*	FR (1918)	35mm	Positive Dupe Neg Dupe Pos	Nitrate Acetate Polyester	2	521 m	Tinted and toned
G3 (Cineteca del Friuli/Lobster Films)	*Da Capodistria a Fiume italiana*	IT (1918)	35mm	Positive Dupe Neg Dupe Pos	Nitrate Acetate Polyester	1	336 m	Tinted and toned BW
RM (Istituto Luce)	[La battaglia dall'Astico al Piave Ta pum]	IT (1927)	35mm	Dupe Neg Dupe Pos	Safety	4	1073 m	BW
MI (Cineteca Italiana)	*La battaglia dall'Astico al Piave*	IT [1927]	35mm	Positive	Nitrate	2	[402 m]	Tinted
TO (Museo Nazionale del Cinema)	*Dio segnò i confini d'Italia*	IT (1918)	35mm	CTN Positive	Acetate	1	540 m	BW

Tab. 1. Report of the witnesses collected after the film archive survey.

Witness "G" from Cineteca del Friuli, in Gemona, is a 35mm nitrate print further subdivided into three witnesses. "G1" and "G2" are two tinted and toned reels, respectively 290 and 230 metres in length, that witness the 1918 French version, whose first public screening in Paris is known to date from 7 August 1918 [2]; witness "G3" is a short fragment of the Italian version, found within the film *Da Capodistria a Fiume italiana*. During the 1990s, Cineteca del Friuli and Lobster Film duplicated and restored the film materials from 1918 (G1, G2 and G3) at the Haghe Film Lab in Amsterdam. Presently, the restored 35mm copies from the nitrate prints are preserved by Cineteca del Friuli, which houses the preservation master on acetate and the restored print on polyester, while the original nitrate copies are "missing in action", in other words, lost in some nitrate vaults in Paris.

Witness "RM" from Istituto LUCE in Rome is a 35mm duplicate negative and positive on safety stock, consisting of four approximately 1000 m-long reels, with flash intertitles; the black-and-white image contents and intertitles probably witness the 1927 re-edition of the 1918 version, preserving large segments which are missing in "K" and "G". Unfortunately, the materials from the 1910s–20s are no longer preserved at the Istituto LUCE in Rome.

Witness "MI" from Cineteca Italiana in Milan is a 35mm positive fragment on nitrate film consisting of two reels. It is close to the 1927 LUCE edition, as attested by the intertitles and the insertion of later documentary materials. Witnessing the 1927 version, it was recently duplicated by L'Immagine Ritrovata.

Witness "TO" *Dio segnò i confini d'Italia*, became part of the collection of the Museo Nazionale del Cinema in Turin during the 1960s but no information relating to the donor or seller is known. It retains just a few scenes of *La battaglia dall'Astico al Piave*, but it is important because it gives us a missing intertitle with the relative scene of the 1918 Italian version. It was about 540m long and printed on negative film from which the museum printed a positive on triacetate film. In 2015 the museum decided to make a 2K digital scan of the CTN. Unfortunately, all the original information has been lost.

We made further comparisons with other films from the end of the 1920s onwards, such as *Resistere* (1918), *The Other Army* (1917), *Il piave mormorò* (1934), *Guerra Nostra* (1928), *Gloria – La Grande Guerra* (1934), and, like witness "TO" described above, we found them to contain minor parts of *La battaglia*, identifying relationships and contaminations between several films from the period.

We carried out the *recensio* on film as well as photographic and private archives, journals and so on. Indeed, the survey of non-film materials should not just be considered ancillary or secondary work to support, validate and aid the restoration and reconstruction tasks. Instead, it is a core activity central to placing the film artefacts (both in conceptual and material terms) in an intermedial and cultural chain and network. In other words, it frames our research objects as contemporaneously archival, archaeological and historical artefacts within an entangled approach to preservation and restoration.

Our primary sources included the *Gazzetta Ufficiale del Regno d'Italia*, whose reviews attest a first screening of the French version of *La bataille sur le Piave* in Paris on 7 August 1918. Others are the many newspapers that demonstrate the continued circulation of the film, probably in the LUCE re-edited version, with the name *La battaglia dall'Astico al Piave*, till 1933 [3]. As seen, these findings prompt many doubts even about title of the film itself. Furthermore, we identified many primary sources such as texts and volumes of the time, diaries of the men who experienced these events, military reports, photographs, periodicals, etc. and matched them with the photographic documents produced in the same period as the film and the information about the activity of the Film Department [4] of the Italian Royal Army to establish precise correlations between the filmed sequences. This allowed us to reconstruct the days of the second Battle of the Piave and to date and locate most of the sequences in the film. The intersection of images and related captions circulating in the press of the time, such as *L'Illustrazione Italiana* and *La Guerra* series, both published by Fratelli Treves, enabled us to identify not just the same moments in the war operations and the same places of the battle, but also the key characters of the events, shown from different and complementary angles. Furthermore, the cover page of *La Guerra* special issue resembles the title blocks and the intertitles of the film. This comparison work also helped us exclude from the collation some passages of film footage present in the "RM" or "MI" witnesses but not consistent with the first Italian edition.

Fundamental support for the research was given by consulting diaries and sources in museums [5], most of which are accessible through the European Film Gateway (EFG). For example, we consulted the diaries of Major Maurizio Rava [6], preserved in the Museo del Risorgimento in Milan, in which he transcribed important takes from the film. Equally as important in this research phase was the knowledge of some experts of the historical period under investigation [7], which helped us identify, localize and date some sequences, over which there were still some doubts. This enabled us to decide whether to include those parts in our final reconstruction or not.

Examination and collatio. When a large number of witnesses are collected, such as in our case, each one of them requires comprehensive and meticulous study in order to highlight the innovations transmitted by two or more of them (and conversely to isolate deviations in the single versions), variants and errors (generally called *loci critici*) in order to identify and reconstruct the *restitutio textus*.

The restorer must look at the material and production methods, tinting and toning, splicing techniques, etc. to make choices consciously and with a "critical eye", like in an excavation (Carandini, 2000). In other words, a direct and instrumental diagnostic investigation of the artefact has to be made (Venturini, 2007b). The descriptive-analytical study of the physical characteristics of films has a long history, which partly derives from the pioneering application of the so-called evidential paradigm by "excavator" Harold Brown (Brown, 2020). A particularly important step in our workflow was the production of apparatus documenting the witnesses using a descriptive and morphological approach to the material artefacts, in order to produce both isomorphic and non-isomorphic descriptions.

The isomorphic descriptions consist of visualizing the artefact with different instruments. While the habit of using digital interfaces and "surrogates" progressively reduces opportunities to actually touch the physical artefacts, our field deals with this issue as the very latest in the long history of the mediation and representation of artefacts. Indeed, the historiography of material culture has learned how to operate from disciplines such as palaeontology and archaeology, which abound "not only in artefacts from the past, but also in ways to document and study them [...] visual media are indispensable in the process of documentation, that is, the practice of transforming things from the past into manageable and malleable forms" (Olsen et al., 2012). Three different ways of documenting "things from the past", such as film artefacts, supported our work: screeners, edge-to-edge scanning and "repro-set" shootings.

Screeners, to quote again from the archaeological field, are "proxies of our vision of the past" (Olsen et al., 2012) which allow historical practice, and especially practice on material culture and physical artefacts acting as intermediates, to come closer, as proxies [8], to us (Figure 1). The proxies of each witness indicate the frame number, which has been added to simplify identification and identify each one for the following documentation activities. This kind of visualization facilitates comparisons between the witnesses, even when they are not physically in the lab, as well as the non-isomorphic description as we will see below. Furthermore, we must consider that our screeners come from dpx sequences originating from different digital sources (such as from different film scanners, digital routes and laboratories) and that the witnesses were printed through different photochemical routes and laboratories.

Fig. 1. example of a proxy file taken from the reel 2 of witness "K" on which we have added the frame reference number (1453) to make it univocal.

Edge-to-edge visualization, practised in Udine since the early 2000s, could be framed as a mode of visualization grounded on the philological tradition and an equivalent to the so-called "mechanical" or "photographic" edition of a manuscript or a book (Venturini, 2007a). Edge-to-edge scanning is "digital representation of the complete film strip as opposed to the sequence of frames provided by conventional film scanners (which ignore the rest of the film strip area)" (Gschwind, 2002). It allows archivists, restorers and scholars to observe and analyse various pieces of information, such as the edge codes or other handwritten annotations. For our study, it was particularly useful for those witnesses ("RM" and "MI") that we were not allowed to observe directly but we needed to analyse for the reconstruction choices (Figure 2).

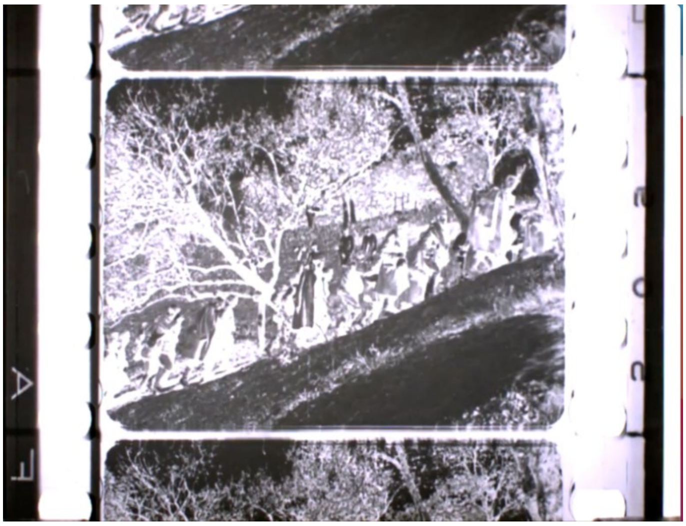

Fig. 2. example of an edge-to-edge taken from reel 1 of witness "RM" (frame 3093); even if it is a negative copy, it is possible to identify the overlapping of the positive perforations; it shows the Producers' Edge Marks "AGFA" on the left and the numbers "509" that are a part of the edge code, on the right.

Moreover, edge-to-edge representation and visualization relate a different media history, which is what we are looking for. "Repro-set" photographic documentation could be seen as a first and consolidated example of a diagnostic approach, originating from those used in the fields of traditional cultural heritage. It is an adaptation of the set-up proposed by Barbara Flueckiger to obtain diagnostic documentation using the photographic technique.

To date, we have produced documentation of the practices leading to the current morphology of witness "K" by taking pictures of all the useful evidence, such as splices, colour indications on the film edges and the brand of the film manufacturer, which will help us with the textual and visual reconstruction. Furthermore, this kind of documentation of the damage, errors or defects occurring in the copy will help us to distinguish them in the digital restoration phase (Figure 3).

For witness "G", the "repro-set" documentation was created with the sole purpose of mapping the colours reproduced on the copy through the Desmet process. This will be used as a reference for the reproduction of the tinting and toning colours in the reconstructed version. All the files produced have been made for different purposes and helped us with the non-isomorphic description.

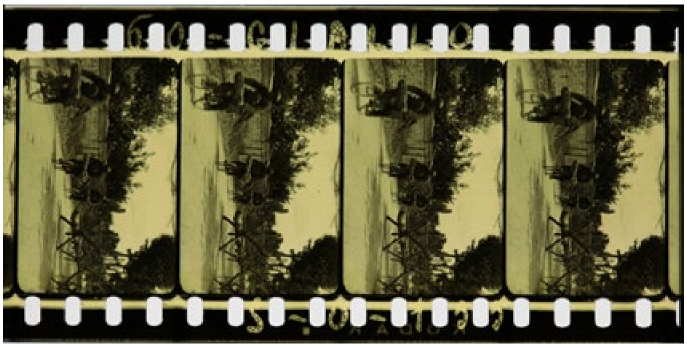

Fig. 3. example of a "repro-set" documentation with the handwritten indication for the tinting color to print "60-GIALLO" and the identification code of the film "S–O–155". It is also possible to see the edge code KODAK ▪ that allows to date the film strip to 1917. Picture taken at La Camera Ottica Lab of the University of Udine.

Non-isomorphic documentation is the description of the artefact through découpage and annotations. In a genealogical and archaeological perspective, before being thought of as equivalent to a present-day metadata recording and digital annotations, the non-isomorphic description is based on ancient layering tools such as so-called découpage. On one hand, this is a prismatic theoretical concept, as recently re-framed by film scholars such as Kessler, Barnard and Le Forestier, which has grown up since the outset of classical European film theory (Le Forestier, Barnard and Kessler, 2020). In this meaning, découpage is seen as an anatomical and entomological approach to the formal and material artefact that can be used in order to dissect it. On the other hand, a second and specific meaning of découpage, which has played a particular role and function since the time of the inception of film culture in the 1920s and 30s, is the sceneggiatura desunta (usually translated in English as "technical screenplay"), a framework for understanding a film as a whole, both as a formal and conceptual structure and as a more concrete architectural artefact (May, 1939). More specifically for our interests, it is philological and archival attention to historical artefacts in an age of scarce study resources. In this perspective, to apply the philological method in order to critically frame the film tradition is to dissect and examine film as an organic and formal structure. Far from being a mere tool for textual analysis, the non-isomorphic description aims to document a material and editorial layout and at the same time lays the foundations for its reconstruction and transmission.

In practice, we created a first non-isomorphic description in Excel files in which we describe, annotate and report several pieces of information. By keeping the physical editing with the handwritten annotations on the borders as a reference, we transcribed the numbers of the scene/intertitle and its colour indications, the references to the first and the last frames in the proxy files (and the count of the frames) and/or the visual recordings produced through the "repro-set" documentation devices.

4. Results

We meticulously analysed all the witnesses, each of which retains its own specific material and cultural history. We deemed it very useful to subdivide the alterations into damage, errors and defects in order to create a series of rules of engagement for the subsequent restoration operations: both damage and errors can be amended because they are part of the later history of the film artefact; defects must be preserved since they are part of the original (Brandi's "Duration") and they describe how technical limits and/or specific non-normative practices can shape the film right from the start (Canosa, 2001).

Textual reconstruction. After the *découpage* of each witness, the non-isomorphic collation and annotation were reported in an Excel file. We then based the reconstruction on the numbering of the scenes. This was done in an isomorphic way through non-linear multitrack editing programs and with multiscreen displays on DaVinci Resolve (Blackmagic) to compare all the witnesses with each other and identify the best element for our reconstruction. In this phase, we recognized variants and errors (*loci critici*) which needed to be resolved by applying mechanical law or conjecture (*iudicium or emendatio ope ingenii*).

Witness "K" turned out to be the best first-generation element for the reconstruction of the 1918 Italian version. If we found shots and sequences in several witnesses or if the images were too degraded to be clear and usable (the end of reel 2 of "K" suffers from gelatine and base decomposition), editorial choices were made by weighing up the quality of the image and the completeness of the scene, comparing the number of frames and preferring "G" for its temporal proximity to the reference witness and for the considerably higher image quality. When the scenes of "K" were shorter, but the sense was not lost, we always preferred a higher image quality and did not insert the few missing frames from other witnesses. In part, after a careful comparison of every witness, the missing sequences were found in "RM" and "G". From witness "MI", however, we chose the final sequence of the film since it is longer than the others and qualitatively better. Very recently, we finally found what we believe to be the lost scene corresponding to intertitle 26 in witness "TO" [9]. In addition, we are working on the comparison and inspection of twelve DVDs found in the George Eastman House Collection preserved by the Library of Congress and on a nitrate negative fragment very recently discovered at the Cineteca Nazionale in Rome, which, among other different materials, preserves a few missing shots, including the fourth Italian intertitle [10].

As regards the intertitles, we decided to maintain the original ones from the Italian 1918 version as surviving in "K". They display the code "R37" in the bottom-right corner to identify the film, which is the same for the Italian and the French version (in which an "F" has been added for French); in the bottom-left corner, it is possible to see the number of the intertitle, which helped us to find them in other films too, as was the case for intertitle 26, recently found in the film *Dio segnò i confini d'Italia* preserved by the Museo Nazionale del Cinema in Turin, which allowed us to add the corresponding sequence. Where missing in "K" but found in "G", we did not opt for a digital simulation and reconstruction of the title block, font and structure, but decided to report only the text and the numbers of the intertitle and the film on a neutral background, with the texts in square brackets. For the translations from the French, as a reference we took the intertitles found in the 1927 Italian version (witness "RM") or non-filmic documentation such as the captions of the photographs produced at the same time by the Film Department of the Italian Royal Army, censorship approval, the intertitles list, and so on. We made the same decision to keep them as neutral and identifiable as possible within the filmic text for the intertitles attributed to the film found in witness "RM".

One of the *loci critici* we discussed during the reconstruction phase is the first four missing Italian intertitles. We found them in the French 1918 version, but they are the other way round and they do not fit with the Italian 1927 version (Figure 4).

Fig. 4. The four intertitles from the French 1918 version follow an unruly order but they are the only existing proof of the first intertitle. The number in the bottom-right corner identifies the film (R37, the same number for the Italian and the French version) and the version information (F, for French) while in the bottom-left corner it is possible to see the number of the intertitle: 3-2-4-1.

In order to reconstruct them, we had to rework the witness and ask many questions about how to deal with them since we do not have documentation supporting the choice to change the order. We should suppose it is due to the different importance of the Italian monarchy in France, which made the film information (title and director) more important, while in Italy the presence of the portrait of the King and other Generals of the Royal Army forced the audiences to stand up and pay tribute. Furthermore, the fourth intertitle identifies the "PREMIERE PARTIE" of the film, but during the film there are no other indications about where it ends or the overall number of parts in witness "K" or "G"; only in witness "RM" is the third part indicated, but we are not sure whether it should be taken it into account since it is a later and very contaminated version.

Lastly, we created a timeline including all the scenes and intertitles and, at the moment, we are working on restoring them through the digital intermediate route. Then, we will record it back on film to reproduce the tinting and toning through the Desmet method and scan the 35mm colour print for conformity at least between the photochemical and digital theatrical copies, which could not be achieved otherwise. However, we will produce a first release in DCP, applying the Desmet digital process for the reproduction of the 1918 tinting and toning palette, using the handwritten annotation on the edge of witness "K" as a reference since these notes come from the original camera negative. Here is another of the *loci critici*: in several cases, the indication does not correspond with the real colour in the surviving print, or the shades are different when the same colour is indicated (Figure 5).

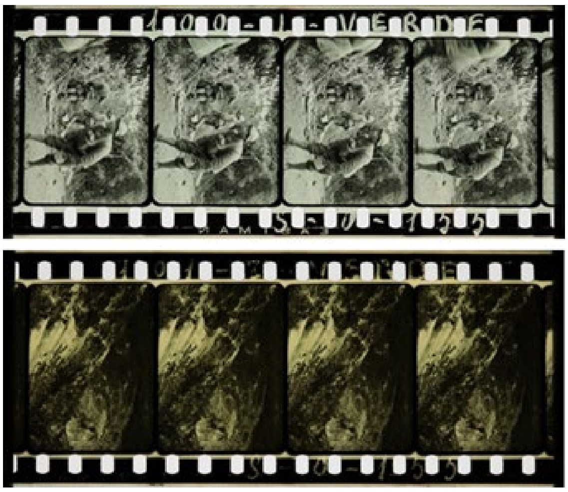

Fig. 5. Even though the indicated color is the same and the shots are in succession, they appear in two different colors. Above: shot n. 100 – Green Tinting (from witness K – reel 2 – frames 7931-7934) with the handwritten indication "100 – I – VERDE"; below: shot n. 101 – Green Tinting (from witness K – reel 2 – frames 7949-7952) with the handwritten indication "101 – I – VERDE"

We will have to discuss which shade to take as reference for the reconstruction and we will probably use the shots made with the "repro-set" documentation as a reference. Furthermore, we will screen the Italian ("K") and the French ("G") 1918 versions and make a comparison between the colouration of each scene, and we will discuss which colours to attribute to the "RM" scenes, since they are from a black-and-white negative duplication.

5. Conclusions

At present, the reconstruction covers more than 90% of the film (more than 1170 metres out of the 1255 metres recorded by the censorship visa), which is an exceptional result that can indirectly resolve and clarify the relationships and contaminations between several films and documents from the period.

In conclusion, as is more and more easy to understand, despite having chosen the 1918 Italian version as a reference, our aim is not strictly focused on the canonical reconstruction and restoration of this single chosen version. Rather our aim is to give an account of the restoration process of the final product and of the many different practices that shaped the multiple originals, the many relationships among the sources, the different genealogies, as well as the accidents, contaminations and finally the archival status and provenance of the film materials. Hence, we intend to build up a web-based historical-critical digital environment for the films and to document the film restoration process. In this environment, it will be possible to see the restored film like a normal cinemagoer, but, according to the audience's interests, it will also be possible to watch the original materials, analyse the variants and see the analogies or differences among them, while explaining the *loci critici*; to see the restoration interventions and make before-and-after comparisons; and also to see both the edge-to-edge and the "repro-set" documentation, and, obviously, all the non-filmic sources on which our reconstruction is based.

6. Conflict of interest declaration

The authors of this paper state that there are no conflict of interest including financial, personal, or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, their work.

7. Funding source declaration

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9. Short biography of the authors

Serena Bellotti is a PhD student in History of art, cinema, audiovisual media and music at the University of Udine. She is working at the restoration of *La battaglia dall'Astico al Piave* (1918), carried out by University of Udine and at the restoration project of *Spedizione Franchetti in Dancalia* (1929) in collaboration with Istituto LUCE.

Simone Venturini is professor at the University of Udine and one of the founders of La Camera Ottica lab. He is the scientific coordinator of the FilmForum and director of Udine's IMACS. His research interests include history and theory of film archives, film restoration, media archaeology and production studies. He published in Springer, Berghahn, AUP, Carocci, Marsilio, and journals such as JFP, Cinéma&Cie, and Bianco e Nero.

Notes

[1] Film title: Battaglia dall'Astico al Piave (La). Produced and distributed by the Film Department of the Italian Royal Army. Metres: 1255; censor visas: 13649; requested on 5 November 1917; approved on 11 July 1918: http://www.italiataglia.it/search/opera (Last accessed: 5 July 2021).

[2] Gazzetta Ufficiale del Regno d'Italia, 8 August 1918.

[3] "Kinema", June 1930; "Il mattino illustrato", 9–16 June 1930 (23); poster announcing the projection of the film *La battaglia dall'Astico al Piave 1915-1918* in the Teatro Civico in La Spezia, 1933 (Preserved by Museo Centrale del Risorgimento, Id. Code: SIMP_071).

[4] The Film Department consisted of both the photographic and the cinematographic sections. They shared vehicles, equipment and shot several of the same contexts and events from similar points of view.

[5] Museo della Battaglia in Vittorio Veneto; Museo Storico Italiano della Guerra in Rovereto and Museo Centrale del Risorgimento in Rome.

[6] Starting in January 1917, and for remainder of the First World War, he directed the Army Cinematographic Section of the Press Office of the Supreme Command (Rome, Archive of the Historical Office of the Army General Staff, F1, Cs, Uv, b. 299, note 15 May 1917)

[7] We have talked to Camillo Zadra, director of the Italian War History Museum in Rovereto, the "Battaglia del Solstizio" Historical Cultural Association, Elena Nepoti (Imperial War Museum) and Alessandro Faccioli (University of Padua).

[8] In computer science, a proxy is an intermediary machine, while in digital post-production, a proxy is a "duplicate file of a project's source footage, a transcoded file that's smaller in file size and at a lower bitrate than the original". Etymologically, the concept of proxy is related to "procuracy", from the Latin *procuratio* "caring for, management", and *procurare* "to manage", in short, the agency of "one who acts instead of another". Lastly, proxy also recalls an idea of proximity, due to the etymology of "proximus", wherein the idea of "nearness" and "vicinity" does not so much recall what is near in terms of closeness to the origins but instead close to us: the "latest, the most recent; the next, the following".

[9] This evidence came from our talk with Alessandro Faccioli (University of Padua), whom we would like to thank.

[10] We want to thank the president of the Cineteca del Friuli, Livio Jacob, for his advice about the Library of Congress materials and Alberto Anile, Sergio Bruno, Valentina Rossetto and Maria Assunta Pimpinelli for their help about the material preserved at Cineteca Nazionale.

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Modern methods for the visualization of lenticular film colors

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ABSTRACT

Some of the first home movies shot in color used a 16mm lenticular film produced by Kodak from 1928 to the late 1930s. This very special film stock called Kodacolor is embossed with an array of hundreds of vertical cylindrical lenses that allowed recording color scenes on a black-and-white panchromatic silver emulsion. There are multiple possible methods to extract the color information from the film images. Scanning the silver emulsion in high-resolution and letting a software extract the encoded color information represents an efficient method to obtain digital color images from these historical motion pictures. In this context, a new approach based on artificial intelligence has demonstrated to be more efficient for the localization of the lenticular screen than other previous methods. An alternative solution consists in digitizing the color images while these are created with the original optical method. While this last approach has the advantage of better representing the original historical appearance, it requires specific equipment and skilled operators.

KEYWORDS Lenticular film, Kodacolor, Color reconstruction, Deep learning, Film digitization

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1. Introduction

This paper presents and compares two novel approaches for reconstructing the color content of 16mm Kodacolor lenticular film. The first approach uses artificial intelligence to localize the color information in the digitized silver emulsion and provides a new modern tool to access lenticular films in color. The second approach reconstructs the color with an optical method, separating the color components by means of a moving slit that sections the entrance pupil of the imaging system used for the digitization. The close analogy with the original projection setup allows to consider the latter optical reconstruction a positive color reference.

2. Historical context of lenticular film

Since the birth of cinema in the mid 1890s, inventors and researchers set out to apply techniques of color photography to motion pictures. However, decades had to pass before a practical solution to record color information on motion pictures was developed.

In the 1920s the industrial exploitation of 'autonomous colors' such as tinting and toning was at its climax (Yumibe 2012), but at the same time a series of two- and three-color photographic processes were trying to improve their results and finally enter the market. Color processes based on temporal synthesis reunite color separations on the screen by displaying them in the same rapid succession as they have been recorded. The primary colors were added to the black and white separations either by filtering the projected light with a spinning filter wheel, as in Kinemacolor (Kindem, 1981), or by tinting the individual film frames, as in Friese-Greene (Bedding, 1909). Since the color separation images were taken at slightly different times, the reproduction suffered from pronounced color fringes around moving objects.

The lenticular film process, on the other hand, produced three color separations taken at the same time, and recorded them in a single film frame. Kodak was the only company that successfully produced lenticular film at an industrial scale. The film was marketed from 1928 under the name Kodacolor. However, most of the inventions behind the process have been made before the company acquired the rights to exploit the technique (Capstaff and Seymour, 1928).

The fundamental ideas behind the lenticular process for the photographic reproduction of colors can be found in the work done by Liesegang before the turn of the century (Ahriman, 1896) and by Lippmann a few years later (Lippmann, 1908). Liesegang envisioned a 'pixelated' spatial encoding of colors with a perforated screen, while Lippmann described in detail the structure of a lenticular film that would allow a better representation of reality. In the early 1900s Berthon combined the two concepts and started endeavoring the application of the lenticular color process to moving pictures (Berthon, 1910). In 1909 he patented a set-up including a tripartite red-green-blue filter as part of the imaging lens combined with a lenticular structure in front of the light sensitive panchromatic black-and-white film. The realization of this optical design had some major challenges. For instance, the lenticular structure engraved on the celluloid base defines the resolution of the image, so the lenticules had to be minuscule. For the technical implementation on an industrial scale, Berton found the assistance of Albert Keller-Dorian, who was the director of a company with expertise in engraving techniques (Jacquet-Loew, 1923). Berton intended to produce a film with minuscule lenticules either in a honeycomb-like shape (Fig. 1) or as a linear array (Berthon, 1910). The Keller-Dorian-Berthon process was patented in 1915 (Keller-Dorian and Berthon, 1914) but the first World War delayed the development. The cooperation continued until the death of Keller-Dorian in 1924, resulting in no more than some short experimental shots.

In 1926 a short film was successfully produced (Ede, 2013). However, the scarce success of the financial investment forced Berthon to sell the patents to Kodak, who instead managed to develop the Kodacolor film product in a comparably short time.

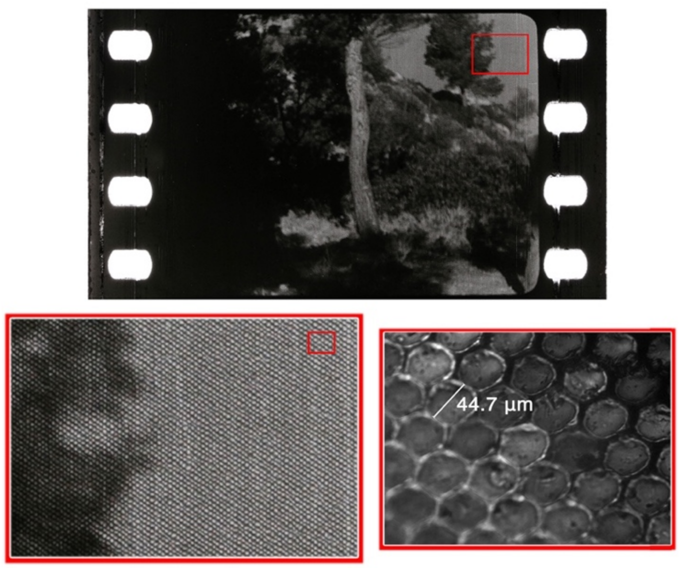

Fig. 1. A 35mm frame of a Keller-Dorian sample with a 'beehive' lenticular screen, visible in the underlying enlarged details.

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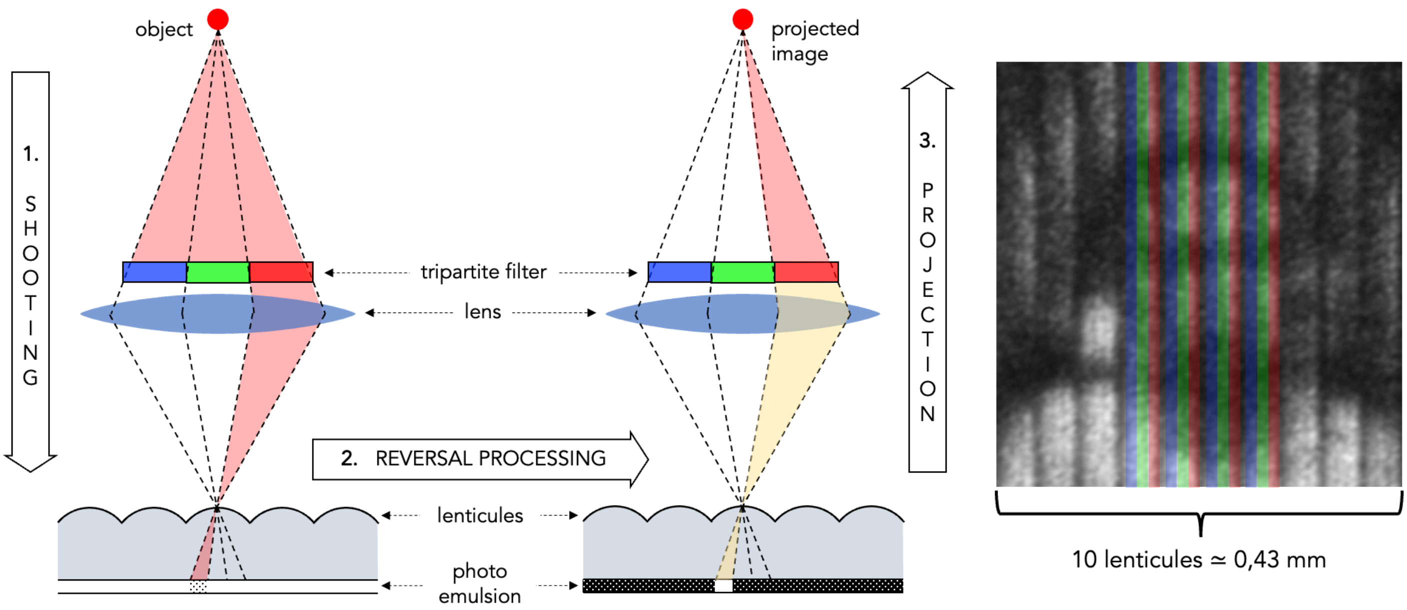

Fig. 2. Kodacolor lenticular film system – Left: Diagram describing the three stages of the lenticular color reproduction—shooting/processing/projection—for an 'object' represented by a red dot. Right: Front view of the processed photo-emulsion with superimposed stripes that indicate the location of the color separations.

The result was a 16mm reversal film with a linear vertical lenticular screen, aimed at amateurs, which was released in 1928. AGFA was working on a very similar product, called Agfacolor, which was ready to hit the market in 1932 (Eggert, 1932). However, no trace of any actual footage shot by amateurs could be found by the authors so far. The process was likely abandoned before its release.

A widespread market success was necessary for a novel color technique to survive for a sufficient time and have a significant impact on the landscape of cinema. If a new color process allowed to use existent hardware for film recording and projection, it had more chances of success (Jacquet-Loew, 1923), while additional costs of specific equipment—that could become obsolete in a short period of time—would likely dissuade exhibitors and amateurs alike to adopt novel processes. Also, the possibility of producing copies for distribution was an essential requisite for the success of a film technique (Mitchell, 1951). Kodacolor did not have these requirements, and it also had limitations in (i) image brightness—typical of all additive color processes—(ii) image detail and (iii) color gamut. After some success in amateur filmmaking, these limitations determined a quite sudden decline when a superior product was introduced by the same company. The introduction of chromogenic colors in the form of Kodachrome was a game changer for the film industry, and all other existing color processes on the amateur market rapidly disappeared. A wide color gamut could be reproduced by Kodachrome with subtractive synthesis, producing images with high level of detail using standard recording or projection equipment. Therefore, lenticular film rapidly lost appeal and Kodacolor disappeared from the market towards the end of the 1930s.

2. Characteristics of Kodacolor film

The lenticular system is based on the possibility to partition the entrance pupil of the lens into three separate parts, given the fact that the whole area of the entrance pupil uniformly contributes to the image formation. Additive primary colors (red, green, and blue) are assigned to each part using a tripartite color filter (Fig. 2-left). The camera lens focuses the image on the film and the color components are recombined, but their light arrives at the focal point from different directions. The tiny cylindrical lenticules focus the tripartite exit pupil of the camera lens on the film emulsion, so the color components expose separated areas of the film emulsion.

In the 10 mm wide image area of the 16mm Kodacolor film there are around 230 vertical lenticules. The motion picture was captured with the red-green-blue filter in front of the camera lens. The lenticules' focal length corresponds to the film thickness. A camera equipped with a 15 mm lens and a f/2 aperture allowed the color components to expose the photographic emulsion separately (Capstaff, Miller and Wilder, 1937). After exposure, reversal processing created positive silver-based images with spatially encoded color information:

the silver densities associated to the red, green, and blue components lie side-by-side underneath each lenticule (Fig. 2-right). The value of the color component is inversely correlated to the local amount of light-absorbing silver.

Fig. 3. Kodacolor ad suggesting a setting for the appreciation of the films (Movie Makers Magazine, 1928).

In the original procedure, the colors of lenticular film were displayed with a regular 16mm projector equipped with a tripartite filter similar to the one used during shooting. The projection was rather dim, and it could be only shown to a few people in a small projection setting (Fig. 3). Nowadays, the original filter attachments for cameras and projectors are hard to find, and analog projection is a threat to the unique reversal originals due to shrinkage and fragility of the film material. It is therefore difficult to display these films with the original procedure.

4. Numerical color reconstruction

The transformation of the image content into digital form enables a viable way to make these movies available to the public, while at the same time it preserves the image content that is otherwise subject to decay due to the aging of the film material. An efficient approach to obtain digital color images from lenticular film is to scan the film in high-resolution—with the emulsion facing the imaging system—and let a software extract the encoded color information. In 2013 two independent works were presented in different fora (Reuteler, Fornaro and Gschwind, 2013; Aschenbach, 2013), the first of which was conducted in the framework of the SNF project doLCE at the University of Basel. The software reconstructs the color accomplishing two main tasks: (1) the localization of the lenticular screen, and (2) the conversion of the side-by-side silver densities into RGB values.

4.1. Localization of lenticules' boundaries

The lenticular screen is quite clearly discernible as a regular vertical pattern overlaying the photographic image (Fig. 4-A). The numerical localization of the dark lines that mark the boundaries of the lenticules (Fig. 4-B) is essential to find and allocate the color information from a monochrome emulsion scan. The automatic localization with signal processing is sometimes complicated. The lines are not necessarily perfectly vertical and straight already from the film fabrication or became damaged and warped due to aging. Geometric distortions and defocusing might occur during scanning due to film misplacement or optical aberrations of the imaging system. In addition, the silver particles constituting the photographic image obscure the lenticular pattern in all dense areas of the image. The doLCE software positively localizes the lenticular borders and efficiently reconstructs the colors in certain cases (Reuteler and Gschwind, 2014). However, when the above-mentioned complications are relevant, the proper localization of the lenticular screen is error-prone and often fails.

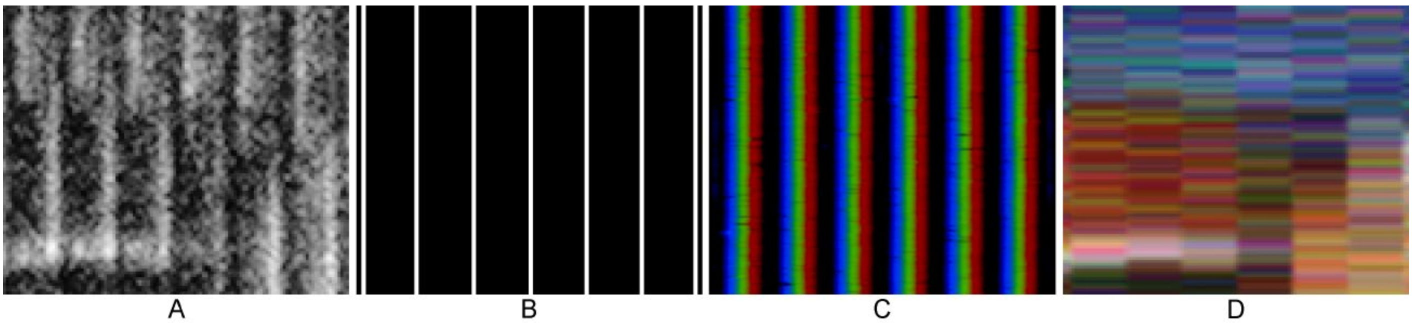

Fig. 4. The color reconstruction process – A: The input image. B: The lenticules' boundaries. C: The position of the color components. D: The final color image.

Instead of seeking to improve the success rate by introducing additional parameters to the existing software and making it more flexible, it was found convenient to adopt a completely different approach. A database of successful reconstructions carried out by doLCE was used to train a new computer algorithm called deep-doLCE (Trumpy *et al.*, 2021; D'Aronco *et al.*, under revision). The dataset of successful doLCE reconstructions was treated with techniques of data augmentation, so the training makes deep-doLCE able to handle the typical situations in which doLCE failed.

4.2. From grayscale to RGB

Once the lenticular boundaries have been accurately localized, the gray levels of the monochrome image (Fig. 4-A) have to be converted into color. This conversion is performed with a series of convolutions and pixel wise operations based on the spatial locations of the three color components (Fig. 4-C). The proper location of the color components with respect to the lenticule boundaries have been determined by recreating the original optical setup for projection and shining white light "backwards" inside the projection lens. In this experimental setup, the macro digital image reported in Fig. 4-C was captured from the emulsion side of the lenticular film.

The extracted RGB values are assigned to all the pixels localized within the lenticule in the specific row (Fig. 4-D), resulting in a pattern with horizontal stripes. The same 'stripy' pattern is also found in the images resulting from the optical color reconstruction.

5. Optical color reconstruction

An alternative approach to obtain the colors of lenticular film in digital form is to use an optical setup equivalent to the historical assembly. To perform the digitization directly, however, the color images must be focused on a much smaller area—corresponding to the image sensor—than the projection screen. The image structure of the color image captured in this configuration has the advantage of bearing a closer resemblance to the original projected image than the digital color reconstruction described in Sec. 4.

Nevertheless, the significant differences between the modern and the historical setups must be considered. The historical setup requires a wide-open lens aperture (f/2), otherwise the light intensities of the lateral red and blue components get attenuated in comparison to the central green. The large aperture was also an advantage for the lenticular process both in recording—due to the limited film speed—and in projection—due to the limited image brightness. In the modern setup for digitization, a macro lens with a wide-open aperture may produce a significant longitudinal chromatic aberration, such that it becomes impossible to find a common focus for all colors.

The problem caused by the chromatic aberration is solved with an approach that reconstructs the color by optical means, but it extracts the color components as separate images with the same spectral composition. Instead of replicating the original process with the tripartite color filter and a digital color sensor—as depicted in Fig. 5-A—a slit is used in front of the imaging lens, exploiting the fact that the color components of lenticular film are all black-and-white. The slit lets the light expose the sensor for one color component at a time, while the area corresponding to the other colors is covered. Three monochrome images are captured in succession with the slit in the three different positions, as depicted in Figs. 5-B. The digital images are assigned to their respective color channels (B1 to R, B2 to G, and B3 to B), so correct color images are obtained.

There is no focal mismatch between the color channels, and the longitudinal chromatic aberration is excluded by using a narrow band light source. In addition, the described method has the advantage that the exposure of the three images can be optimized independently. However, the digitization speed is reduced compared to the classical approach (Fig. 5-A), as three consecutive images have to be taken for each film frame.

While carrying out the described scanning operation, an accidental property of the information recorded by the lenticular system was made evident. In line with early Lippmann's idea (Lippmann, 1908), the horizontal difference in position between the blue and the red color channel produces a shift in perspective of the recorded image content. When the monochrome color separations are reproduced by assigning them to the left and the right eye respectively, the perceived image receives a moderate but clear stereoscopic effect. The lenticular process involuntarily records depth information which can be made visible today with stereoscopic visualization.

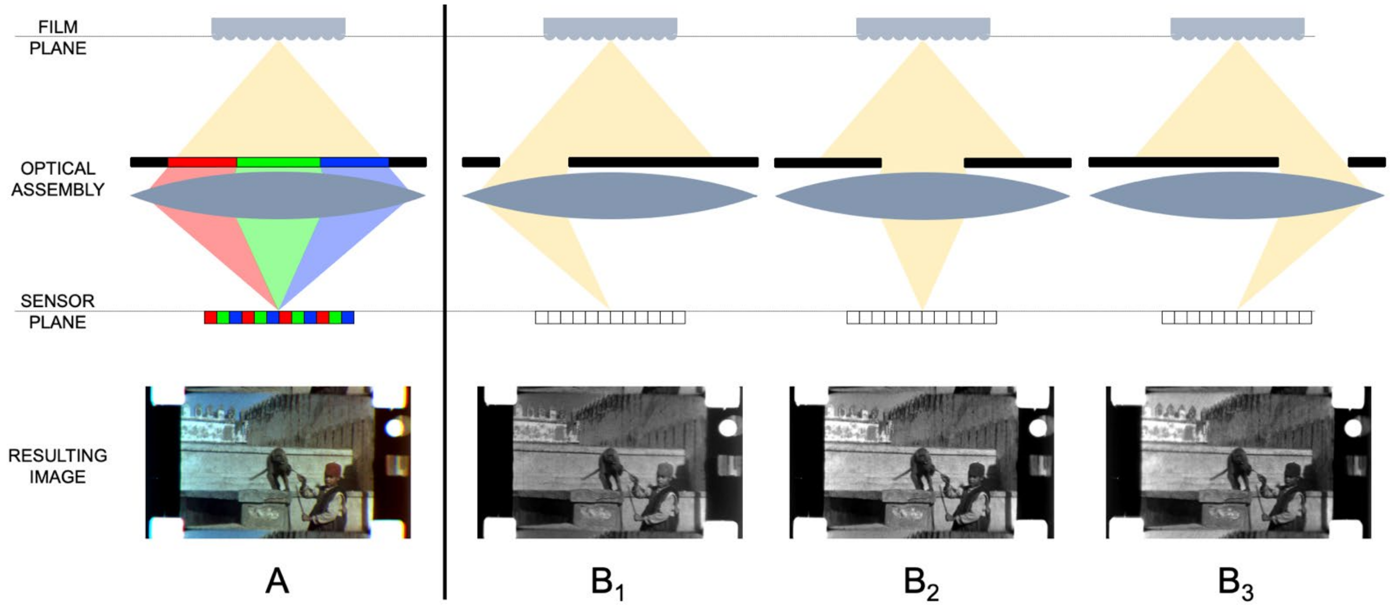

Fig. 5. Representation (not in scale) of the digitization process of the optically reconstructed lenticular color. A: Single image capture with a color image sensor and the tripartite color filter. B: Triple image capture with a monochrome image sensor and a moving slit.

6. Color correction

In order to obtain digital colors that properly represent the original analog projection of Kodacolor lenticular film, the images resulting from the digitization must be assigned to the proper RGB space. It is thus necessary to define the "*Kodacolor1928*" RGB space, which is calculated from the transmittances of the original color filter for projection. Transmission spectra were measured with a double-beam spectrophotometer (Shimadzu UV-1800) and colorimetric calculations (CIE, 2005) were performed considering the 1931 CIE 2° standard observer (CIE, 2019) and the irradiance spectrum of a typical film projector (Kinoton FP38), which was measured with a spectroradiometer (Konica Minolta CS-2000). The resulting CIE xy chromaticity values of Kodacolor1928 are R = [0.6991, 0.2900], G = [0.2569, 0.6687], B = [0.1399, 0.0704], and W = [0.2997, 0.3025]. The diagram in Fig. 6 displays the CIE 1976 UCS values (Hunt and Pointer, 2011) of Kodacolor1928 in comparison with DCI-P3 (SMPTE, 2011), which is commonly used in digital cinema projection.

In order to generate image files that convey the proper color information, the color values in the Kodacolor1928 space are converted to a standard RGB space for correct visualization. The whitepoint of the lenticular RGB space (XYZ = [0.991, 1, 1.315]) does not correspond to any standard whitepoint, therefore a chromatic adaptation transform (CAT) is necessary (Moroney *et al.*, 2002).

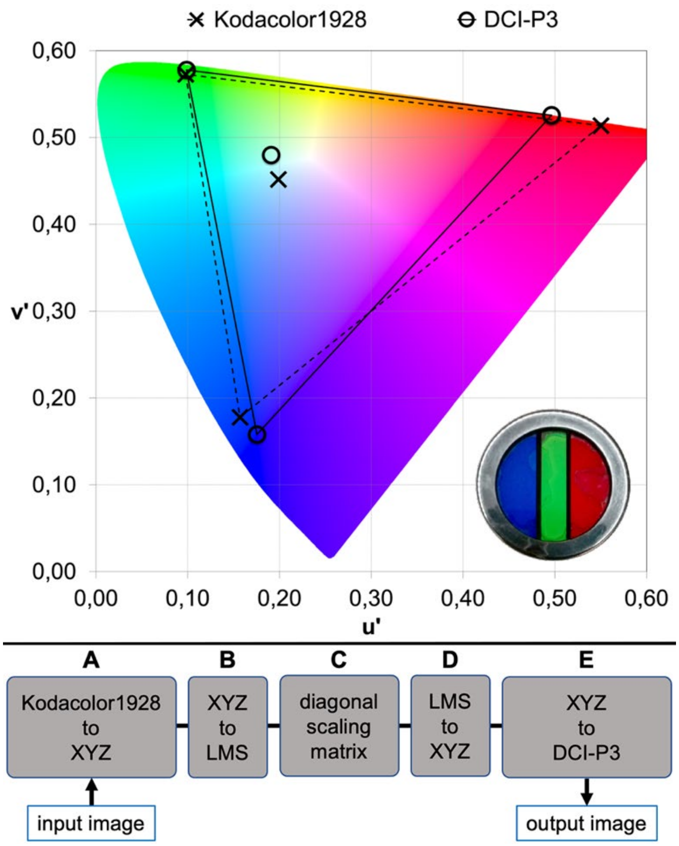

Fig. 6. Top: Chromaticity values of Kodacolor1928 space derived from the transmittances of the filter for projection (reported in the plot) in comparison with DCI-P3. Bottom: The five-step process for the color correction of digitized lenticular films.

In view of the linear von Kries model (Brill, 1995), the adaptation scaling must be performed at the cone response level (LMS), and therefore the color space conversion requires five steps, which are reported at the bottom of Fig. 6. The colorimetric specifications of Kodacolor1928 define the first 3-by-3 matrix, which provides the XYZ values of the RGB input image (step-A). The conversion from tristimulus to cone response and back (step-B and step-D) are the 3-by-3 matrices of the CIECAM02 Color Appearance Model (Moroney et al., 2002). The chromatic adaptation consists of the scaling factors resulting from the ratios between the LMS values of the destination and provenance whitepoints (step-C). In the present work we chose DCI-P3 as destination space, whose colorimetric specifications define the last 3-by-3 matrix (step-E) (SMPTE, 2011).

7. Results

The results of the methods described in the previous sections are reported in Fig. 7.

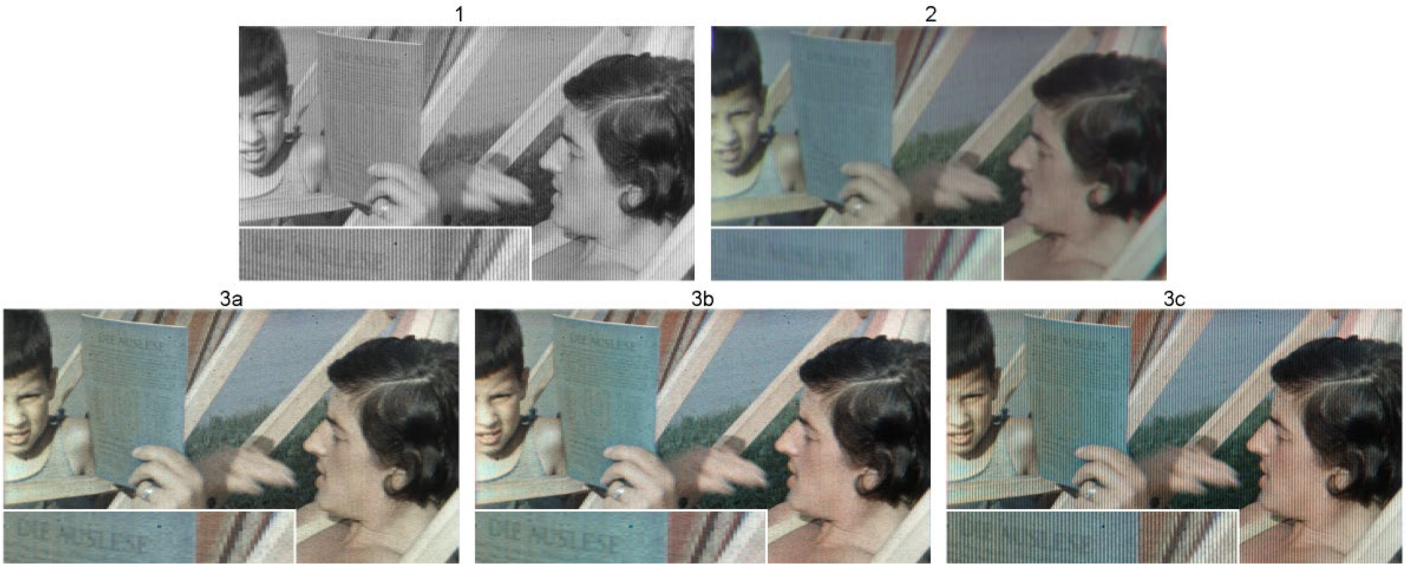

Fig. 7. Digital images of a lenticular film frame with inset enlargement. 1: Black-and-white scan of the film emulsion. 2: Slit scan. 3a: Output of deep-doLCE. 3b: Output of deep-doLCE after color correction. 3c: Merge of luminance from 1 and chrominance from 3b.

The scan of the film emulsion (Fig. 7-1) has an image structure that is characterized by the silver-based film grain and by the regular vertical pattern of the lenticules. In the color image resulting from the slit scan described in Sec. 5 (Fig. 7-2), the film grain is not visible, but the pattern of the lenticular screen is still evident. The image has a limited sharpness and the readability of the magazine title “DIE AUSLESE” is reduced. The color image resulting from the digital reconstruction with deep-doLCE described in Sec. 4 (Fig. 7-3a) has a very good readability, thanks to the effective interpolation approach developed by D’Aronco (D’Aronco *et al.*, under revision) and to the attenuation of the lenticular screen pattern. The color correction described in Sec. 6 (Fig. 7-3b) enhances the reds, owing to the prominence of the Kodacolor1928 space in the red region (Fig. 6-top).

Image 3b of Fig. 7 has a high level of image detail and accurate colors, but it lacks the image structure given by the film grain and the lenticular pattern. This situation suggests applying a method to transfer the image structure of the black-and-white scan to the color image. The method can be borrowed from video technology, separating the luminance and the chrominance using the YCrCb color space (Poynton, 2003). The extracted color information is converted to YCbCr, and the luminance channel Y is replaced with the black-and-white emulsion scan. This operation provides a ‘robust’ image structure to the image (Fig. 7-3c) that can be found appealing when the image is visualized on a big screen.

8. Conclusion

The projection of lenticular film with the original historical equipment is nowadays difficult to implement. Regardless of the approach adopted, the digitization of Kodacolor deliver a result that necessarily deviate from the original

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viewing experience. A bright, sharp image can raise concerns in terms of restoration ethics (Trumpy *et al.*, 2018), but it must be considered that the original screenings of lenticular film were always of poor quality and the new digital version can trigger a rediscovery of precious amatorial footage.

The close analogy between the original projection setup and the optical reconstruction described in Sec. 5 allows to consider the colors resulting from the optical reconstruction a positive reference (Fig. 7-2). Deep-doLCE provides a new modern tool to access the color of lenticular films and the resulting colors are sufficiently close to the reference (Figs. 7-3). The software is robust, successfully localizes the lenticular screen and provides convincing colors. As soon as the testing phase will be completed with more lenticular films, and the computational pipeline for final look of the reconstructed image is finalized, the software will be made available as an open-source project on publicly accessible repositories.

9. Conflict of interest declaration

No financial/personal interests have affected the authors' objectivity and potential conflicts do not exist.

10. Funding source declaration

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12. Short biography of the authors

David Pfluger holds a PhD in physical chemistry. After working in cinema post-production, he entered the field of time-based media preservation. He has been part of several projects in the field of film and video conservation. In the current Scan2Screen research project he is part of the technical team developing a multispectral film scanner specifically aimed at the challenges of color film preservation.

Lutz Garmsen - Filmmaker, media artist, designer, and lecturer for experimental and animated film. With a strong background in analog film and optical printing, since 2003 Lutz started working on experimental film digitizers. Since 2019 he collaborates with Prof. Barbara Flueckiger to design, test and improve a versatile multispectral scanner.

Giorgio Trumpy - Imaging Scientist with solid experience in bridging the gap between art and science. His fields of expertise span from optics to spectroscopy, from colorimetry to image processing, from heritage conservation to visual arts. Currently Associate Professor at NTNU and Research Scientist at the University of Zurich.

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Fine Arts on Film: The Hand-Painted Work of Stan Brakhage

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ABSTRACT

This paper will approach the topic of color in cinema by examining the case of the hand-painted films made by experimental filmmaker Stan Brakhage. Specifically, I will present the example of some hand-colored pre-print elements belonging to the National Cinema Museum in Turin and preserved at the Haghefilm lab in Amsterdam in 2011. I will argue that these films challenge traditional understandings of cinema by belonging simultaneously to the realm of film and to that of the fine arts and will show the consequences of this liminal position both at a practical and a theoretical level. In particular, I will explore the challenges related to the preservation of some of these films, and will relate them to broader issues of originality, medium specificity, and philological recreation of experimental cinema practices.

KEYWORDS Cinema studies, Film preservation, Experimental cinema, Stan Brakhage, Hand-painted film, Originality

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1. What Is Cinema? Old Questions, New Answers

Starting in the early 2000s, the introduction of digital technology in the realm of cinema has rekindled scholarly interest in the ontology of the medium. Questions like "What is cinema?", which seemed to have lost their appeal for the academic world, have attracted renewed attention on the part of film theorists as soon as digital technologies started supplanting analogue ones. While some scholars have decried the end of cinema in the digital age, others have seen in the digital revolution only one of the many technological transitions that cinema has been going through since its birth. Following the need for a compass to help navigate such turbulent times, works of classical film theory such as André Bazin's famous collection of essays on the ontology of cinema have been recovered from their decades-long neglect to be reread and reinterpreted in the light of the changed technological landscape; concurrently, different disciplines have been integrated with film theory in order to provide new answers to deep-rooted questions.

As I have argued elsewhere, including the practice of film restoration and preservation in discussions over the ontology of cinema can contribute to a fuller understanding of some of the issues raised by the recent technological transition (Negri, 2016). For instance, film preservation engages issues of originality, medium specificity, and mechanical reproducibility by virtue of its being the only type of restoration in which the end-product is a copy. If it might seem arbitrary to operate a distinction between an original and a copy when dealing with an art that is based on technical reproduction, it is also true that, from a film restoration perspective, any copy of a film is an original in and of itself, insofar as any copy displays technological and historical peculiarities that render it unique. Digital technology hardly changes this; if anything, film preservation highlights some continuity from the analogue era by showing that certain technological elements cannot be reproduced regardless of whether the restoration is performed digitally or analogically (Fossati, 2018).

A particularly relevant example of this mechanism is provided by experimental cinema. By breaking the rules of mainstream narrative filmmaking in its modes of production, distribution, and exhibition, experimental cinema emphasizes the complexity of cinema's nature and the need for a broader and more flexible understanding of the medium. Because of the lack of standardization of experimental cinema practices, the preservation of experimental films can be incredibly challenging while also highlighting complexities and contradictions that are integral to cinema itself.

In this essay, I will examine the case of Stan Brakhage's hand-painted films by focusing on some film elements related to his *Spring Cycle* (1995), owned by the Museo Nazionale del Cinema in Turin, Italy, and preserved at the Haghefilm film lab in Amsterdam in 2011. I will argue that Brakhage's filmmaking practice blurs the line between cinema and the fine arts, and that this hybrid nature can be best appreciated by looking at the preservation of his films. Acknowledging Brakhage's hand-painted work's liminal position affects our understanding of cinema by broadening the range of forms that the medium can assume at different stages of its existence, including the archival one.

2. Stan Brakhage's Experimental Filmmaking

When Stan Brakhage began experimenting with fully hand-painted films in the 1980s, he was already considered one of the founding fathers of American experimental cinema. According to experimental cinema scholar P. Adams Sitney, it is generally impossible to attribute the stations of evolution of avant-garde cinema to the invention of a single filmmaker, with one notable exception: the forging of the lyrical film by Stan Brakhage (Sitney, 2002, p. 155). As Sitney writes,

The lyrical film postulates the film-maker behind the camera as the first-person protagonist of the film. The images of the film are what he sees, filmed in such a way that we never forget his presence and we know how he is reacting to his vision. […] In the lyrical film, as Brakhage fashioned it, the space of the trance film, that long-receding diagonal which the film-makers inherited from the Lumières, transforms itself into the flattened space of Abstract Expressionist painting. […] The film-maker working in the lyrical mode affirms the actual flatness and whiteness of the screen, rejecting for the most part its traditional use as a window into illusion. (Sitney, 2002, p. 160)

In other words, the lyrical film as conceived by Brakhage is an expression of the subjectivity of the filmmaker, who strives to reproduce on the screen his own visual perception. This idea is ripe of consequences: while initially still working in the legacy of Maya Deren, who also tried to translate subjective experience into film, Brakhage has nonetheless been pushing for a more radical reinvention of film form since his early works. A consequence of this stylistic and ontological transformation is the refusal of Renaissance perspective, embodied by the diagonal composition which had been a staple of traditional filmmaking since the Lumière brothers, in favour of a flat space that is more influenced by Abstract Expressionist painting, particularly that of

Jackson Pollock, than by narrative cinema. The screen is therefore no longer a window into an illusory world, but rather a canvas for the filmmaker's vision.

Brakhage's idea is further clarified in his own writing. In the often-cited opening of his book *Metaphors on Vision* from 1963, Brakhage explains the drive behind his filmmaking work:

Imagine an eye unruled by man-made laws of perspective, an eye unprejudiced by compositional logic, an eye which does not respond to the name of everything but which must know each object encountered in life through an adventure in perception. How many colors are there in a field of grass to the crawling baby unaware of 'Green'? (Brakhage, 1963, p. 30)

Here, Brakhage calls for the recuperation of the perceptual innocence of a child who has not yet entered the realm of language and is therefore able to distinguish all the colors that adults group under the linguistic label of "green". The search for this pre-linguistic innocence includes a rejection of the laws of perspective, which Brakhage sees as artificial and arbitrary. His commitment to lyrical cinema, in different ways throughout his life, is Brakhage's way to go back to that irretrievable unprejudiced vision.

In the earlier part of his career, Brakhage experimented mostly with montage, superimpositions, the splicing together of positive and negative film and the manipulation of the film stock both at the development stage and in post-production. In *Reflections on Black* (1955), for instance, the influence of Maya Deren's "trance film" is still clear, but the search for a new form that could explore more directly the dynamics of vision and consciousness starts emerging. *Reflections on Black* portrays the inner vision (or hallucination?) of a blind man. While most of the shots are quasi-naturalistic, the use of repetitions, jump-cuts, and flashes of light betray the subjective nature of the man's perception. In *Reflections on Black*, Brakhage also starts working directly on the film stock to achieve effects that the camera alone could not produce. The man's blindness is symbolized by star-shaped figures scratched directly on film so as to erase his eyes, or substitute them with a different type of metaphorical vision.

The direct intervention of the artist on film materials is key to Brakhage's poetics, as a way to both work around the limitations of the camera and leave a distinctly authorial mark on his work. From this perspective, the climax of Brakhage's research could not be other than cameraless films. After all, the lens of a camera is in itself an eye ruled by compositional logic, and color film stocks are manufactured to appeal to a taste that is already poisoned by socially-created expectations – in Brakhage's words, "that picture post card effect (salon painting) exemplified by those oh so blue skies and peachy skins" (Brakhage, 1963, p. 25).

Fig. 1. Reflections on Black (Stan Brakhage, 1955). The man's blindness is symbolized by star-shaped scratches on the film's emulsion.

The earliest and probably best-known example of this new inspiration is the cameraless film *Mothlight* (1963), a collage of organic material (leaves, seeds, flowers, insect wings) glued in-between two perforated 16mm Mylar tape strips – so that *Mothlight* is not only a cameraless film, but technically also a filmless film. Even though Brakhage replicated the experiment on 35mm with *The Garden of Earthly Delights* in 1981, this production process was too labour-intensive to become a staple of his filmmaking.

His hand-painted films, though radically different from these collage works, can be seen as embodying the same desire to portray a vision freed from the constrains of the camera, of color film emulsions, of culture in general. Brakhage had already began painting on film earlier in his career, but it was not until the late 1980s that he began making entirely hand-painted films on a regular basis. This shift in style is certainly due to practical reasons (making hand-painted films is cheaper as it leaves out the negative processing stage, it can be done without camera equipment, etc.), but the deep reason probably lies within Brakhage's later interest in what he calls "hypnagogic vision" – that is, what the eye sees when the eyelids are closed.

Hypnagogic vision is the climax of Brakhage's research on the subjectivity of perception. What is more subjective than one's vision when their eyes are closed?

It is important to remark that this kind of vision is different from imagination or fantasy; rather, it is a fully perceptual experience, free from any referent in the world outside of the seeing subject. It is pure color, the closest an adult can get to the "unprejudiced eye" of the child who has not yet learned that the grass is green. No cameras or color film stocks can possibly reproduce those images; only the hand of the artist himself can. In an interview, Brakhage himself links hypnagogic vision with painting, specifically Abstract Expressionist art. He said:

Somewhere after beginning to give attention to what I see when my eyes are closed, I recognised pattern likeness to Jackson Pollock's interwoven whirls of paint, and then I realised that I had seen it before […]. It began very quickly to touch some childhood memories. (Smith, 2017, p. 42)

From this excerpt, the connection between hypnagogic vision, abstract painting, and childhood perceptual innocence is clear. Only the direct intervention of the artist on the film strip can replicate what the artist sees in the most unmediated manner. Painting alone, however, is not enough as it lacks one key feature of perceptual experience: movement. For this reason, the film strip is more than a canvas, but is rather an object that fulfils its purpose only when projected.

Fig. 2. Spring Cycle (Stan Brakhage, 1995). Pre-print materials. Courtesy of Daniela Currò.

3. *Spring Cycle* (1995) and the Issue of Originality

From a production perspective, the 16mm film strips hand-painted by Brakhage can be considered pre-print materials – that is, film elements that are not supposed to be projected but are needed to produce the projection print. Unlike what usually happens with traditional narrative cinema, though, the processing of these films is rather complex and can be considered as part of the making of the film itself. An example of this complexity is provided by the instructions that Brakhage wrote to Sam Bush, lab technician and frequent collaborator of Brakhage, with regards to the printing process to be used for the 1998 hand-painted film *The Birds of Paradise*:

I want it ... printed thus: superimpose loops #1 and 2, then superimpose loops #2 and 3, then superimpose loops #1 and 3 ... (take each loop around long enough so that the MOBIUS effect of #1 and #2 has occurred at least once – i.e. each flipped once in the printing: you can also go into the frames of #1 and/or #2 [diagram here] as you, say, run the MOEBIUS loops through a 2nd or 3rd time. Then I'd like a brief (1 minute and a half minute) interlude where loops #1 and #2 superimposition and loops #2 and #3 supers are bi-packed, all; then, finally breaking open into a non-orange negative section of the above bi-pack on non-orange negative and finally loops #1and #3 superimposition on non-orange negative... P.S. DON'T frame-IN on the single perf #1 and #3 combination and/or on #3 at all in the print – i.e. let it be a kind of exact refrain in all this.

From this description, included in a private correspondence between Marylin Brakhage and Luca Giuliani (former head of the archive of the National Film Museum in Turin), it is clear that the hand-painted materials represent just one of the stages of the production of the finished film, and that Brakhage exerted complete control over every single step of the workflow. Given the enormous difference between the hand-printed strips and the finished product, which element constitutes the "original" film by Brakhage? The answer is not easy.

Mark Toscano has worked on several preservation projects of experimental films at the Academy Film Archive, including films by Brakhage. In his essay "Archiving Brakhage", Toscano goes over the artist's working habits in order to map possible preservation strategies for such complex productions. For instance, he describes Brakhage's habit of editing directly on the positive print, leaving the camera negative alone – if there even was a camera negative, given Brakhage's preference for reversal film. In this case, Toscano writes, the edited positive is the artist's original. (Toscano, 2006: 15) In this case, originality is placed in the author's idea of the finished work. The camera negative, which would normally be considered the best source element for a restoration, is only a necessary step to fulfil the author's creation, but it is not an original in itself. This is an example of how experimental cinema can diverge from traditional narrative filmmaking both in its practices and in its restoration processes, due to the frequent presence of an individual author and to the creative freedom governing every step of a film's making. As we will see shortly, the case of hand-painted films complicates this already complex scenario.

From this account, it is clear that originality in cinema is a manifold concept that shifts depending on the perspective adopted, and in turn influences the broader issue of the nature of cinema as a medium. This complexity emerges more clearly in film restoration, where it is necessary to define what is meant by "original" before undertaking the restoration project. For instance, a film might have been released in different versions, each of them "original" in its own right. The case of experimental films is even more complex since, as we have seen, there are many stages to the production of a film, each of them unorthodox compared to those of traditional narrative filmmaking and therefore revelatory of the artist's creativity and artistic vision.

In the case of hand-painted films the problem is even more complicated, as shown by the film elements related to *Spring Cycle*, a 16mm hand-painted film that Brakhage made in 1995 and sold to the National Film Museum in Turin in 1997. When the Museum decided to undertake a preservation project on *Spring Cycle* in 2011, it was necessary to understand exactly what the original printing process was and, concurrently, what was the nature of the elements in their possession. The materials conserved at the Museum consisted of four film cans with one short hand-painted fragment in each can. The title on one of the cans was *Spring Cycle*, while the other three had "Mobius" written on them.

An email correspondence with Marylin Brakhage clarified that "Mobius" was not a title, but rather a reference to the artist's technique. Brakhage used to tape film strips in the shape of a mobius loop, which is a loop with a half-twist in it, to be printed successively on the same film stock in a series of superimpositions. This is confirmed by the writing on the label on one of the film cans, reading "'SPRING CYCLE' loops A+B/ mobius B,C+ D". As Mrs. Brakhage recalls, "After receiving a print back from the lab, made from his painted film, from directions such as these, Stan would then make final edits and that, then, would serve as the original work from which an internegative would be made for further printing." The printing and editing stage are therefore integral part of the production process, and are controlled by the artist as much as the hand-painting on blank film. Brakhage himself was very clear on this. In his description of *Spring Cycle*, he wrote: "Note: I am the sole author of this film: Sam Bush of Western Cine Service, Denver, is a paid employee; and I've added the credit, at end, simply to fairly praise his workmanship". This shows how Brakhage considered the lab work to be part of the making of the film, a film of which he was the only author.

If, as Mrs. Brakhage writes, originality in this case should be attributed to the internegative made after printing the hand-painted strips according to Brakhage's instructions, what is to be made of the hand-painted strips themselves? Are they only pre-print elements like any other? The answer to these questions depends on the perspective we decide to adopt. If the focus is on the finished work, the film that is going to be projected as the author meant, then the hand-painted fragments are only one stage on the path towards the screen. However, this answer is clearly unsatisfactory; how can a work hand-painted by the artist himself not be considered an original? A different answer is possible, although it requires a shift in perspective from a conception of film as a series of images projected on a screen to one of film as an archival object. This new perspective would bring cinema closer to the fine arts, where a work is considered unique and irreproducible by virtue of its being the direct product of an authorial effort. In fact, Brakhage's hand-painted films cannot be mechanically reproduced in any way, as all their nature is indissolubly tied to their physical characteristics, including the materiality of their colors.

The National Cinema Museum preserved the moebius loops that Brakhage made in the production process of *Spring Cycle* at the Haghefilm lab in Amsterdam in 2011. Despite their status as pre-print materials, these film strips have been preserved as they were found – that is, without being superimposed one to the other as Brakhage indicated in his note to Sam Bush. Each of them was both scanned in HD resolution and photochemically duplicated on 16mm film stock using a Matibo Debrie contact printer with no wet gate, in order not to damage the original paint. The decision to preserve the loops in their original form testifies to the original status of these objects, which can be considered works of art in and of themselves regardless of their use as pre-print materials in Brakhage's making of *Spring Cycle*. Nonetheless, the outcome of this preservation, as it happens with any preservation work, is nothing but a reproduction. In the case of experimental cinema, because of the artist's direct intervention on the film strip, this paradox is more apparent; still, it is a paradox that informs any preservation work and shows cinema's own paradoxical nature as a medium based on mechanical reproducibility, and yet made of objects that are unique and, in many ways, irreproducible.

The example of Brakhage's *Spring Cycle* shows how any restoration of these materials, be it analogue or digital, is bound to produce a ghost of the original, with which it would share no more than its disembodied appearance. Rather than lamenting the loss of the object in reproduction, though, this scenario highlights the multifaceted nature of cinema, that cannot be reduced to one aspect or the other, but is rather the product of the interaction of different drives, materials, experiences, archival artifacts. At the same time, it shows some aspects of continuity between the analogue and the digital realm, insofar as, in both cases, the outcome of a preservation work shares only some features with its source material. If Brakhage's hand-painted work can be considered as fine arts on film, it is because some aspects of cinema can be likened to painting, including the uniqueness of some of the objects that can be found in archives. This perspective could open up new exhibition strategies, closer to those of the fine arts, which would highlight the value of the objects while teaching a new history of cinema where the film would no longer be only a story, but also a work of art not dissimilar from a painting.

4. Conflict of interest declaration

The author declares that there is no conflict of interest related to the publication of this essay.

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7. Short biography of the author

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The Relationship between Photo Retouching and Color Grading

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ABSTRACT

This paper deals with photo retouching and color grading. It proposes a simplified workflow for both of them. It also points the commonalities and the differences, and further explore the relationship between the two, including a phenomenological point of view as well as an aesthetic point of view. It also discusses the implications of that relationship in pedagogy.

KEYWORDS

Photography Retouching Workflow, Color Grading Workflow, Color Aesthetics, Phenomenology of the Creative Process, Pedagogy.

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1. Introduction

The aim of this paper is to explore the relationship between photo retouching and color grading. The idea of this paper came to life when I started to reflect on my practice as both a photo retoucher and a color grader, and trying to understand if I approached both in the same way, or if I had different modus operandi for each of them.

I am particularly interested in two aspects: (i) why do we make the decisions we make in a creative process, here in retouching a photo or in grading a film, and (ii) what are the aesthetic implications of this relationship between photo retouching and color grading. I am speaking from the point of view of a scholar dedicated to photography and film philosophy and aesthetics, but also from the point of view of a long-term practitioner as both a photo retoucher and a color grader. The work presented here is therefore the result of a constant dialog between practice and theory.

There are many publications about the aesthetics of photography (see for instance Costello, 2018) and the aesthetics of film (my favorites are Alekan, 2001, and Storaro, 2011; see also for instance Jarvie, 2015). There are a few publications about photo retouching (most of them are mostly guides about how to use the softwares) and color grading (see for instance the excellent Haine, 2019), but they are mostly technical. And this is mostly through online tutorials that ones learns to use photo retouching or color grading softwares. There are very few publications specifically about the aesthetics of photo retouching and the aesthetics of color grading, and these topics are sometimes vaguely touched upon in books about photography aesthetics and film aesthetics, or in books about photo retouching and color grading. But in my knowledge, no one has ever explored the relationship between the two. The main aim of this paper is to touch upon this relationship.

As far as color is concerned, there are a few excellent books about the theory of color (see for instance Mollica, 2012, or Bleicher, 2012).

The outline of the paper is as follows: the first part deals with photo retouching, and tries to answer the question of why we do it in the first place. Then, a simplified workflow for photo retouching is proposed, and a discussion about aesthetic considerations follows.

A second part then deals with color grading, and proposes a simplified workflow for it, as well as a discussion about aesthetic considerations concerning it.

A third part compares the two approaches, points the commonalities as well as the differences, and also shows how the two approaches can feed each other.

And finally a conclusion wraps-up the paper.

2. Photography Retouching and Color

Most professional photographers nowadays use softwares from the adobe suite. One particular program, Lightroom, has been developed with the photographer workflow in mind, and offers various ways to save a lot of time in the process. Even though the topic I discuss here is not related to the use of a particular software, part of how I do things might be.

There are also numerous plug-ins that exist today, whose job is to allow a professional photographer to save time. I am very fond of Color Efex Pro (and Silver Efex Pro for Black&White photography) [1].

2.1. *Why do we retouch a photograph*

Let us first go back to the time before the digital revolution. You did not have that many options to control the final look of an image. You had to carefully think at the moment of taking it (see for instance the visualization technique developped by Ansel Adams in Adams, 1995). And then, the rest of it was a matter of how you developed your film, and then how you printed the chosen picture. This was all chemical, and particularly for color photography, you would generally rely on a strong collaboration with a lab. Occasionally, some photographers would do their own developing and printing jobs, particularly in Black&White photography, but that was not the norm.

Today, retouching a photo is something a photographer can do on their own much more easily. All they need is to open the raw digital file inside a software, and then push buttons and see the corresponding result. This process is non-destructive. It has become entirely part of the creative process. Because there are so many possibilities now, you end up playing with the possibilities and expanding your horizons.

So why do we retouch a photograph? We do it to improve the look of the photograph, in terms of contrast, colors, framing, final look, etc. But we also do it to try new things, to play with the possibilities of the tools we use. Photo retouching is therefore an investigative process.

2.2. *What is the color component of photo retouching*

In this whole process, not everything is directly related to color, though most of it has an impact on how color is perceived. For instance, changing the exposure of a picture impacts the perception of color saturation: making a picture darker tends to make us perceive it as more saturated.

The first steps of a retouching workflow often deals with brightness and contrast. And then we start playing with color. We can do several things at this point. We can check the setting of the white balance, and if we are using raw files, we can choose a different white balance even after the picture has been taken. We can also tell the software where our real whites are and let the software change the settings accordingly. This whole process, called “removing a color cast”, consists in compensating for some technical limitations of the camera we used, or the circumstances of the picture.

There is then the possibility of wanting our picture to look a bit different colorwise. For instance, if you took the picture of a sunset, and you noticed that your camera tended to bring the whole scene a bit more towards yellow than pink or orange, you can then add a tint of pink or orange to make the picture look closer to what you remember or what you intended.

2.3. *A possible workflow for photography retouching*

Let me now propose a simplified workflow for photo retouching. First of all, as mentioned earlier, I mostly use Lightroom to do my work on pictures. With Lightroom, you can import images, sort them, define all sorts of metadata, retouch them, and then export them. I will deal here only with the part of the workflow that deals with retouching pictures.

I also want to point out a very important principle in art making. There are no immuable laws. Even when you have a workflow in place, occasionally you will choose to deviate from it. Besides, this workflow is also meant to be rethought, and hopefully improved with time.

<u>Photo Retouching Simplified Workflow:</u>

- **test the auto setting:** it consists in using a button that provides automatic settings for the given picture, based on some values that the software extracts from the image. Sometimes, the resulting retouching is close enough and I continue from there, and sometimes the original picture is closer to what I want and I then start with the original picture.
- **adjust the exposure:** it is possible at this stage to modify the white balance inside the software, but I rarely do it. It is because I have usually set the white balance up before taking the picture, and therefore rarely need to change it later. But this is a possibility that is worth mentioning. Personally, I often tend to lower the exposure a bit. I have found that, most of the time, the auto button tends to set an exposure that is a bit too bright for my taste. But occasionally, I will do the opposite, increase the exposure slightly. There are no rules. It is mostly a matter of experience and taste.
- **adjust the contrast:** I tend to prefer more contrasted pictures, because that makes them more pictural, more graphical, which is usually closer to my personal taste in term of images. For those first steps, auto, exposure, and contrast, I usually use my eyes only. Then, I rely mostly on the histogram, which is a diagram showing the repartition of the values of all the pixels of an image from black to white, and a bit on my eyes.
- **adjust the highlights and the shadows:** the idea behind those two steps is to occupy the whole range of brightness from black to white, in order to have the best possible distribution of pixels. This is not always the best option, but more often than not, it brings the image closer to a pleasing image.
- **adjust the texture, the clarity, the dehazing, and the sharpening:** these four sliders have to do with the granularity of the picture, and how it looks in terms of details. I barely change them, but often just a bit, to increase the crispiness of the picture.
- **adjust the vibrancy and the saturation:** we finally get to the color aspect of retouching pictures. I usually utilize two sliders to do it, the vibrancy slider and the saturation slider. In most cases, I increase both a bit and that gives me a richness in terms of color that I like. Occasionally, I will desaturate slightly, but only for very particular photos.
- **use the color efex pro plug-in:** I will then open the picture in color efex pro, and will play with some of the possibilities of this plug-in to enhance the picture. It is important to notice that part of the settings that I use prior to opening the color efex pro plug-in are decided with the use of the plug-in in mind. From experience, I know how to prepare an image before running the plug-in. If I was not planning on using the plug-in at all, I would make different choices. Once in the plug-in, I have many options. Some of them have to do with some creative techniques effecting contrast, other effecting color, and so on. Some of the looks are also mimicking some vintage looks.

2.4. *Aesthetics considerations for photography retouching*

I often wonder why I make the choices I make, or why photographers in general make the choices they make, in particular regarding color. One way to answer that question is by saying that a photographer remembers the scene he took a picture of, and consciously or subconsciously tries to match the picture and the memory of that scene.

A perfect example of that is when taking a picture of a sunset. The captured picture will always deviate from what was really in front of our eyes. And the temptation would be to correct the picture later, to make it as close as possible to what we remember.

But that would be forgetting that a picture is only a representation of reality. The truth is much more complex. When I retouch a picture colorwise, I try find the color treatment that would serve that particular picture best, that would enhance the power of evocation of that picture.

Concretely, there is a part of habit in the process. We tend to do things the way we are used to doing them. But how did we come up with this way of doing? This process is usually incremental. We first learn to do it through practice, on the one hand, and from learning, on the other hand. We can learn from someone, from a book, from an online course or tutorial. All these activities build up our artistic sensitivity, which is also ever evolving.

Then, once we have a basic workflow, we keep experimenting, and we keep learning from courses, books, tutorials. That process will constantly open perspectives, suggest other ways to do it, sometimes better ways, sometimes not. But as we gain knowledge about the process, be it in practice or by learning, we expand our horizons and the possibilities.

At the same time, we develop a way to adapt to a particular photo our own way of doing things, our own style. Maybe we try to match aesthetics we love, from photographers we admire. Maybe we are also trying to match other media, like painting or film.

In the end, there is something subtle guiding us in this quest for beauty, for the most aesthetically satisfying picture. It has to do with what motivated us to take the picture in the first place, what we want to express through that picture, something that has to do with some universal truth, but seen through the prism of our own experience and our own peculiarities.

Figure 1 is an example of a photograph before retouching (left) and after retouching (right).

Fig. 1. The image on the left is the raw picture, as taken with the camera. The image on the right is a possible version of the picture after retouching it.This picture is part of the series "Calanques".

3. Color Grading and Color

Let us move on to color grading. I got involved in it quite naturally. Because I had done a lot of photo retouching. Because I was making films. And because it made sense to me to do my own color grading on my film projects. And then I started doing it for other people.

3.1. *Why do we grade films*

There is a slightly different reason why we grade films, compared to photo retouching. In color grading, there is an important motivation which is to save shots. There are situations when the images recorded by the cinematographer present some technical problems (low light, important color cast, etc.). One of the goals of color grading is then to save the shot, that is, to bring it to a place where it can be used in the film without disrupting the flow of the storytelling.

The rest of the job pretty much resembles that of a photo retoucher, with one big difference: we are now working on moving images, that is, we are not just retouching one still image, or a series of a few images, but 24 or 25 or 30 images per seconds, from the beginning of a clip to the end of a clip, clip after clip, from the beginning of the film to the end of the film. This work is comparatively huge in terms of involvement and time, and there are also considerations about the unity of a shot, of a sequence, of a film.

3.2. *What is the color component of color grading*

As with photo retouching, the whole process of color grading does not have to do with color, although it can be argued that everything a color grader does impact color perception. But there are mostly two operations that directly have to do with color.

The first one consists in removing a color cast, that is, identifying what is supposed to be white and trying to bring those particular pixels back to white. It can also be done by using some particular scopes, called parade, which display the repartition of luminosity for each of the three sensors (red, green blue), and often allows to detect discrepancies between them, thus indicating a possible color cast.

The second one concerns finding the look of a clip, a sequence, or an entire film. This often includes considerations on whether the mood of that particular clip, sequence, or film should be colder or warmer.

3.3. *A possible workflow for color grading*

Let me now propose a simplified workflow for color grading. The software I am using is Davinci Resolve, which has imposed itself as the professional tool for color grading. It was first developed only as a color grading tool. Now, Davinci Resolve is an entire post-production suite. The workflow I propose here is not specific to Davinci Resolve though.

Also, as I stated previously for photo retouching, a workflow is a guideline. But there is no law preventing to occasionally deviate from that workflow. And a workflow is also here to be continuously improved.

<u>Color Grading Simplified Workflow:</u>

- **brightness / contrast / highlights / shadows:** for color grading, I prefer using curves, which is a tool I rarely use for photo retouching. The reason why I like curves in color grading is that it allows me to do several operations all at once, while using at the same time my eyes and the scopes. With some experience, it takes only a few seconds to correct the brightness / contrast / highlights / shadows of a clip all at once. To use the curves tool, I usually set up a point close to white and then move it until I get the expected result. And then I set a point close to black and do the same thing.
- **removing a color cast:** I use again the curves tool to do it, but this time, I use it color by color (red, green, blue). I will mostly use the scopes as a guideline, but I also keep an eye on the image itself.
- **secondary correction:** the first two steps are called primary correction, meaning they are applied to the whole image. A secondary correction is a correction that is only applied to a part of the image, for instance a face. It requires the use of a mask, and then tracking of the mask across the whole clip. This is used only when necessary as it is very time consuming to set it up and adjust it. This is due to the fact that you often have to check the mask frame by frame, and adjust it when it deviates from where it is suppposed to be set up, which often happens when the object that is tracked, for instance a face, is moving fast in the shot. It is often used to lighten or darken an area of an image, to make it more or less present. It is also used to adjust a color, for instance a skin color.
- **adjusting between clips and sequences:** this step consists in adjusting consecutive clips and/or sequences in order to smoothen the experience of the viewer. Sometimes, the opposite effect is sought after: increase the transition effect between one clip and another, or between one sequence and another.
- **working on the look of a clip / sequence / film:** the last step consists in working on the look of a clip, sequence, or film. This usually requires applying some additional effects on the images, often through the use of LUTs (Lookup Tables) which are preset tables allowing to apply entire looks and/or filters to clips. Color is often an important component of the look of a film. This is mostly due to the correlation between color and mood.

The last two steps can be inverted. It is sometimes possible to start working on looks before doing all the clips or sequences matching.

3.4. *Aesthetics considerations for color grading*

Again, the question that comes to mind is: why do we, as color graders, make the choices we make? The answer here is not much different from the one I gave for photo retouching. Habit is part of it, improving a process too, and matching a particular aesthetic we like.

But there is a big difference here. Photography is usually a one-person medium. Film is a collaborative medium and the color grader is not the only person making decisions on the color grading process. The director is also involved, quite often too the director of photography, and sometimes other people too (some producers, some studio executives). It makes the process more complex, and requires the color grader to be able to argue their choices, and also to be flexible enough to integrate the vision of other people, even when that vision contradicts their own.

Figure 2 is an example of a frame before color grading (left) and after color grading (right).

Fig. 2. The image on the left is the frame as it was captured by the camera. The image on the right is the frame after it has been color corrected. This frame was extracted from the music video "Emmanuelle".

4. A Dialog between Photography Retouching and Color Grading

Let us now investigate on the relationship between photo retouching and color grading. This is rarely done because it is not so common to find people who do both. I happen to do both, and I have consistently and often written accounts of my work as both. This led me to think that a good color grader has to be a good photo retoucher (the opposite is not necessarily needed). It is due to the fact that the building blocks of working on the look of a film is to work on the look of images.

Writing consistently on my work as both a photo retoucher and a color grader also led me to see a dialog between the two, pointing the similarities as well as the differences, and developing an understanding about the tight relationship between the two, and how they could mutually influence each other. This, of course, also has important implications from a pedagogical point of view.

4.1. *Similarities between photography retouching and color grading*

As you probably noticed, there are similarities in the workflows I presented for photo retouching and color grading. In both cases, we deal with the same first three steps: correcting brightness and contrast, correcting color, and applying a look.

Another similarity has to do with the kinds of tools we find in the softwares that we use to do these jobs. Even though color grading has a few additional tools, the tools we use for the first three steps are very similar. There are sliders, curves, and scopes (mostly a histogram for photo retouching).

Finally, aesthetic considerations about what makes an image beautiful and/or meaningful and/or impactful are also very similar.

4.2. *Differences between photography retouching and color grading*

Let us now investigate about the major differences between the two. The first major difference has to do with the nature of the medium. Because a film is a rapid succession of still images, there are important additional considerations to take into account when color grading.

First, at the very basic level, we color grade a clip and not a still image. It means we have to select the referent image carefully, if we want the correction to translate in a satisfying way to the other frames of the clip.

It also requires to test the correction we made on the referent image across the whole clip, by watching it entirely to see if there is anything else to adjust. This is particularly difficult when the nature of the material is changing drastically across the clip, as is the case for a long sequence shot.

In that particular case, it is often possible to have dynamic settings of some color grading parameters, that is, to have some parameters that can vary during the shot according to what happens in the shot.

We also mentioned earlier what is called a secondary correction. Of course, it is not uncommon to correct only part of a photograph when we retouch it. But with film, we are also concerned with tracking, that is, with the fact that this secondary correction has to be applied along a clip and not just to a still image, and to the right area of the image, frame after frame.

There is also the question of clips matching, which does not exist in photo retouching, except when we work with serial photography. When matching clips, it is not just the aesthetics of a still image that we are after, but also the aesthetics of an entire sequence. And that requires different analytical skills and aesthetic knowledge. This is equally true when matching the sequences of a film to give its visual unity to a film.

4.3. *The relationship between photography retouching and color grading*

I would like to expand the previous discussion about similarities and differences between photo retouching and color grading by exploring the relationship between the two a bit further.

Because the nature of the medium is not the same (still images versus moving images) and because the nature of the work is different (solitary work versus collaborative work), it is not uncommon to make some discoveries in one medium and then translating that discovery (when possible) to the other one. Some of my work as a photo retoucher has deeply influenced some of my work as a color grader, and vice versa.

Because the workflow is not entirely the same, and because the tools are not entirely the same, discoveries concerning aesthetics and also the use of tools and the workflow can happen indifferently in one medium or the other. This is also why a photographer can be influenced by a filmmaker and a filmmaker can be influenced by a photographer.

But this relationship goes much deeper. And this is something that is harder to explain since it is mostly phenomenological, that is, based on a lived experience [2]. It is a bit as if those two things were only one thing for me and, as I work on a photo, I mobilize knowledge from both the photo and the film worlds, and from both my experiences as a photo retoucher and a color grader. It is the same when I work on a film as a color grader. This is also the reason why I keep learning about photography to feed my film work, and why I keep learning about film to feed my photo work.

4.4. *Pedagogical implications of the relationship between photography retouching and color grading*

There are important implications of that relationship between photo retouching and color grading in the area of pedagogy.

I always have students of color grading work on photo retouching first, and I encourage them to keep doing so all over their career. First, because the problem of photo retouching is a simpler one than the problem of color grading, and a building block for it. But also because the questions you ask yourself as a photo retoucher, consciously or unconsciously, can inform to great lengths the questions you ask yourself as a color grader.

I also suggest to students of photography who are particularly interested and fluent in photo retouching to look into color grading as a career, or at least as a strong interest of theirs. This is due to the fact that working as a color grader can inform back on your process as a photo retoucher, and make you a better photo retoucher.

In those two cases, I am not only talking about the tools, and how you can discover various uses of them when going back and forth between photo retouching and color grading. I am also speaking about aesthetics, and the various parameters and aspects that contribute to all the decisions we make while photo retouching or color grading.

Those operations are very complex, and it takes a lot of times to refine the artistry. Any input that can help refine it is always welcome. And working in photo retouching can definitely help refine the artistry of color grading. And the same is true the other way around.

5. Conclusion

In this paper, I have dealt with photo retouching and color grading. I have questioned why we were doing it in the first place. I have then offered a simplified workflow for both.

I have also discussed the commonalities and the differences between the two, exploring the tight relationship they had with each other. I have also explored some implications of that relationship in pedagogy.

The next steps of this research would be to expand even further on the relationship between the two, as well as to develop further the implications for practice and pedagogy. In particular, it could be really interested to give some more detailed accounts of a phenomenology of photo retouching and color grading, and see where the creative processes in both activities intersect and diverge.

6. Conflict of interest declaration

The author declares that nothing affected their objectivity or independence and original work. Therefore, no conflict of interest exists.

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8. Short biography of the author

Ivan Magrin-Chagnolleau is an artist philosopher who has been involved in art making as well as academic research and teaching for most of his life. He is affiliated with the CNRS in France, and currently works with the PRISM Laboratory in Marseille, a joint-lab between CNRS and Aix-Marseille University investigating on the relationships between art and science. He is also affiliated with Chapman University in California. His interests include: the creative process and its phenomenological dimension, art and philosophy, aesthetics, artificial intelligence and creativity, art and spirituality.

Notes

[1] I owe the discovery of that plug-in to Rick Sammon (2016).

[2] For the readers who are insterested in learning more about phenomenology, you can read for instance Husserl, 1985, Husserl, 1992, or Merleau-Ponty, 1976.

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What about discoloration in plastic artifacts? The use of Fiber Optic Reflectance Spectroscopy in the scope of conservation

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ABSTRACT

Fiber Optic Reflectance Spectroscopy (FORS) is a well-established technique for the study of traditional artworks. Nevertheless, its application for the analysis of modern and contemporary materials such as plastics is still a pioneering line of research. In this work, the application of FORS for the discoloration assessment of cultural heritage plastics is presented. The spectroscopic method successfully characterized the discoloration of a selection of naturally aged historical plastic objects in situ, and the results of yellowing and fading measurements are discussed. Even though further research studies are required to elucidate the potentialities and limitations of FORS in the investigation of cultural heritage plastics, this study paves the way for its application as a preliminary tool for the detection of incipient and severe discoloration in the plastic heritage caused by polymer and colorant degradation (e.g. yellowing, darkening and fading). The results suggested that FORS may be considered a reliable method for in-situ rapid characterization and monitoring of cultural heritage plastics degradation phenomena in museums in the scope of collection care.

KEYWORDS Historical plastic objects, Discoloration, FORS, In situ analysis, Colorimetry

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1. Introduction

Man-made polymers are increasingly used in modern and contemporary art and plastic artifacts are now common in heritage collections worldwide. Those usually include designer pieces, artworks and mass-produced objects. Many plastics have stability issues that limit the lifespan and, at present, their conservation is a crucial concern in heritage science.

Plastics are available in a wide range of formulations and are generally made by mixing a base polymer together with property and processing modifiers (additives) (Salamone, 1999). This process also includes the coloring, and colorants (i.e. dyes and pigments) are commonly used for the mass coloration of plastics (Charvat, 2004; Müller, 2003; Webber, 1979).

Therefore, color is one of the key elements that determine the visual appearance of a plastic object and the study of its alteration is a research priority as a wide range of polymer-based objects already displays color modifications (Quye and Williamson, 1999; Shashoua, 2008, Lavédrine *et al*., 2012). Among the different causes of deterioration, light is one of the most effective. Following exposure to light, polymers and/or colorants may undergo different degradation phenomena and their alteration, alongside with surface soiling, can be responsible for the plastic discoloration. The degradation of the polymer and its consequent discoloration (yellowing and darkening) has been widely studied (Hawkins,1984; Allen and Edge, 1992; Rabek, 1995), while little is known on the fading of colorants (Allen and McKellar, 1980). The effect of light usually result in changes of the original objects' appearance. Besides chemical changes visible through color variation, the absorption of light may also induce physical damage resulting in the plastic surface embrittlement and microcracking (Micheluz *et al*., 2021).

The detection of the earliest stages of discoloration can support the preservation of entire collections and help to define better conservation strategies. To this end, in situ and rapid methods of analysis would be an ideal tool for performing a preliminary investigation of the objects.

Fiber Optic Reflectance Spectroscopy (FORS) is a well-established technique in the study of objects surfaces and color analysis of traditional artworks on parchment, paper, textiles, stained glass/windows, wall, canvas, and panel paintings. The interests in the application of FORS in studying plastic-based objects is testified by the increasing number of publications on the subject (Cucci *et al*., 2013; Izzo *et al*.; 2019; Pintus *et al*., 2021). However, to the best of the authors' knowledge, it has never been applied to the study of plastic discoloration in the cultural heritage field.

This study intends to present preliminary results of analytical study carried out using FORS on discoloration in naturally aged historical plastic objects. These data made it possible to insight into the discoloration that develops from polymer and colorant degradation. Color measurements were also made to characterize the color variation.

2. Materials and methods

2.1. *Cases studies*

The selection of case studies includes a series of food containers with a red lid made of polyethylene (PE) (Fig. 1i, ii) and polystyrene (PS) (Fig. 1iii), and a naturally aged white telephone made of acrylonitrile butadiene styrene (ABS) (Fig. 1iv), probably produced in the second half of the 20th century.

The red plastic elements and telephone were specifically chosen because show evident discoloration, namely fading and yellowing, respectively. Due to the presence of Portuguese inscriptions such as 'Grão' (chickpea), 'Arroz' (rice), a Portuguese production can be attributed to the food containers.

Those objects were gathered from a private collection, which includes more than three hundred objects entirely made of plastic elements. The collection contains items from Portuguese plastic industry from the 1930s to 2000s and was studied as part of the research project "*The Triumph of Bakelite - Contributions for a History of Plastics in Portugal*" (Callapez, 2017), which contributed writing the history of the Portuguese plastic industry (França de Sá *et al*., 2020).

Discarding surface effects such as grime, dust, deposits on the surface, substance migration and absorption from adjacent surfaces, the observed discoloration can most likely be related to light-induced damage. Unfortunately, information on past storage and exhibition history of the red plastic elements and telephone are not available and contributions of relative humidity and temperature to the plastic degradation cannot be excluded.

2.2. *Fiber Optic Reflectance Spectroscopy (FORS)*

FORS measurements were recorded using a reflectance spectroanalizer MAYA 2000 Pro (Ocean Optics, USA), with single beam optical fibers QR200-12-MIXED (Ocean Optics, USA), equipped with a linear silicon CCD detector Hamamatsu and a halogen lamp HL-2000-HP (20 W output) (Ocean Optics, USA) in the 380-1000 nm range. The analyses were obtained with 8 ms integration time, 15 scans, 8 box width, and acquired at 45°/45° measurement geometry. Calibration of the spectrophotometer was performed using a 99% Labsphere Spectralon diffuse reflectance standard.

2.3. *Color measurements*

Microflash mobile colorimeter DataColor (DataColor International, Switzerland) was employed for measuring the color of the red historical lids. The colorimeter is equipped with a Xenon lamp and the 1976 CIELAB color coordinates (L*, a*, b*) were calculated over an 8 mm diameter measuring area, considering the D65 standard illuminant and the 10° colorimetric observer (CIE 1964). The reflected specular component was excluded (SCE mode) in the measurements. The instrument was calibrated with a white (100% reflective) and black (0% reference) balance, in accordance with the DataColor calibration procedure. The white (porcelain) and black trap standards were provided by the manufacturer. The reported values are the average of three measurements, which proved to be sufficient to guarantee reproducibility. The color measurements of the naturally aged telephone were obtained from FORS spectra as the area of analysis was too small for the portable colorimeter. The 1976 CIELAB color coordinates (L*, a*, b*) where extracted from the Vis reflectance spectra (400-700nm) considering the spectral distribution of D65 standard illuminant and the color matching functions CIE 1964 standard colorimetric observer (10° standard observed) with 10 nm of step (Oleari, 2016).

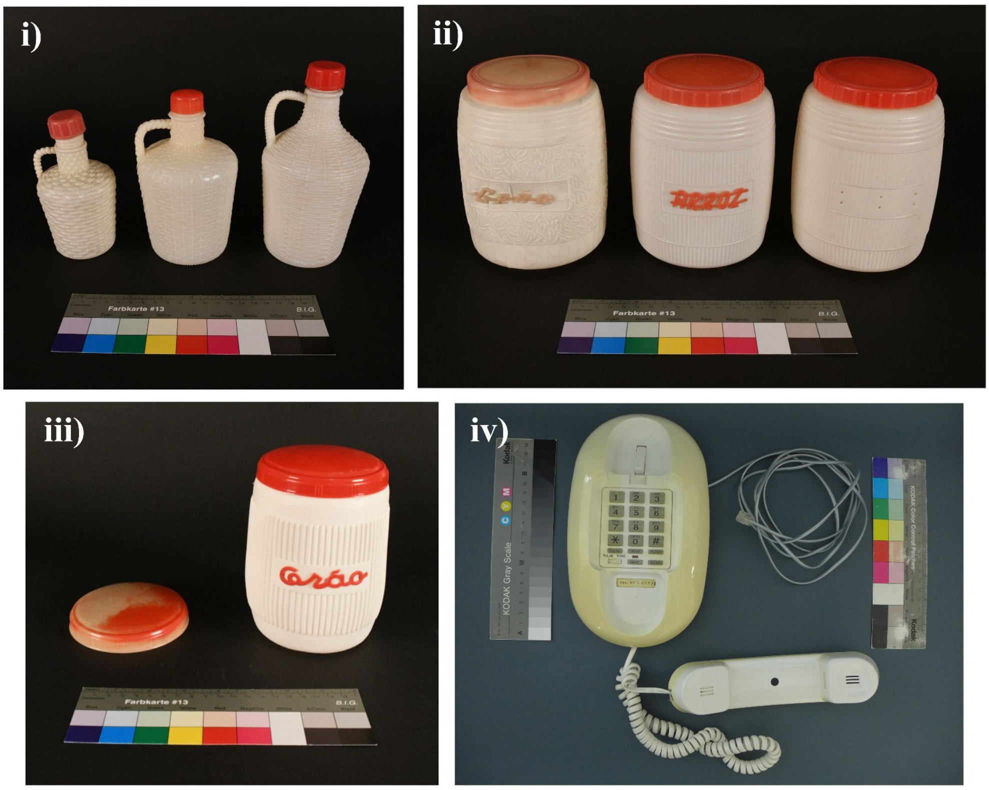

Fig. 1. The historical plastic objects under study, food containers with PE (i, ii) and PS red lids (iii), and ABS telephone (iv).

3. Results and discussion

In-depth material characterization of the red lids by means of infrared and Raman spectroscopy was recently conducted (Angelin *et al.*, 2021a) and the investigation revealed that Pigment Red 53 (5-Chloro-2-[(2-hydroxy-1-naphthalenyl)azo]-4-methyl-benzenesulfonic acid, $C_{17}H_{12}ClN_2O_4S^-$, C.I. n. 15585) is the main red colorant in mixture with Pigment White 6 (titanium dioxide TiO_2, C.I. n. 77891).

The synthetic organic pigment is found either faded (Fig. 2i, ii, iii) or well preserved (Fig. 2iii). Among the plastic samples, only lid **h** made of PS is not discolored (Fig. 2iii) which is characterized by the highest positive a* values and strong absorption in the blue-region (400-550 nm) due to π–π* and n–π* electronic transitions of its hydrazone/keto and azo/enol tautomeric forms, respectively (Hunger and Schmidt, 2018; Angelin *et al.*, 2021b). The s-shape profile of the spectrum was already observed for other modern red synthetic pigments based on *β*-naphthol (2-naphthol) - such as Pigment Red 1 (C.I. n. 12070), Pigment Red 3 (C.I. n. 12120), Pigment Red 48 (C.I. n. 15865), Pigment Red 49 (C.I. n. 15630), Pigment Red 57 (C.I. n. 15850) (Lewis, 1988; Feller, 2001). When fading occurs, significative changes in the FORS spectra and in the colorimetric coordinates are observed. The absorption in the blue-region (400-550 nm) gradually disappears up to the completely loss of the s-shape (Fig. 2). This matches with the loss of the red color and whitening of the plastic elements as confirmed by the color measurements which show an increase of the L* coordinates and a decrease of positive a* values (Table 1). Fading of *β*-naphthol-based Pigment Red 48 in artificially UV-aged polypropylene (PP) films showed analogous spectral and color variations (de Freitas Brito Cavalcanti and Silveira Rabello, 2019). The final color of the red plastic lids is determined by the superimposition of the individual contribution of the Pigment Red 53 and Pigment White 6 as the polymeric matrixes does not absorb in the visible range (indeed plastics are nearly colorless) (Webber, 1979). As fading of the plastic lids becomes more severe, a shift of the inflection point towards lower wavelength is observed along with the appearance of an absorbance band between 400 and 550 nm (Fig. 2i, ii). Similar trends in reflectance measurements were already observed when parent organic pigments were mixed in different proportion with titanium dioxide pigment (Lewis, 1988). It would be likely related to the increase contribution of the white pigment at the expense of the red colorant.

While most of the lids show a homogenous discoloration, the lids **d** (Fig. 2ii) and **g** (Fig. 2iii) are instead characterized by a spotty pigmentation. For these two objects, significant differences in the FORS spectra and colorimetric coordinates between points of same plastic lid were observed. Where the color is almost completely faded (points 1 of lid **d** and **g**), an increase of the positive values of coordinate b* was detected likely due to the contribution of the polymer yellowing.

Sample	L* (σ)	a* (σ)	b* (σ)
a	44.41 (0.04)	25.63 (0.07)	8.68 (0.10)
b	41.13 (0.06)	35.13 (0.54)	13.71 (0.29)
c	40.71 (0.11)	41.23 (0.05)	17.38 (0.12)
d_1	60.76 (0.58)	5.50 (0.07)	7.49 (0.11)
d_2	47.91 (0.03)	23.89 (0.05)	11.23 (0.15)
e	41.69 (0.24)	29.23 (0.19)	11.03 (0.03)
f	41.98 (0.04)	36.06 (0.04)	13.21 (0.02)
g_1	57.72 (0.20)	4.17 (0.05)	15.26 (0.03)
g_2	34.40 (0.43)	40.94 (0.04)	22.93 (0.14)
h	37.20 (0.18)	48.77 (0.10)	26.16 (0.14)

Table 1. Average values and standard deviations (σ) of the naturally aged PE and PS red lids colorimetric coordinates.

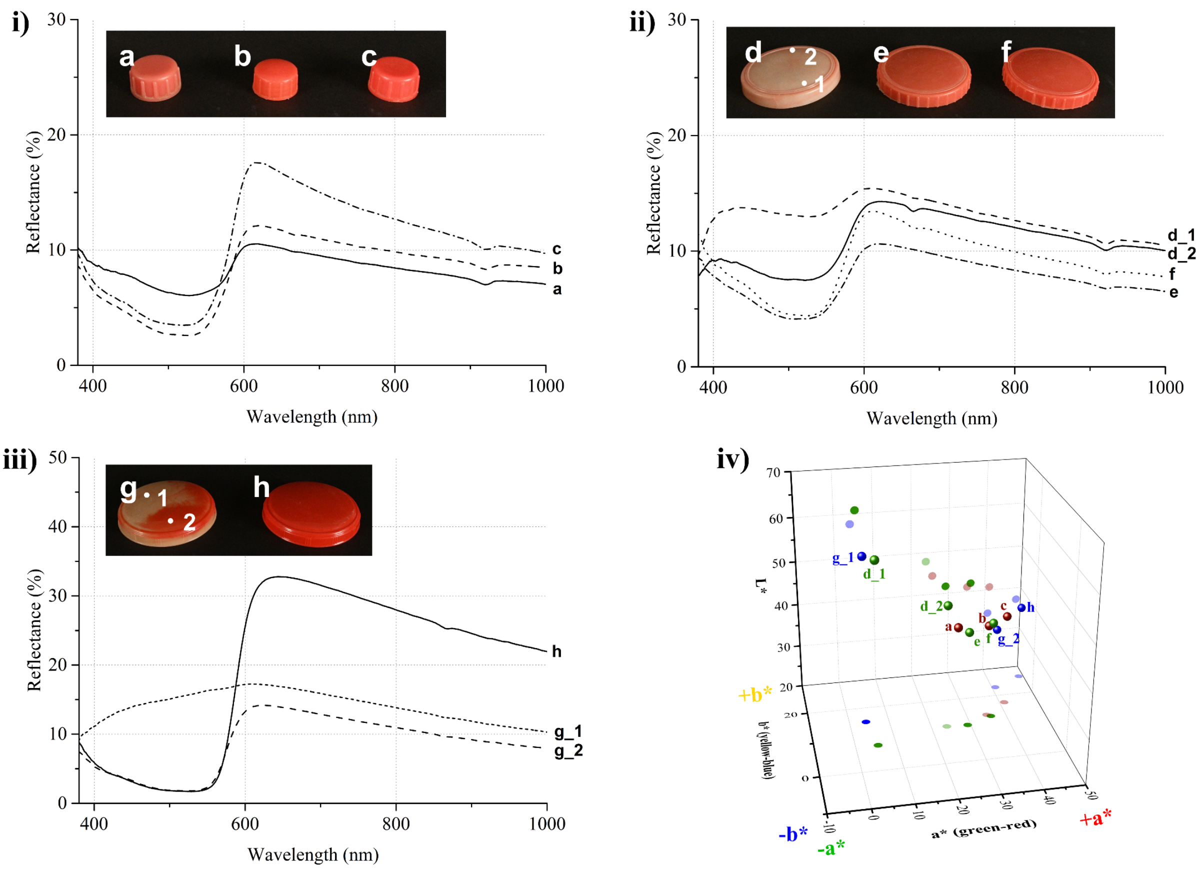

Fig. 2. Naturally aged PE (i, ii) and PS (iii) red lids FORS spectra and their L, a*, b* values in 3-dimensional CIELab76 Color Space (iv). Projections of the points along L* vertical axis and a* and b* perpendicular horizontal axes are also reported.*

The ABS telephone is characterized by areas with different degrees of yellowing. The bottom part of the handset, as well as its housing, are "pristine" white due to limited exposure to light (Fig. 1). The top of the handset and of the entire object are completely discolored (Fig. 3i, inset).

Interestingly, one can observe a gradient of yellowing along the side of the handset, which corresponds to areas more or less exposed to direct light. The portion of the handset that partially fits inside the telephone housing, and hence is less exposed to light, seems of the same color of the bottom (Fig. 3i, points 1 and 2), whilst the upper portion shows intense yellowing (Fig. 3i, points 3-5). The application of FORS enabled the detection of spectral differences among the analyzed points on the side of the handset (Fig. 3) and the base for housing was used as a reference for the original color. By comparing the reflectance spectra, it is possible to note that the slope of the rising edge between 400 and 450 nm progressively disappear from the whitest to the yellowest areas (points 1 and 5 respectively). This results in a shift towards higher wavelengths of the maximum of the reflectance, enhancing the yellow component. Similar reflectance drop on the first tens of nanometers as a result of yellowing was also observed after both artificial and natural light aging of ABS polymer plates (Signoret *et al.*, 2020). Although points 1 and 2 in the telephone transmitter appeared white at the naked eye, the reflectance spectra profile indicates an incipient yellowing, probably in an early stage. The formation of new chromophores as a consequence of the photo-oxidation of the ABS can be responsible for yellowing at the phone surface (Boldizar and Möller, 2003; Jouan and Gardette, 1992; Saviello *et al.*, 2014).

The colorimetric analysis showed a significant color variation between the analyzed points (Fig. 3ii). The exposed areas are characterized by higher positive b* values with progressively lower L* values, which indicates respectively yellowing and a slightly darkening of the plastic (Table 2).

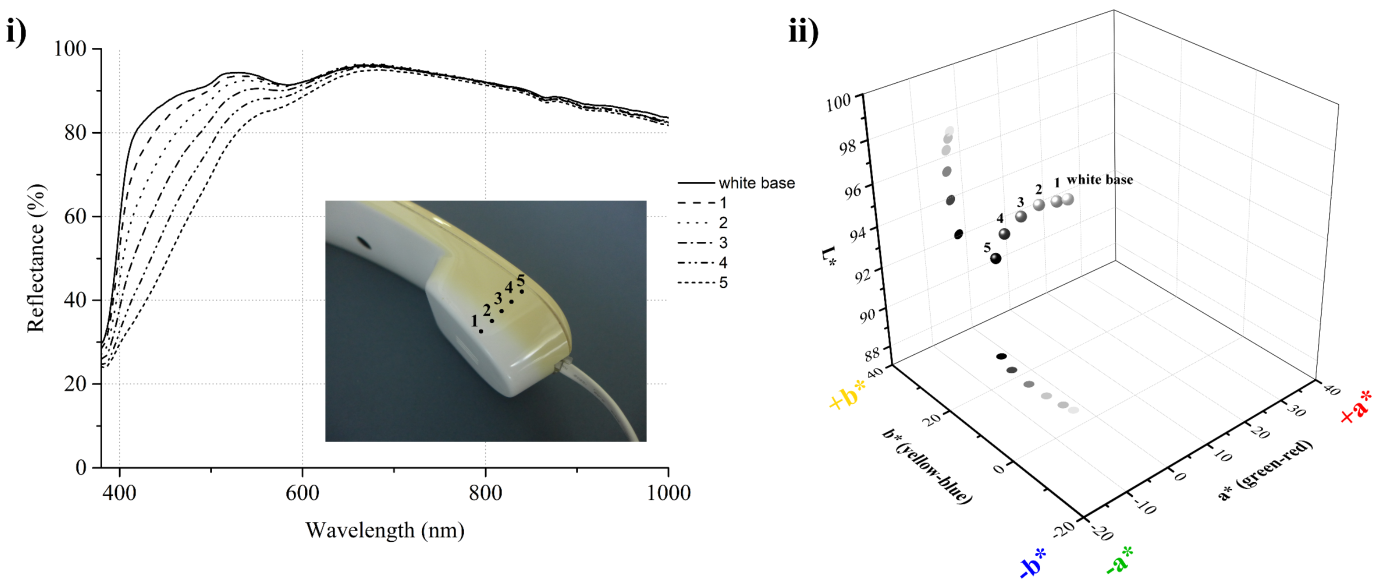

Fig. 3. FORS spectra of the naturally aged ABS telephone (i), and their L, a*, b* values in 3-dimensional CIELab76 Color Space (ii). Projections of the points along L* vertical axis and a* and b* perpendicular horizontal axes are also reported.*

Sample	**L*** (σ)	**a*** (σ)	**b*** (σ)
White base	97.08 (0.02)	-2.03 (0.10)	4.35 (0.07)
1	96.79 (0.01)	-2.48 (0.12)	6.93 (0.03)
2	96.28 (0.03)	-3.12 (0.20)	11.31 (0.05)
3	95.29 (0.03)	-3.34 (0.09)	16.56 (0.02)
4	93.88 (0.01)	-2.99 (0.15)	22.53 (0.02)
5	92.07 (0.02)	-1.69 (0.17)	27.66 (0.03)

Table 2. Average values and standard deviations (σ) of the naturally aged ABS telephone colorimetric coordinates.

4. Conclusion

This study proves the suitability of FORS for the characterization of discoloration in historical plastic objects. The fading of a selection of PE and PS red lids and yellowing of a naturally aged ABS telephone were successfully detected.

FORS demonstrated to be suitable in detecting different levels of fading severity, which correspond to different stages of degradation. In the case of organic pigments based on β-naphthol, the shift of the inflection points toward lower wavelengths could be used as an indicator of the fading rate. The loss of the characteristic s-shape profile indicates the complete degradation of the organic pigment. Contribution of the yellowed PE matrix to the faded color of the plastic elements was observed at the highest /most severe stage of deterioration, where the red color was almost completely lost.

A degree of superficial yellowing was visible on the side of the telephone transmitter. In areas where the telephone results still preserved (and white), FORS revealed an incipient stage of yellowing. Thus, FORS measurements could be considered a useful preventive tool for detecting early degradation phenomena not detectable by simple visual inspection.

This work tackles the conservation problem of discoloration in plastics in collections. Only a few studies have already discussed the topic, and this work opens new avenues in the use of FORS for the assessment of discoloration in plastic heritage. Being FORS able to detect alterations also even before the chromatic effects become visually evident, its application can represent a preliminary step in a multi-technique protocol to investigate the discoloration of plastic objects in museum collections and a reliable analytical tool to monitor the progress of degradation. The detection of discoloration by FORS would inform effective conservation strategies and guide conservation scientists to further and more careful scientific investigation. Indeed, additional and complementary analytical methods can be selected to fully grasp the polymer degradation fully (e.g. Fourier transform infrared spectroscopy, FTIR) (Angelin *et al*., 2021c) and colorant alteration (e.g. pyrolysis gas chromatography/mass spectrometry (Py-GC/MS)) (Micheluz *et al*., 2021).

The interaction between ultraviolet-visible-near-infrared (UV-Vis-NIR) radiation and plastics poses new challenges due to the inherent complexity of the plastic material and lack of experimental protocol for the reflectance analysis. Vis reflectance spectra can be used to identify colorants and discoloration, as both polymers and additive packages should not absorbed in this spectral region. Still despite this, the use of the information collected in the UV and NIR portions for the identification and condition assessment of plastics should be clarified with further research. Plastics show a prevalent specular component in the reflected beam (due to their very smooth surfaces) and specific scattering processes (due to the semi-crystalline or amorphous structure of the plastic itself), hence, a full understanding of its application is still lacking. The geometry of acquisition can strongly influence the resulting reflectance spectra profile where diffusely reflected beams should be maximized in the detection.

5. Conflict of interest declaration

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7. Short biography of the author(s)

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Is a house named “yellow” really yellow? Survey on the perception and naming of the yellow color on building facades depending on its hue, lightness and saturation

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ABSTRACT

The article's primary goal is to present the author's online color survey results. The study was aimed at checking which colors chosen from NCS Color System's four yellowish hue groups: G80Y, G90Y, Y, and Y10R are considered as "yellow." The 28 nuances differed in hue, lightness, and chroma, were presented separately on color swatches and building facades. At first, the respondents assessed the yellowness of selected colors and then indicated the most appropriate ones for the color term "yellow." The analysis of the 444 results confirmed the high importance of saturation and lightness (whiteness/blackness level) in color appearance and naming. The research proved that a given color is likely described as "yellow" only when its parameters of lightness and saturation are similar to the prototype of the yellow color category, characterized by high saturation and high intrinsic lightness. The clarity of the hue was also the significant factor.

KEYWORDS Yellow, Color in architecture, Color attributes, Color naming, Color appearance, Color perception

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1. Introduction

The yellow color has been common in architecture since the earliest times. For ages the rationale and ways for using this hue in built environment were diverse, but it was always present in many varieties due to its positive connotations with sun, light and metal gold, as well as the popularity and availability of ochre pigments. Yellow ochre was not only the oldest yellow pigment but also one of the first pigments ever used by humans. Thus, warm, orangey yellows were and still are shaping the chromatic perception of many towns and villages around the world. In contemporary built environment, yellow plays an important role in the city visual communication system and corporate identity, being also common color of mailboxes, taxis and tramways. Thanks to new materials and technologies, highly saturated yellow as a visual attractor appears both in public buildings and spaces, being modern and an intriguing color in architecture (Tarajko-Kowalska 2021). Many research confirms (e.g. Janssens and Küller, 2009), that yellowish hues from groups: YR (yellow-red), Y (yellow), and GY (green-yellow), according to the NCS – Natural Color System nomenclature, are constantly most preferable for residential buildings facades in many countries, especially in Europe. But, compared to the other primary colors, pure yellow occurs only in a narrow band of the spectrum with a wavelength of 570–580 nm (Lancaster, 1996). Varieties of yellow may differ in one, two, or three of the color attributes: hue, lightness and saturation (chroma), thus creating a full spectrum of tones and shades. In the environment many yellowish tones exist, as it *"can tend toward green on the one hand and toward orange on the other",* being described as color of gold, lemon, sulphur and saffron (Pastoreau, 2019). This richness of nuances can be represented for example by Latin vocabulary, where the most frequently used adjective *flavus* describes saturated yellow, while *fulvus* means darker yellow, *croceus* - saffron orangish yellow*, luteus* is used for ordinary yellows present in flora and fauna, *aureus* represents gold, *luridus* grayish yellow etc. (Pastoreau, 2019).

In residential architecture yellows are usually used in pastel tones with high lightness level, in muted shades with low chroma, or as earthy browns. So the question arises: is a house colored yellow really perceived as yellow? Because in most cases very dark or very pale tones cease to appear yellow anymore. Also, the latest studies on color-emotion relations confirm that less saturated and darker yellows do not even produce the same emotional reactions as highly saturated ones (e.g. Schloss *et al.*, 2020). The same conclusion comes from the author's recent study on the use of the yellow color in architecture and built environment, where only those examples in which highly saturated tones were used, seem to carry all the characteristics and associations assigned to the yellow color, considering its symbolic, functional, and decorative aspects (Tarajko-Kowalska, 2021). While thinking or reading about the "yellow building", don't we imagine a brightly colored house, clearly visible in the landscape or being a visual attraction in public space? Those findings and questions led the author to research which samples and building facades, colored in yellowish hues, different in the attributes of lightness and saturation, are still considered as "yellow". The main purpose of the article is to present the results of this color survey [1].

2. Method

To conduct the research, an online questionnaire was prepared in Google Forms. The main reason for choosing this form of survey was the author's desire to obtain as many results as possible, with participants' minimal workload. The study was also meant to be entertaining for participants so that the responses obtained were not forced but reflected the real observers' opinions.

2.1 *Survey structure*

The study consisted of three parts. The first part was dedicated to collect the respondents' data. Participants reported their gender (female/male) and age (<18, 18-29, 30-39, 40-49, 50-60, >60). They were also asked to specify the level of their experience with color (none, basic, middle, or advanced) and give the information if their proper color vision was confirmed by a medical examination for driving license and/or any color tests. It was also possible to make quick tests online while filling the survey, by clicking the given links to the Ishihara test (http://colorvisiontesting.com/ishihara.htm) and X-rite test (https://www.xrite.com/hue-test).

In the second part, participants were rating on a scale from 1 to 5 (1 – definitely not, 2 – rather not, 3 – not sure, 4 – rather yes, 5 – definitely yes) if randomly presented color samples can be considered "yellow" (Figure 1). After that, responders were asked to indicate three color samples (from all twenty eight color samples seen before) they think are most adequate for the color term "yellow".

The third part of the study was dedicated to building facades (Figure 2). Similarly to previous part, the respondents were asked at first to rate on a scale from 1 to 5 the level of "yellowness" of the presented building façade, which was computer-painted in one of the twenty eight selected colors - same as color swatches seen before. After finishing, they chose three facades, which colors they consider the most appropriate for the term "yellow". On average, to complete the survey took around 10-15 minutes.

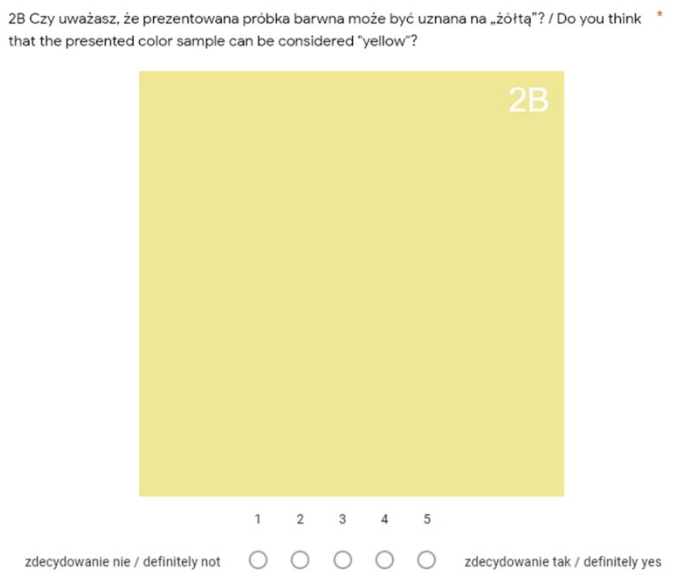


Fig. 1. General appearance of the questionnaire for color sample (question: Do you think, that the presented color sample can be considered "yellow"?)

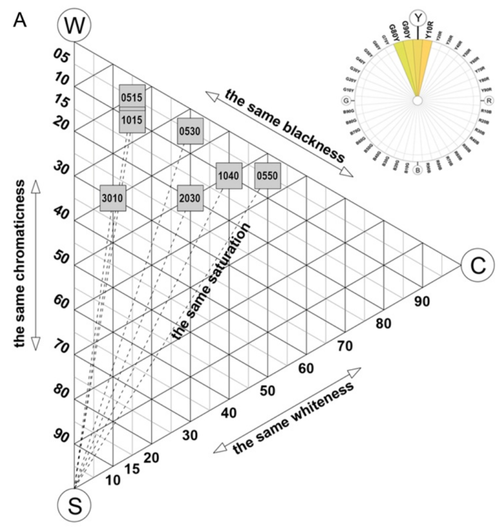
Fig. 2. General appearance of the questionnaire for building façade (question: Do you think, that the presented building facade can be considered "yellow"?)

2.2 *Colors selection*

In order to conduct the survey, 28 colors, differing in hue, lightness (whiteness/blackness level) and saturation (chromaticness), were specified, then used to color the samples and facade of the selected building. The colors used in the survey have been chosen from NCS Color System's four yellowish color groups: G80Y, G90Y, Y, and Y10R. The Y20R group was also considered, but due to strong orange appearance of the nuances it was finally rejected in favour of the G80Y group.

Authors' wish was to represent all the color families: pastel (high lightness and chroma), pale (high lightness and low chroma), vivid (highly saturated), rich (low lightness and high chroma) and finally dull (low lightness and low chroma). However, due to the fact that selected colors were to be presented also on the building façade, very dark and highly saturated colors have been eliminated from the list. Another limiting element was the number of samples for presentation. Finally, seven nuances were selected from each hue group to represent the colors that often appear on the facades of residential buildings: 0515, 0530, 0550, 1015, 1040, 2030, 3010. The author made the choice based on her experience as an architect-designer and on the knowledge of the color palettes offered by various manufacturers of facade paints and plasters. The NCS triangle was used to provide the same nuance for samples from particular hues (Figure 3).

A



B

nuance (aabb)	w	s	v	c	m
0515	80	05	0,95	15	0,16
0530	65	05	0,95	30	0,31
0550	45	05	0,95	50	0,52
1015	75	10	0,9	15	0,17
1040	50	10	0,9	40	0,44
2030	50	20	0,8	30	0,37
3010	60	30	0,7	10	0,14

Fig. 3. Selection of the colors to the survey; A. NCS triangle with position of the 7 selected nuances and NCS circle with selected hue groups: G80Y, G90Y, Y, Y10R;

B. Table with selected nuances and their parameters: s - blackness (aa), c - chromaticness (bb), w – whiteness, v – lightness, m – saturation.

As the color samples were to be presented online, to reflect the colors of a specific notation, the NCS Colourpin Application was used, which ensures a high degree of compatibility between the appearance of the physical NCS Colour samples and the one presented on the displays of electronic devices. Of course, the author realizes that in the case of patches showed online accurate color presentation cannot be fully ensured. However, in the case of the conducted research, the perfect match of the appearance between the physical samples and the one visible on the screen was not the highest priority and in the author's opinion it did not significantly affect the obtained results.

2.3. *Building selection*

For the rating of "yellowness" level of the facades, Njálsgata House in Rejkjavik on Iceland was chosen (Figure 4). This residential building from early 20th century undergone in 2015 contemporary refurbishment and reorganisation by Krads architects (https://www.archdaily.com/923370/njalsgata-house-krads). The building was selected mostly because its form and style can easily accept different shades and tones of yellowish hues. The house has also gray roof and neutral, almost achromatic neighborhood, which reduced possible influence of adjacent chromatic colors on the perception. For the same reason the photo was taken on a cloudy day, to avoid sun contrasts and shades, which could affect final color appearance.

Fig.4. Façade of Njálsgata House in Rejkjavik on Iceland selected for the presentation of colors in survey.

3. Results

The results of the study were presented and analyzed in two ways. The first part consists of the outcomes of "the yellowness" assessment of the individual 28 colors. Those results were presented in individual column charts for each of the 28 swatches and facades, generated automatically in Google Forms, and then the summary graphs for each hue group (G80Y, G90Y, Y, Y10R) were created by author. The second part contains the results of the color selection most appropriate for the term "yellow." These effects were presented as horizontal bar charts (also generated in Google Forms Program) ranked from the nuances most frequently chosen to those with the slightest indications.[2]

3.1 *Participants*

The author collected the data presented in this article in May 2021 for around one month. During that period, 444 participants took part in it, 332 females (74,9%) and 112 males (25,1%). They were primarily Polish students and academic teachers from the Cracow University of Technology, Faculty of Architecture, but also students of Industrial Design from the Cracow Academy of Fine Arts and others. More than half were in the age range 18-29 (53,3%). Next age group was 40-49 and 30-39 range with about 16% each. There were also some participants in the age range 50-60 (8%) and over 60 (4.7%), as well as few in age less than 18 (1,3%). Only 21% of the participants do not have any confirmation for their proper color vision besides their declarations. Most of the respondents (90,4%) declared some experience with color (basic – 28,1%, middle – 38%, advanced- 24,3%). Detailed participants data are presented in Table 1.

Total number of participants			444		
Gender		**Female** - 332	**Male** - 112		
Age range					
<18	**18-29**	**30-39**	**40-49**	**50-60**	**>60**
6	237	70	75	35	21
Experience in work with color					
none	**basic**	**middle**	**advanced**		
43	125	168	108		
Confirmation of proper color vision					
not confirmed			95		
medical test for driving license			297		
Ishihara's test			82		
X-rite test			66		
other			33		

Table 1. Survey participants statistics data

3.2 *Results of part I – The assessment of yellowness of individual colors appearance on swatches and building facades*

In the rating if presented color can be considered "yellow" (at first assessed on swatches, then on facades), the highest unanimity and percentage of "yes" responses (percentage shown together for answers 5 - “definitely yes” and 4 - “rather yes”) was achieved by the nuance 0550 (highest saturation/lightness, lowest whiteness). The undisputed number one became color 0550-Y with the “yes” results equal 96.2% for sample and 98.2% for facade. The colors 0550-G90Y and 0550-Y10R achieved only slightly worse results, with the percentage of "yes" indications consistently higher for the facades (93,9%, 91,2%) than for the swatches (83,8%, 84,2%). For the 0550-G80Y nuance, a high level of the consensus occurred only for the elevation (82% to "yes"), while for sample over 50% of the responses were negative.

The highest percentage of "no" responses concerns the nuance 3010 (lowest saturation/lightness, highest blackness), which for all hues was not perceived as yellow either for the color swatches or the facades in more than 90% (in most cases, the percentage of the summed up answers 2 - "rather no" and 1 - "definitely not" reached 98.9% for samples and 95% for facades).

Also for the 1015 nuance (low saturation, high whiteness), the negative responses dominated in the case of samples, changing slightly together with the hue from G80Y to Y10R (97.1% - 74.1% - 75.8% - 80.8%). In the case of facades, the responses were very diverse, except for the hue G80Y with 72% to "no." There was a slight "yes" tendency for hues G90Y and Y (53.5% -49.2%), but for Y10R the numbers of "yes" and "no" responses were nearly even.

The nuance of 2030 (average level of saturation/lightness, lowest whiteness) brought interesting results, as it existed a discrepancy in its perception between swatches and facades. There was a high percentage of the "no" answers for the samples, slowly decreasing while changing the hue (94.5% -93.5% -85.3% -77.2%). In the case of the facades, the situation was different. While for greenish yellows G80Y and G90Y, the percentage of negative responses was still significant (71.6% -52.3%), for hues Y and Y10R there were more responses to "yes" (51.9% - 68.2%).

In the case of the 1040 nuance (high saturation, average blackness/lightness), the hue also played a significant role. Only for the Y there was a high "yes" percentage for both the samples (81%) and the facades (97%). Y10R hue has still high "yes" responsiveness for facades (80%), while for samples it was only 60%. For the greenish yellows of G90Y, there was still a high percentage of "yes" responses to facades (74%), but "no" responses began to dominate in the swatches (42.5%). For the G80Y, the "no" responses predominate for both the samples (80%) and the facades, although here to a lesser extent (60%).

In the case of the 0530 nuance (highest lightness, middle saturation, lowest blackness), full agreement of the "yes" responses occurred for the hues G90Y and Y, with a higher percentage observed for the facades (96%, 92%) than for the samples (77%, 72%). At the Y10R hue, a large variation in the results for the swatches was observed, together with a slight dominance of the "yes" answers for the facades (60.5%). For the G80Y, there was a full discrepancy in the responses, with 65% "no" for the samples and 58% "yes" for the facades.

For the 0515 nuance (highest lightness/whiteness, low saturation), there was also a dissimilarity of opinions between the samples and facades assessment. Here, too, the hue played a decisive role. For the swatches, the responses were mostly negative, with the percentage of "no" gradually decreasing with the hue change from G80Y to Y10R (89%-69% -50.4% -49%). For the facades, with the change of the hue, the number of positive responses increased from 49% to "no" for the G80Y to 61% to "yes" for the shade Y10R.

Detailed results of part I of the survey are presented in Table 2.

hue / nuance		0515		0530		1015		1040		0550		2030		3010	
G80Y (%)	C	s	f	s	f	s	f	s	f	s	f	s	f	s	f
	1	66,8	26,6	35,9	10,4	85,1	44,9	58,5	34,3	30,7	5,9	81	40,4	94,8	88
	2	22,3	22,6	28,9	14,7	12	27,1	21,7	22,6	21,7	4,1	13,5	31,2	3,6	7,7
	3	7,7	22,8	19,9	17,6	1,8	16,9	10,8	14	19,9	7,2	3,6	14,7	0,0	3,6
	4	2	17,6	10,8	29,8	0,2	6,8	6,8	13,1	16,7	17,6	0,7	8,6	0,5	0,5
	5	1,1	10,4	4,5	27,5	0,9	4,3	2,3	16	11,1	65,2	1,1	5,2	1,1	0,2
G90Y (%)	C	s	f	s	f	s	f	s	f	s	f	s	f	s	f
	1	45,1	11,7	2,9	0,5	42	5,2	19	6,8	2,3	0,7	74,3	27,5	94,6	83,1
	2	23,9	20,3	6,5	0,2	32,1	16,5	23,5	7,2	5	1,4	19,2	24,8	3,8	10,8
	3	19,9	23,9	12,9	2,9	14,4	24,8	25,7	12	9	4,1	5	20,3	0,5	5,2
	4	7,9	24,2	31,4	14,2	8,6	33,4	23,7	24,6	20,1	12,1	0,7	16,9	0,2	0,5
	5	3,2	19,6	46,3	82,2	2,9	20,1	8,1	49,4	63,7	81,7	0,9	10,4	0,9	0,5
Y (%)	C	s	f	s	f	s	f	s	f	s	f	s	f	s	f
	1	26,2	12,6	3,4	0,2	44,9	6,8	2,3	0,5	0,9	0,5	64,1	9,9	94,6	76,5
	2	24,2	21	8,6	1,6	30,9	18,1	3,8	0,7	2	0,2	21,2	16,9	4,3	15,6
	3	24,8	23,3	15,8	5,6	16,7	26	13,1	1,6	0,9	1,1	10,4	21,2	0,0	8,1
	4	17,8	25,3	37	26,9	6,1	28,2	24,4	12,4	9,5	6,1	3,2	28,4	0,2	0,9
	5	7	17,8	35,2	65,7	1,4	21	56,4	84,9	86,7	92,1	1,1	23,5	0,9	0,9
Y10R (%)	C	s	f	s	f	s	f	s	f	s	f	s	f	s	f
	1	18,3	2,7	15,8	7	52,6	12	7	2,9	2,5	1,6	49	2,9	93,7	78,8
	2	30,7	14,7	19,9	13,1	28	24,4	13,1	8,4	5	2,9	28,2	11,1	4,1	12,6
	3	18,5	21,7	24,2	19,4	13,5	28,2	19,6	9,5	8,4	4,3	10,8	17,8	0,9	7
	4	21	33	25,1	30	5	21,2	30	24,2	21,9	14,7	9,5	28	0,2	1,1
	5	11,5	28	15,1	30,5	0,9	14,2	30,2	55,1	62,3	76,5	2,5	40,2	1,1	0,5

Table 2. Results of part I. Yellow color appearance (perception) on color samples (s) and on building facades (f) in %. 1-definitely not, 2-rather not, 3-not sure, 4-rather yes, 5 -definitely yes.

3.3. *Results of part II – The best examples of the yellow color on swatches and building facades*

The color 0550-Y was found to be the most appropriate for the term "yellow" for both the swatches (93,4%) and the facades (80.8%). Among the presented samples, it was the color with the highest level of both saturation and lightness. It also has no admixture of other primary colors (it is neither reddish nor greenish). Thus, it can be treated as a "unique hue" and the most similar color to the typical representative for the yellow color category (see Witzel, 2018, Schloss et al., 2020).

The colors 0550-Y10R (71% for samples and 48.5% for facades) and 0550-G90Y (52.7% for samples and 63% for facades) were second. Also, these colors are characterized by the highest saturation and lightness, but their hues have slight admixtures of red and green, respectively. The remaining color 0550-G80Y in this nuance came in a relatively high fifth place for facades (26.9%), but for the samples, it was in the ninth position with only 4.1% of the response.

The next places were colors: 1040-Y, 0530-Y, and 0530-G90Y. A small percentage of the answers were also given to the nuances 1040 and 0530 for the Y10R hue, and in the case of the facades also for the G80Y. The nuance 3010 was not indicated even once for any of the hues.

Neither for the samples nor the facades were indicated colors having both a high degree of whiteness and low saturation (0515, 1015) or low saturation and low lightness (3010). Thus, saturation was the decisive parameter in that case.

For colors with an average saturation level (0.35, 0.37) lightness and blackness were the decisive parameters. The darker nuance 2030 (brightness 0.8) was not indicated at all, while the lighter 0530 (brightness 0.95) was ranked relatively high for hues Y (28.5% samples) and G90Y (20.5% facades) (see detailes on Figure 5).

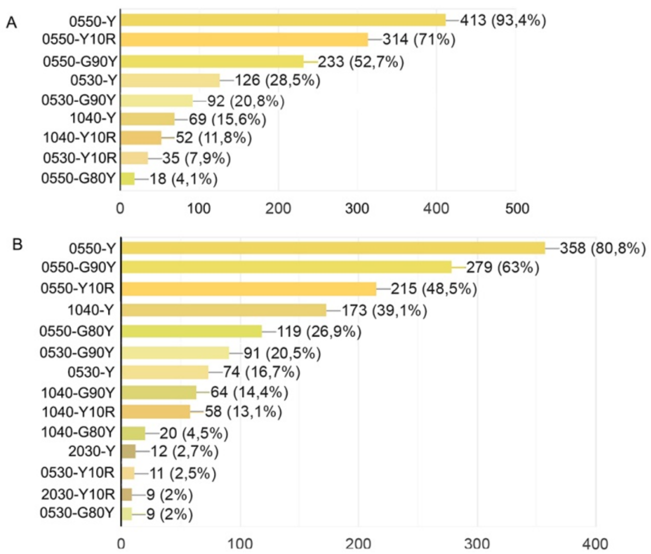


Fig 5. Results of part II - Color swatches and building facades considered as most suitable for term "yellow". Ranking list of top 9 nuances for swatches (A) and 14 (B) nuances for facades.

4. Conclusion and discussion

The analysis of the results confirmed, also emphasized by other researchers (e.g., Witzel, 2018, Witzel et al., 2019, Schloss et al., 2020, Divers, 2021), the importance of saturation and lightness (the degree of whiteness/ blackness) in colors appearance and naming. The attribute of saturation was the most significant when indicating adequate colors for the term "yellow" (the higher the chroma, the more often the color was chosen). Next, the decisive parameter was the degree of whiteness and blackness - colors with a high blackness or whiteness were rarely indicated as "yellow."

The research proved that a given color is likely described as "yellow" only when its parameters of lightness and saturation are similar to the prototype of the yellow color category, characterized by high saturation and high intrinsic lightness (Schloss et al., 2020). Color appearance is also typically assessed by reference to one of the unique hues (Witzel, 2018). That explains why the most frequently indicated was the purest hue Y, then Y10R and G90Y, and least often G80Y. The clarity of the hue was the decisive factor, especially in the case of both highly saturated and whitened colors. It seems that the confidence of indicating "no" increased with dark and low saturated colors because both parameters are different from the typical yellow prototype mentioned previously. In addition, dark yellows cross the color category from "yellow" to "brown" (Schloss et al., 2020), and the hues of G90Y and G80Y visually turn green.

In the comments to the survey, the respondents assessed the survey as giving "fun" but at the same time causing confusion and raising deep doubts about the nomenclature and definition of colors with variable saturation and lightness, and what can still be called "yellow" and what not. So, there is a need to go beyond the basic color categories in the scientific research, as they do not cover the whole variability of perceived color "subcategories", depended its parameters (in case of yellowish hues this will be, e.g., when lighter: beige, darker: brown, greener: lime, redder: ochre, orange, see Figure 6). This can be achieved by extending (but not replacing) the "hue paradigm" with the "value-chroma paradigm" (see Divers, 2021). This is important particularly in environmental color design as the vast majority of nuances present in natural surroundings are not highly saturated.

The research also reveals that various nuances are more likely declared "yellow" on the façades than on the samples. This is especially evident when the swatches were rated as not yellow while the facades were still placed in the yellow category. It is known that color is perceived differently on the sample than on the facade.

However, the reason for these discrepancies may also be that the color of the sample is evaluated strongly by reference to the typical yellow prototype. In contrast, for the facade, observers base their judgment more on experience and cultural traditions. Thus, the color tests and color choices, which concern particular objects (such as buildings), should not be performed only on color samples, as they may give completely different, even opposite results.

Those findings may be a starting point for a wider discussion on the actual preferences of yellowish colors for building facades and the way of describing them in the context of not only the hues but also, perhaps even above all, their lightness and saturation.

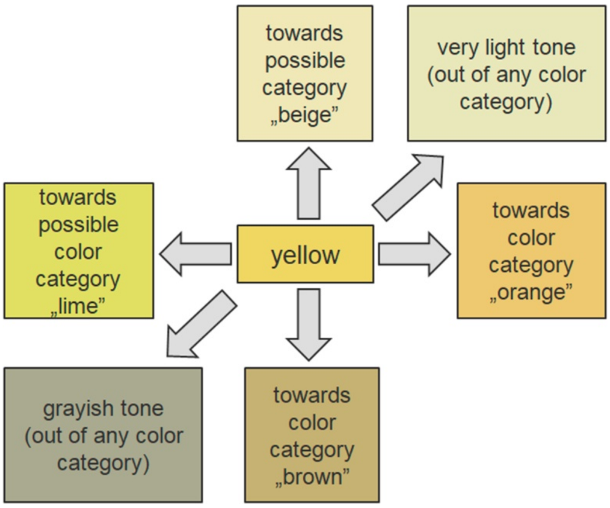


Fig 6. Potential yellow color "subcategories", depended on the parameters of hue, lightness and saturation.

Conflict of interest declaration

The author declares, that nothing has affected her objectivity or independence in the production of this work. There are no actual or potential conflicts of interest, including financial, personal or other relationships with other people or organizations, that could inappropriately influence (or be perceived to influence) this work.

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Short biography of the author

Justyna Tarajko - Kowalska - PhD. Architect, lecturer at the Cracow University of Technology, Faculty of Architecture. Author of over 60 articles on the topic of color in architecture, published in Polish and English. In scientific studies, she concentrates especially on the issue of color in the built environment, as well as the history of color in architecture and space.

Notes

[1] The idea to carry out this survey was born during the author's research on the color yellow in architecture and the built environment, the results of which were presented in the article entitled 'Yellow color in European architecture and built environment: traditions and contemporary application' (Tarajko-Kowalska, 2021). For that reason, presented study is of a more technical nature and the author intentionally does not mention the cultural background of the use of yellow, which was described in detail in the paper mentioned above.

[2] Supplementary data to this article with detailed results of the study presented on diagrams can be found online at: https://drive.google.com/drive/folders/1f5eFCWPU3F_MOAADmP1vvWIDbP0OYbo2?usp=sharing

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Scientific basics in art from the Theories of Colour: Authors, methods, rules, applications

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ABSTRACT

In the "chromatic way of thinking", between Art and Science, between the Nineteenth and Twentieth centuries, colour played an essential role: between Romanticism and Modernism, between Impressionism, Post-Impressionism, Neo-Impressionism (and other derivated movements). This complex phenomenon (with its experiences and manifestations) is connected programmatically to the equally complex phenomenon of the Theories of Colour, which has to insert in the debate about contemporary artistic theories. In a broad cultural and scientific territory, starting from the qualified literature and from the publications of the time, the analysis methodology addresses the relationships between institutions, and the exchanges between individual theorists and protagonists, paying attention to the artists that have punctually and consciously applied and experimented those theories, up to the examples in executive techniques, practised in relation with their training. It is consistent with my thirty-year investigations on 48 chromatic beliefs, collected and systematically compared (Marotta 1999). The critical rereading of the treatises and works through their interrelated cultures and experiences confirms a system of knowledge stratified and verified in practise, in an international and interdisciplinary dimension, all to be explored.

KEYWORDS Theories of Colour, Artistic movements, Impressionism, Treatises and publications, Techniques

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1. Introduction

Part of the contemporary "chromatic way of thinking" is rooted openly and continuously with some theories from the past (or, on the contrary, in strong dissent with them): the intuitions and observations of figures from the Eighteenth and Nineteenth century, such as Goethe and Runge, have been fruitfully resumed (from various points of view and with a significant increase in the scientific field) by Michel-Eugène Chevreul (fig. 1), Charles Blanc (fig. 2) from James Clerk Maxwell (fig. 5) to Ogden Nicholas Rood (fig. 4), up to Ludwig von Helmoltz (fig. 5) and Wilhelm von Bezold (fig. 4) throughout the Nineteenth century (for images of the relevant Models see Marotta 1999). Nevertheless, it is confirmed how much the aforementioned contributions have exercised decisive influences in the formation of artistic movements that have been decisive for the Nineteenth-century culture, such as those linked to Impressionism (in all its variants): works by painters such as the French George Seurat and Paul Signac, or the Italians Gaetano Previati (fig. 3) and Giovanni Segantini, are born programmatically from the comparison and application - between science and art - of the same theories just mentioned.

Fig. 1. Michel-Eugène Chevreul (1786-1889).

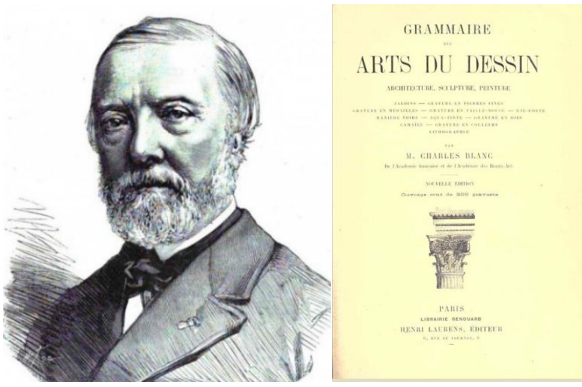

Fig. 2. Charles Blanc (1813-1882).

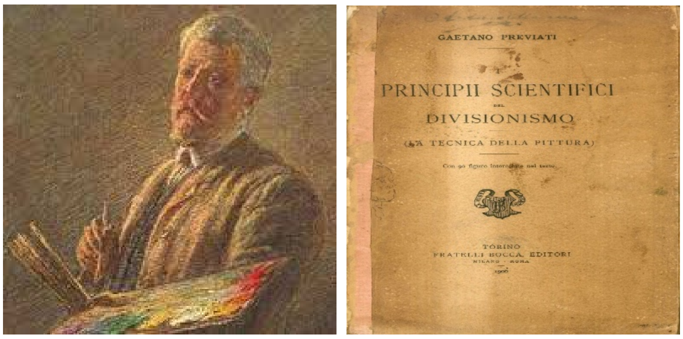

Fig. 3. Gaetano Previati (1852-1920).

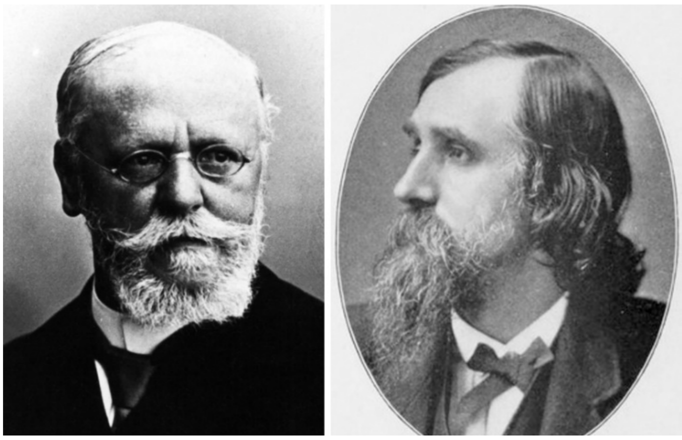

Fig. 4. Wilhelm von Bezold (1837-1907) and Ogden Nicholas Rood (1831-1902).

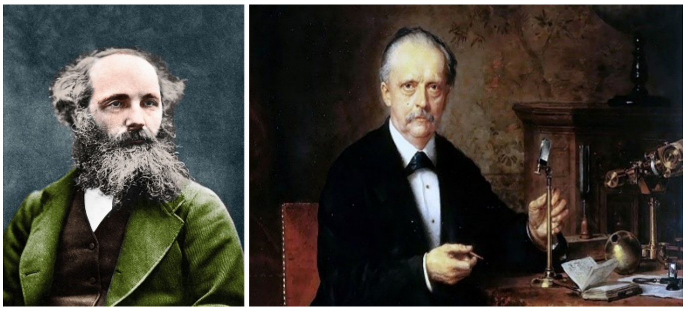

Fig. 5. James Clerk Maxwell (1831-1879) and Ludwig von Helmoltz (1821-1894).

2. Between science and art: Chevreul's theories in Monet's experience

Our journey begins with the relationship (a little examined) between Monet and the French chemist Michel Eugène Chevreul (Marotta 1999) - above all according to the rule of simultaneous and subsequent contrast - in the representation of gardens (a passion and an artistic practice by Monet) content of famous pictorial cycles. Chevreul's experience also includes a wide range of applications to the complex universe of vision,

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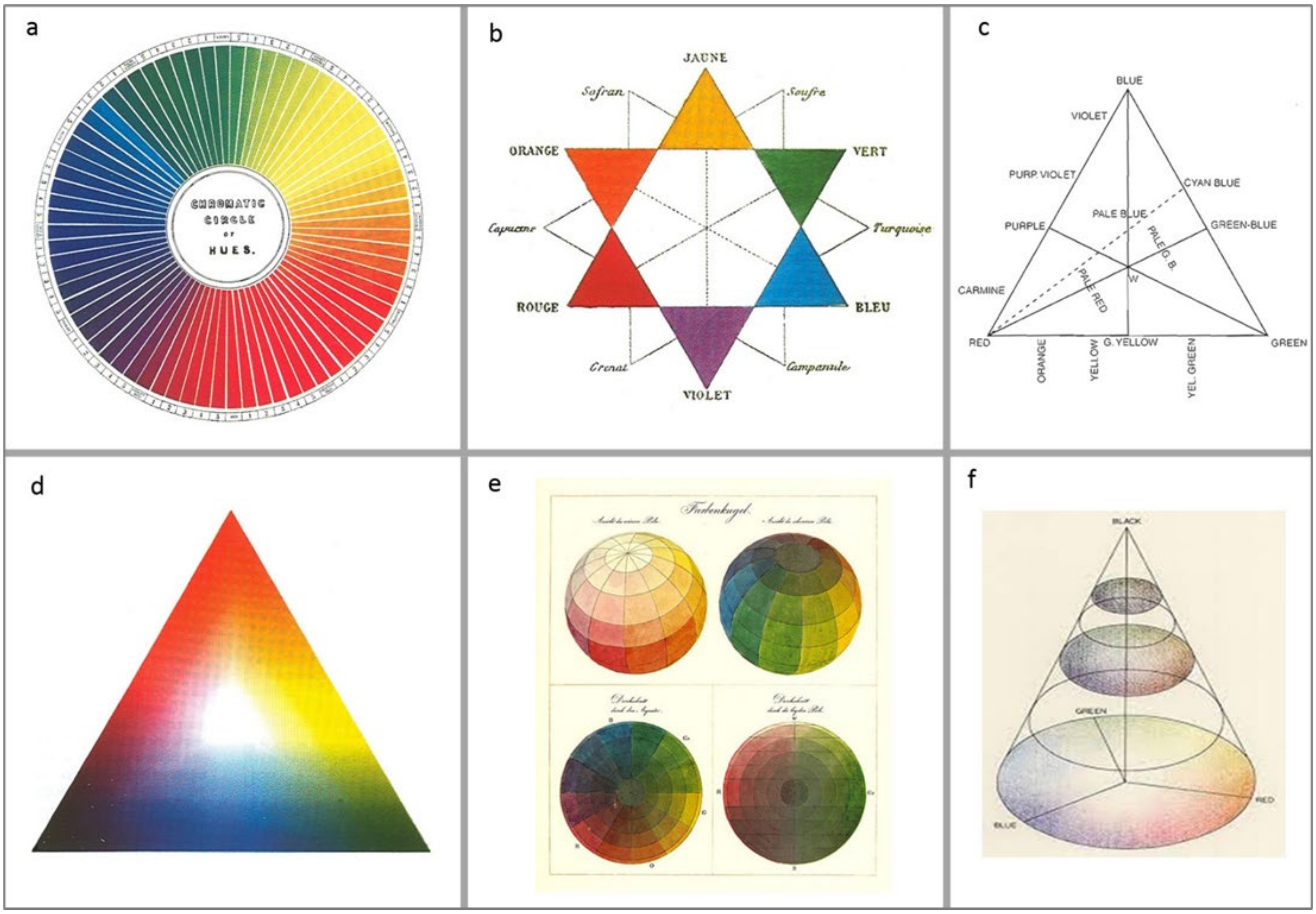

Fig. 6. Models: a. Michel-Eugène Chevreul, Chromatic Circle, 1839; b. Charles Blanc, Chromatic Rose, 1867-1881; c. Ogden Nicolas Rood, Colour Triangle, 1879; d. James Clerk Maxwell, Maxwell's Triangle, 1861; e. Philipp Otto Runge, Farbenkugel (Sphere of Colours), 1810; f. Wilhelm von Bezold, Colorsystem (Source: Marotta 1999).

Fig. 7. Claude-Antoine Prieur-Duvernois (1763-1832) and Garden in the Bois de Boulogne.

Fig. 8. a. Claude Monet in the garden; b. Claude Monet, Bassin des Nympheas, 1904, Denver Art Museum; c. The garden of Giverny of Claude Monet.

involving different material objects and behaviours, as specified in the title: De la loi du contraste simultanee des couleurs et de l'assortiment des objects colorées (…) from 1839, (Marotta 1999). For the elaboration of his scientific theories, Chevreul had Goethe as his first inspiring basics, but also the essay by Claude-Antoine Prieur-Duvernois (fig. 7), Considerations sur les couleurs et sur plusieurs de leurs apparances singulières (Prieur-Duvernois 1805). He was the Director of the dyeing department at the Gobelins tapestry shop and took an interest in the theory of colour and texture because of his work of controlling the preparation of the dye, which led him to discover that the bigger problems of this procedure did not derive from processes of chemical nature but of optical nature, since the false perception of colour was often due to the influence of the colours in the adjacent context, rather than to innate blemish in the pigments themselves. Particularly interesting (and generally less known) is the part of the book dedicated to the design and care of gardens. Starting from the belief that colour is the most appreciated and evocative part of the plant world, Chevreul applied the principles of simultaneous and subsequent contrast to the choice and combinations of the various plants, indicating the rules to follow to determine a chromatic harmony, in the temporal succession of the various months and seasons of the year. The colour of flowers and leaves, with contrasts, similarity, range, shades, but also size, shape, repetition, variety of landscape, symmetry and correspondences are the fundamental elements of his idea of a garden. His prescriptions are detailed, broad and precise from a botanical point of view too, with a competence that Chevreul had acquired working since 1804 in the Nicolas Buckwellin's Chemistry Laboratory at the Musée National d'Histoire Naturelle in Paris, of which he will be the director from 1864, after the employment at the Gobelins since 1824 (Marotta 1999).

Chevreul's way of thinking about the chromatic harmony of plants turns out to be a rich starting point for the history of art: he approached with an experimental method the representation of nature, which was usual for the time not only in painting but also as part of the recent expansion of private and public gardens (such as the Chamois and Bois de Boulogne parks in Paris). Rare but significant are the references to his instructions on colour combinations for the gardens, such as by Gertrude Jekyll, a painter and gardener who was already famous in the early 1900s for her borders directly inspired by Chevreul's theories (fig. 9). Her most significant innovation is the practice of the tonal theory of colours to informal ranges of plants: 'the creation of paintings with living plants'. For the above-mentioned observation, the relationship between Monet and Chevreul about gardens still needs to be explored (fig. 8a, 8b, 8c).

Fig. 9. Gertrude Jekyll, 1843-1932; Manor House garden, upton Grey, Hampshire, UK.

It is well known that the "theory of simultaneous and successive contrast" was sufficiently widespread among the Impressionists; as it is equally well known, the garden was for Monet a passion and a very important artistic practice: at Giverny with the irises and water lilies (which became famous pictorial cycles) the choice of flowers and plants - according to the harmony of colours and the changing seasons - refers more or less directly to models of chromatic association. Moreover, Monet must have had direct contact with the scientific environment in which he had developed and applied the principles of contrast when, at Geffroy's invitation, he designed a Tapis de Savonnerie for the Gobelins factory, decorated with water lilies; there are traces of this among the small proofs produced and kept in the Gobelins museum. indicated by the author(s). Please consider a limit of max 6-7 for images and tables.

3. Between Science and Art: Blanc, Seurat and the others

On the same themes and methods, I was able to deepen - in part - the developments in the close relationship between the theories of colour between science and art, especially between Seurat (fig. 16) and Blanc. Founder of the Gazette des Beaux-Arts, historian and critic, first professor of Aesthetics and Art History at the College de France, Charles Blanc (Marotta 1999, Zimmermann 1989) is the author of a scientific treatise about optical phenomena (inspired by Chevreul's theory): Grammaire des arts du dessin: Architecture, sculpture, peinture (1876), with the attached model called "Rose of Colour" (fig. 6b) (Marotta 1999), which had an enormous influence (Song 1984) also on Georges Seurat (Fénéon 1966 Herbert 1968). Furthermore, many of the works that the painter later read (not only those by Chevreul and D. P. G. Humbert de Superville, fig. 10) were mentioned by Blanc, while some principles for the analysis and experience of colour, light and shadow have been guided by Thomas Couture's ideas (fig. 10), set out in his most important text, Methode et entretiens d'atelier (Couture 1867).

Fig. 10: D. P. G. Humbert de Superville (1770-1849) and Thomas Couture (1815-1879).

It is essential to remember how Blanc coherently interpreted traditional art (such as Eugène Delacroix's) through Chevreul's theories, an attitude shared by Seurat. He is a pioneer of Neo-Impressionism, but he also confronted with Post-Impressionism, Neo-Impressionism, Pointillism, a name rejected by the involved group (also called pointillistes or confettistes) who chose the term "divisionism". Up to Chiarism, Chromoluminism (and more). In particular, from the years 1880-1882 Seurat marked the transition from a romantic to a scientific Impressionism: by partly overcoming Chevreul's laws on accurate lighting and background shading, he thus realized a new stylistic phase. There is a "technical" reason for it (Cullen 1983): in previous drawings (as with Bathers), George had observed that his method of lightening or darkening the background to surround an element of value through its opposite, creating halos or auréoles (theorized by Chevreul), was exalted in the reflections of the water (according to the observations already intuited by Goethe) (Marotta 1999).

Fig. 11. George Seurat, Bathers at Asnières, 1884.

In the liquid substance, the contrast of the halos around the figures is noticeably clearer and brighter than in the grass. The 1886 marked the last exhibition by the Impressionists and the beginning of new artistic movements anticipating avant-garde experiences. If the first phase of the movement tended to measure against nature realistically, the second (Neo-Impressionism), rightly considered the most important by Faber Birren (Faber Birren p. 299), overcame the antagonism between disciplinary knowledge and artistic creativity, to experience a new scientific observation of the phenomenology of vision, chromatic maxims. Innovators, but at the same time attentive to tradition and coloured light (from Delacroix onwards), these artists can still be considered in part as "post-Newtonian colourists", but already engaged in seeking the subjective perception of the vibration and irradiation of light in nature, but not as uncritical opponents of scientific rules.

As stated in the essential text already mentioned, Couture distinguished two ways in which painters treat colour. The first, used by a group he called "the colourists", engaged in the harmony of colours with natural tones. The second, used by the "luminarists", sacrificed the exact shade of nature to the magic of light: he considered Rembrandt as the "supreme luminary" and Veronese as the "supreme colourist" (Couture 1867: 222-226).

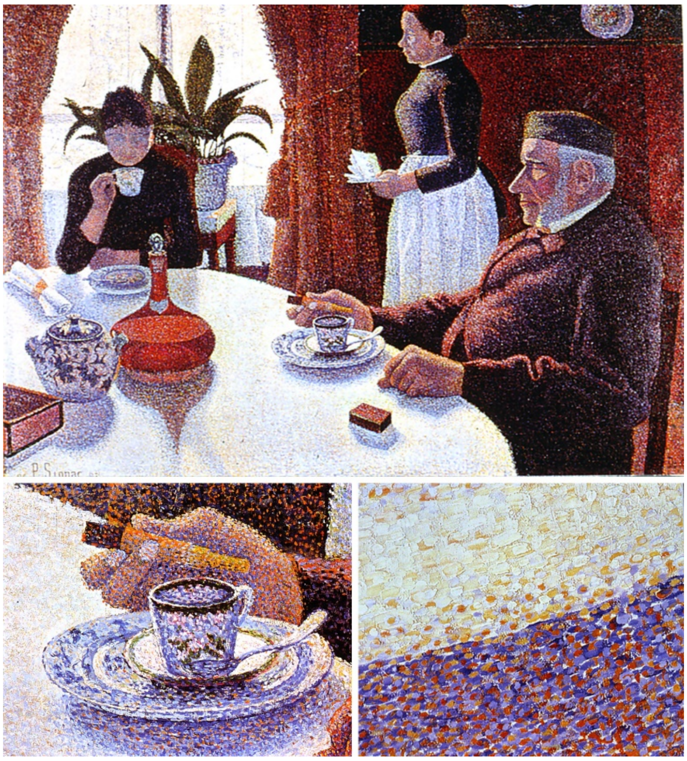

Fig. 12. Paul Signac, La Salle à manger, 1886-1887.

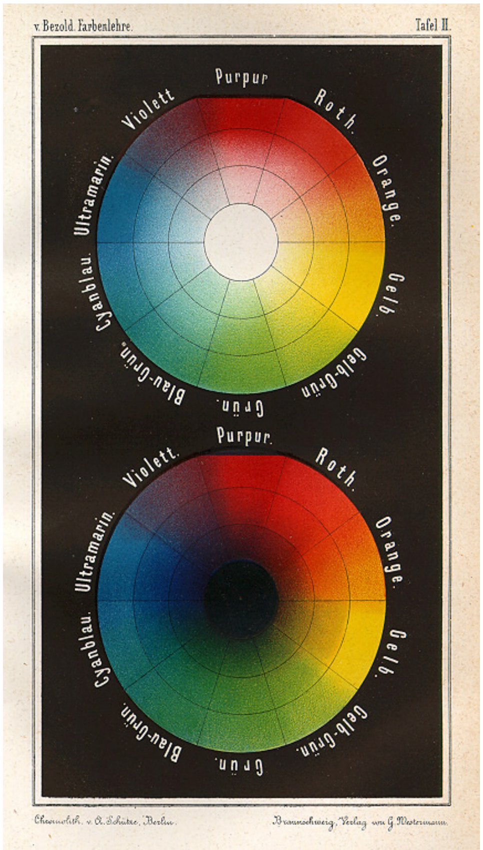

Fig. 13. Wilhelm von Bezold, Bezold Farbentafel, 1874. Signac was inspired by his theory of colours.

Signac also contributed to lay the foundations of the new artistic expression (Divisionism) (fig. 12), underlining the need for precise operations (to perceptually "divide" the colour before the material) based on luminosity and harmony: optical mixing of pure pigments (all the "prismatic" colours and their shades), the separation of the various elements (such as “local colour", lighting colour, their optical reactions), the balance of these elements and their proportion according to the laws of contrast, degradation and irradiation. The developments of Seurat's art concerning scientific culture (especially the part derived from Blanc) confirm the numerous principles that have become the theoretical basics of Neo-Impressionism: the distinction between shade and colour, the idea of optical mixing inducing on the retina vibrations obtained by combining different tones of the same colour.

In this sense, further confirmation came from another very participating theorist in the debate and in the studies of the protagonists of the time: the American Ogden Nicholas Rood with his work on physiological optics, Modern chromatic. He, too, argued that optical mixtures of coloured light rays, which were reflected from the pictorial surface and merged into the observer's retina, would have been much superior in brightness to the effects obtained from the conventional, dull mixes of the palette. Actually, in Seurat's painting, the rays of coloured light coming from each separate stroke or "dot" of coloured pigment were not intended to obtain optical mixtures of greater intensity than their original individual components. Nor were they destined to merge completely on the retina, because they were generally too far apart to do so: it was rather expected that by observing the painting at the right distance - calculated as three times the length of the diagonal of the paintings - the incomplete fusion of the individual brushstrokes would have generated a "vibrant" optical sensation (perception). This was because, as the influential Symbolist critic Félix Fénéon acutely observed in 1886 (confirming Goethe's intuition, later taken up by Philipp Otto Runge), "the retina, which expects distinct groups of rays of light to act upon itself, perceives in very rapid alternation both the dissociated coloured elements and the resulting colour (optically A.D.)". That Seurat's chromoluministic conception based on a profound sensitivity and optical knowledge is attested by Paul Signac too in the following description of the artist at work: "in front of the subject, George Seurat, before placing a touch of paint on a small flap of canvas, observes, compares, tries to glimpse the play of light and shadows, to perceive contrasts, distinguish reflections, fighting with the argument as he fights with nature; then he draws from the small columns of different pigments according to prismatic colours, different coloured elements constituting the tonality destined to best express the mystery that he has discovered.

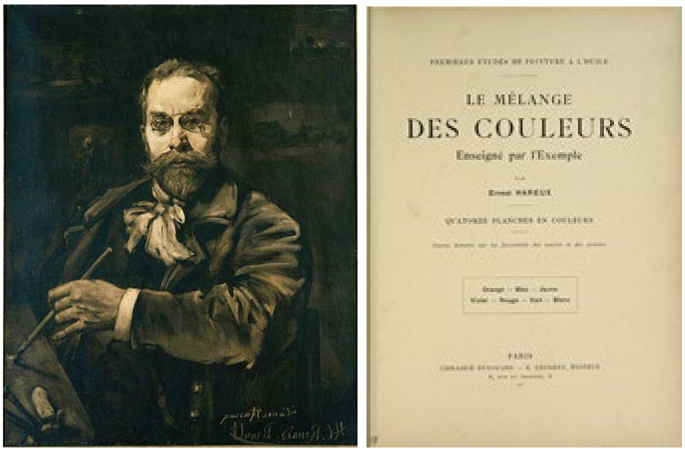

Fig. 14. Ernest Victor Hareux (1847-1909).

From observation to execution, from brushstroke to brushstroke, the painting is realized" (Cullen 1983). A tool to translate chromatic theories for more specific applications is the one shown in Figure 15a: a Complementary Harmony palette, published in 1889 by Ernest Victor Hareux (1900) (fig. 14) conceived as a popular version of the typical Impressionist and Neo-Impressionist palette, confirmation of the expansion that these artists' ideas were reaching. The scarce space grant does not allow to report of a precise list of the individual colours.

Fig. 15. Colour palettes: a. Hareux, Palette of "complementary harmony", 1889; b. Hareux, Le melange des couleurs, 1889; c. Paul Signac, "Prismatic" palette; d. Georget Seurat, Palette.

A brief but significant methodological reflection, aiming at integrating other methodological approaches of a geometric-mathematical nature - beyond the one on the theories of colour - is necessary here. It should remember that George drew inspiration not only from numerous research on physiological optics, such as Rood's - already mentioned - but also from Les phèonomenes de la vision by David Sutter, a critic from Geneva (Sutter 2018), intent on comparing mathematics and musicology.

From the latter, a teacher of Aesthetics at the Ecole des Beaux-Arts from 1865 to 1870, attentive to the construction of figures according to precise geometric patterns, Seurat confirmed (after 1886) the tendency to systematize a visual project more attentive to the geometric composition of the whole and the spatial rendering, also according to the perspective principles (moreover already clearly participant in Blanc's treatise). This conviction reinforced Charles Henry's pseudo-scientific theories (Henry, 1889) based on the principles (fashionable at the time) inspired by the physiology of the nervous system (Maffei 2008).

Based on this, in 1887 George conceived the work La Parade, (fig. 16) with a strict geometric-mathematical structure (between cognition and unconscious) derived from the theories on Dynamogenicity by the scientist.

Fig. 16. George Seurat, portrait; George Seurat, Parade du Cirque, 1888.

4. Previati and the Scientific Basics of Divisionism

The influence of Seurat and on some Italian painters became evident in the First Triennal in 1891 in Milan. Led by Grubicy de Dragon, and codified later (in 1906) by Gaetano Previati in his Principi scientifici del divisionismo (la tecnica della pittura): it is an emblematic title establishing and expressing the programmatic and not casual relationship between scientific way of thinking (also in the chromatic field) and expressions of art, in a relationship known and addressed in all its complexity.

Some painters - mainly in Northern Italy - experimented with these techniques at various levels: they combined Neo-Impressionism with Symbolism, creating paintings (not only realistic) using a divisionist method. For example, Pellizza da Volpedo applied the technique to social (and political) subjects such as Disappointed Hopes (1894) and The Rising Sun (1904).

It was, however, in the theme of landscapes that Divisionism found strong supporters, including Segantini, Previati, Morbelli and Fornara, also playing an important role in the work of the Futurists: Gino Severini (Souvenirs de Voyage, 1911, fig. 17); Umberto Boccioni (La città che sale, 1910, fig. 18); Carlo Carrà (Uscita di scena, 1910, fig. 19) and Giacomo Balla (Lampada ad arco, 1909, fig. 20).

Previati designed his book as a broad and articulated review of critically presented treatises and Authors, in the concrete possibilities and application methods too, in an interdisciplinary dimension. In one of the first chapters, La percezione normale dei colori he talks about the importance of the perceptual whole: "Furthermore, to make a colour right and natural, it is not only the accuracy of its copy from life, as a separate colour, but how much the harmony of the adjacent colours contributes", underlining "the difficulty of arousing an aesthetic balance, completely independent by methodical considerations". He takes the example of the various tones of green that can induce an unpleasant effect: "the serious difficulty of harmonising greens, Rood observes, is well known to all painters and many of them avoid using them as much as possible. The presence in a painting of colours approaching blue-green or emerald-green exerts an almost general feeling of repulsion and makes even a considerable work appear cold and hard" (Rood 1881, p. 56, footnote 5).

Fig. 17. Gino Severini, Souvenirs de Voyage, 1911.

Fig. 18. Umberto Boccioni, La città che sale, 1910.

Fig. 19. Carlo Carrà, Uscita di scena, 1910.

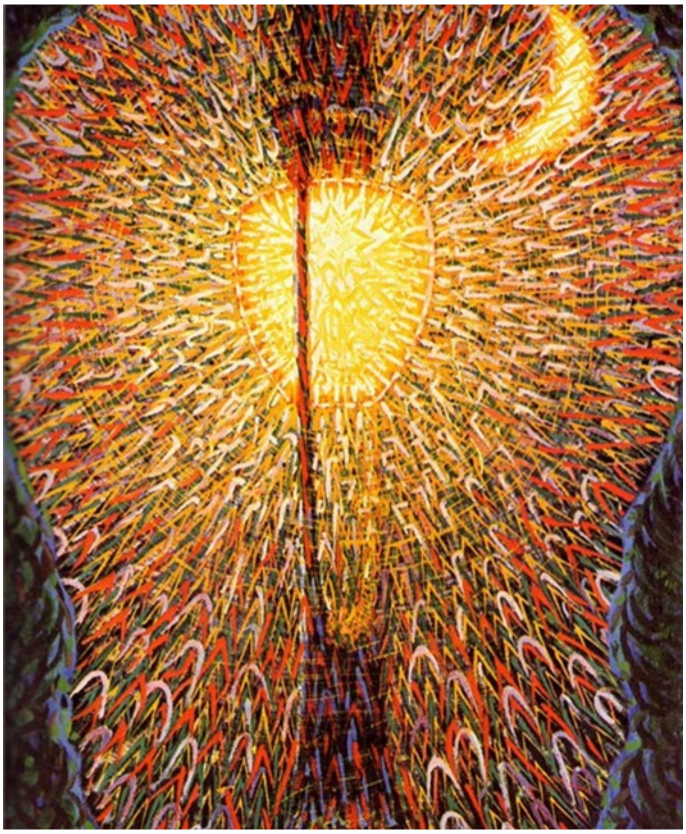

Fig. 20. Giacomo Balla, Lampada ad arco, 1909.

In the chapter on luminosity, Previati agrees that "common to every degree of luminosity, because it is a distinction typical of radiant energy, is the sense of vibration, by which bodies that are touched by light seem to become animated as if the force that arouses vision were in them, a force in which the colouring substances also participate, as long as they are illuminated in the common conditions of the other objects of reality, but which they lose in pictorial use, losing also the property of transmitting the sense, when their use is conditioned by the technical means of impasto and velatura".

And again in relation to the techniques, Previati mentions pastels and tempera which, "compared to wet painting and oil painting, represent a quite relevant difference in tonality, one could say they are brighter than oil paintings and frescoes, while this is not the case, artistically, as long as the art, with which the truth is interpreted, remains equal in the one and in the other; for the obvious reason that the merits of art do not consist, nor come from the qualities of the materials used, but from the relationships that the artist establishes between the colours he uses. He then notes that excessive brightness "substitutes the sensation of pain for that of pleasure".

To give examples - among many others - about the brightness of colours, Previati compared Helmholtz to Bellotti (Bellotti 1886: 93) with Rood's "rotating discs", of which he punctually reported the values in percentage. He defines the models of chromatic theories as "colour cards or tables" with which one tries to offer the complementary of a specific colour at a glance through graphic means or arithmetic calculations. It belongs to the empirical process of determining the complementary colours", considering Newton "the first who had the idea of distributing the 7 colours in a circle that he found most effective in the prismatic spectrum by arranging the saturated colours on the periphery and degrading them to pure white in the centre of the circle". Among the authors, he then cited Otto Runge and Chevreul, demonstrating a more attentive knowledge of Maxwell and Rood.

Fig. 21. Gaetano Previati, La danza delle ore, 1899.

Fig. 22. Gaetano Previati, Paesaggio, 1910.

Chevreul - he noted - used a circle divided into three equal parts by a triangle resulting from three rays by an angle of 120°. For each angle, he placed the typical red, yellow and blue of the solar spectrum and between these he introduced three intermediate shades, thus constituting the first circle of pure and intense colours to the maximum degree, then continuing the description with the "second circle". But he continued with a critical note: "But the defect of this is to give as a reference for real lights the result of mixtures of colouring substances, as indeed all similar papers do, and from these to attribute a way of behaving similar to the mixtures of light rays (therefore confusing additive synthesis with subtractive synthesis), and what most disconcerts every criterion on the intrinsic and enormously different properties of light rays and material colours, that regular distribution reducing the ratio between lights and conversion colouring dyes or volumes of things that cannot be equivalent".

Fig. 23. Giovanni Segantini, The Nature Triptych, Life (becoming), Nature (being), Death (passing away).

Keeping on with the comparisons, he stated that even Rungen "tried to solve this difficult problem, as the Chevreul's chromatic hemisphere (instrument of mediation between Maxwell's triangle and Rood's one, an unsurpassed monument of the tenacious belief of the practical advantage of a systematic ordering of colours among scientists". But this means (it is still Gaetano's way of thinking) "it could not be a guide for the painter, if not when the knowledge about colours and the means to analyze them and those to reproduce them - as Rood opines - respond to a truly scientific classification and execution plan and it is not subject to any arbitrary ideas”.

The possibility of experimentation for the research of complementary colours is more optimistic with the application of the "rotating discs", or Maxwell's discs, based on the mixture obtained from the rotation of different colours.

5. Concluding remarks

In chapter XII about Divisionism, Previati arrives at first partial reflections: "The breakdown of colours tends to obtain luminous vibrations, as well as from the overall shade of the painting, from every single element with visible derivation's from Mile's method, it is enlighted only in the pointilliste, to assume a definitive systematic character in Segantini's works (fig. 23), in particular in the great triptych Vita, natura e morte, a milestone of the glorious journey of art in the conquest of luminous objectivity, the goal of the breakdown of colours".

Previati concludes the argument thus: "as long as more detailed investigations into the priority of the practice of the breakdown of colours in painting will come from art historians, we must therefore reserve to Mile the possession of the hitherto unknown property of an unknown colouring substance, that is being able to reproduce the additions of light through a methodically minuscule separation of complementary colours, which today takes the name of divisionism in art.

These last words confirm how much comparative chromatic theories are an essential approach for a correct context of the birth and development of artistic movements, starting from Impressionism onwards. They constitute the Fil Rouge linking the protagonists of science and art of the chromatic culture of the time - by analogies or differences: as we have experienced and proved (authentic organic system to analyze and learn), they can enrich the culture of chromatic vision (understood as Weltanschauung, that is a complex and interdisciplinary vision of the world) which can still be full of new developments and reflections, in a renewed awareness.

6. Conflict of interest declaration

The author declares that nothing has affected her objectivity or independence in the production of this work. There are no actual or potential conflicts of interest, including financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, this work.

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About the influence of color perceived lightness on psychological functions

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ABSTRACT

As human beings, we are continuously exposed to stimuli that modulate our psychological functioning and behavior, presumably through the influence exerted on our emotions. In literature, among others, the feature of color, mainly as related to the three attributes of hue, chroma, and lightness, represents one of the most explored topics. By the way, the multidisciplinary lens through which it has been investigated and the partial lack of methodological rigor make it difficult, thus far, to unify the research evidence while being able to disambiguate the single contribution of each color's attribute. The current review aims to provide an overview of the most recent literature, focusing on evidence that highlights the role of the perceived lightness of color, in its function as well as aesthetic properties, in influencing psychological functions and behavior. Practical implications and future directions in this research area are outlined.

KEYWORDS Color, Lightness, Psychology, Context

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1. Introduction

Our world is full of stimuli that constantly bombard us, and we tend to give meaning to these stimuli. The stimulus that we perceive, most of all, and that involuntarily modifies our behavior is color. Throughout history, different disciplines, with different research methodologies, have dealt with the study of color. Through a series of theoretical and empirical works, they have created a general framework on the subject, as shown in other review works (Elliot, 2015). The scientific literature presents several works on various aspects of color as a stimulus, such as the physics of color (fundamental properties of color), the physiology of color (processing color information), and the language of color (naming a certain color in different countries); these works have given an idea of how to study color in all its characteristics. However, even today, defining the term color, giving a definition that can be accepted by all the disciplines that study it, is a very difficult challenge. Throughout history, color has been defined in a myriad of ways, and it is fair to say that a universal and definitive definition has yet to emerge (Kuehni, 2005). In a psychological perspective, to fully define or understand the term color, it is important to distinguish two main characteristics that comprise it, the first being the physical nature of the stimulus as such, and the second being the response of the individual who encounters the color (Hunt, 1978). In this case, color can be described as that perceptual phenomenon present in everyday life, capable of influencing our mood and our behavior according to the emotions it arouses. Since the 2000s, there has been a boom in the scientific literature on the subject of color and psychology, with research in this field generally dealing with the relationship between color and human cognition in a broad sense. Unfortunately, as other authors have pointed out, (Elliot and Maier, 2014) research in this field does not all have good methodological rigor. By methodological rigour we mean various aspects including, Failure to control the physical characteristics of colour leads to a confusing design and results that are essentially impossible to interpret (Valdez & Mehrabian 1994). For example, if more than one colour attribute varies at the same time, it is not possible to determine whether a result obtained is due to the colour attribute of central interest or to one or more of the other colour attributes.

In this review, the main aim is to shed light on the previous literature on colour and emotion, and in particular we will focus on the emotions that modulate cognitive performance through lightness. We will analyze recent theories and research regarding the possible relationship between emotions and the perceived lightness of color. Given the vast number of theories on color, starting from Aristotle, Newton, and Goethe, and also given the exponential growth of publications on the subject, we will focus only on the most recent and influential theories concerning the influence of color on emotion, utilizing the most objective works that have methodological rigor. Up to this point, it is best to be patient and humbly acknowledge that the psychology of color is an extraordinarily complex area of inquiry (Kuehni 2012) that is only beginning to manifest itself. The results of color research can be misleading, and because of the great interest of the various areas of research, it can be tempting to conclude before the scientific research is fully in place. There is considerable progress in research on color and psychological functioning, but much more theoretical and empirical work needs to be done before the full scope of this proposal can be identified and hopefully realized, perhaps yielding universal conclusions. So far, a limitation of previous research, which we will try to show in this literature review, is that most of the research conducted in this area, and related theories, has focused heavily on a single colour characteristic, hue. The purpose of this work is to show the importance of other colour characteristics, one of which is lightness.

2. Background on color and emotions

Color exists only in the mind; that is, it is a highly subjective experience that creates strong individual differences (Helm and Tucker, 1962). This can be described as a perceptive, highly subjective response to light entering the eye directly from self-luminous light sources or, indirectly, from light reflected by illuminated objects. Without going into too much detail, our visual system perceives the colours present in the colour spectrum thanks to the presence of three types of cones with different spectral sensitivity, they can be divided into three types, S cones (short), M cones (medium) and L cones (long). At this point, the definition of color that may be considered the most popular at present is the most recent offering provided by the CIE (International Commission on Illumination): "color (perceived): Characteristic of a visual perception that can be described by attributes of hue, lightness, and chroma", and each of these attributes can influence psychological functioning (Suk and Irtel, 2010). In order to better understand this review work it is necessary to point out a distinction between lightness and brightness, which are often confused in the scientific literature. Brightness is the attribute of a visual perception according to which an area appears to emit, or reflect, more or less light, while, lightness is the brightness of an area judged relative to the brightness of a similarly illuminated area that appears to be white or highly transmitting. In summary, color perception provides us with a representation of the physical objects and lights in our three-dimensional environment (Brindley, 1970; Geisler, 1989). This process allows us a complete understanding of the space around us through different processes. the global process of "color perception" gives us a description of the physical properties of these objects and lights; a description of how information about these physical properties is transported by light to the eyes and stored by optics to form the retinal image; a description of how retinal photoreceptors respond to the retinal image; a description of how photoreceptor responses are transformed by visual processing into the way we see the world; and finally the emotional connection generated by the color-object interaction". Each physical characteristic of the color taken individually has little value, but studying them individually allows you to better control the chosen variable, giving it the right importance. One of the characteristics of color that has been little considered up to now is the perceived lightness (which we will discuss in detail later). Lightness is important as it allows us to optimally perceive an object; in this regard, it is right to introduce a neurological disorder (still unclear), in which sometimes it is the only component present. This pathology is known as "achromatopsia", literally means "not seeing colors", or severely reduced ability to discriminate between different colors shades (Heywood and Kentridge, 2003) but which allows, in different cases, to still perceive lightness (Cole et al., 2003) "Monochromatism" means "seeing shades of one color" (seeing the world in shades of grey). In this pathological condition, the fundamental importance of perceived lightness is highlighted and an in-depth study in this field will allow us to identify differences related to the "lightness" variable alone compared to the other physical components of the color.

Color has fascinated scholars for millennia (Patricia, 1991; John, 1993). As a starting point for psychological theories associated with color, one could point to when the theory of color and psychological functioning has been present since Goethe in 1810 wrote his "Theory of Colors" (Johann Wolfgang Von Goethe 1982), in which he linked color categories to emotional response (e.g., warmth, arousal). Historical research on the topic has created at least general conceptual statements about color and psychological functioning, particularly with the general associations people have with colors and their corresponding influence on emotions, cognition, and behavior (Frank and Gilovich, 1988). As mentioned, color can have psychological and behavioral effects (Elliot and Maier, 2014), and it can also have purely aesthetic properties (Schloss and Palmer 2015). Other studies have investigated the relationship between color and other more specific psychological variables, such as sexual attractiveness (Pazda, Elliot and Greitemeyer, 2014), intellectual performance (Shi, Zhang and Jiang, 2015), and food consumption (Genschow, Reutner and Wänke, 2012; Bruno et al., 2013). It is known that emotions can influence our cognitive functions, and these in turn are influenced by colour. In the last twenty years have seen an increase in research in the field of color on different cognitive functions, in fact, if we search in Google Scholar 'colour and cognitive functions', we get around 2 million scientific articles. One of the most investigated cognitive functions is the attentional process influenced by color. On selective attention, for example, it has been shown how red stimuli receive an attentional advantage (Elliot and Maier, 2007). Research on color and alertness has shown that blue light increases subjective alertness and performance on attention-based tasks (Chellappa et al., 2011). Other cognitive functions have been investigated as studies on color and athletic performance have linked the use of red to improved performance and perceived performance in competitions and sporting activities (Elliot and Maier, 2012). Empirical work on color and avoidance motivation has linked viewing red in performance contexts to increased caution and avoidance (Elliot and Maier, 2014). Other studies, on the other hand, have investigated the relationship between memory-emotion modulated by color and how it affects performance in older adults (Mammarella et al., 2016).

As seen from the extensive reference literature, all effects of color undoubtedly depend on certain psychological conditions (or variables) that are independent of the stimulus but vary from individual to individual. These variables have been greatly underestimated until a few years ago (Schloss, Hawthorne-Madell and Palmer, 2015), variables such as the culture of belonging, sex, age, the emotional state of the individual, and the type of task (in the experimental case). These variables make the color-emotion interaction a process that cannot be underestimated and it is not universal. The awareness and realization that understanding these conditions will be an important marker of maturity for future work in this area (Schwarz and Singer, 2013; Tracy and Beall, 2014). These variables, hitherto underestimated, have created several methodological errors, creating results based on false expectations. It is therefore necessary to take individual variables more seriously, and give them their due importance. Starting from the idea that color exists only in our minds, it is important to describe individual differences in color perception. In this regard, a recent psychological theory, the "color in context" theory (Meier et al., 2012) is based on social learning and biology. This new strand of research, with a more fully comprehensive view, for this theory all three of color properties may be important, at both the main effect and interaction levels, with regard to links between color and affect, cognition, and behavior, In addition, this theory places at the center a new variable that can influence psychological functioning, the context. Some responses to color stimuli are presumed to be due solely to the repeated matching of colors to concepts, triggering particular experiences. Others, however, are presumed to represent a biologically ingrained predisposition that is reinforced and shaped by social learning, as in a mechanism of natural selection (Humphrey, 1976). The theory introduced, through this social learning process, color associations can be extended beyond natural bodily processes (e.g., blood flow modulations) to objects close to the body (e.g., clothing, accessories), making the theory applicable to various contexts, taking into account the variables listed above. As the name of the theory implies, it is believed that the physical and psychological context in which the color is perceived influences its meaning and, consequently the responses related to it.

3. Color controversy

A constant feature of this work points to important methodological problems that precluded rigorous testing and clear interpretation (O'Connor, 2011). One such problem has been the inability to pay attention to scientific procedures including investigator blindness to the condition, identification and exclusion of color-deficient participants, and standardization of the duration of color presentation or exposure. One of the most common mistakes is the inability to specify and control color on a spectral level in manipulations. Without this specification, it is impossible to know what precise combination of color properties has been studied and without such control it is inevitable to confuse focal and non-focal color properties (Valdez and Mehrabian, 1994). Another problem is perhaps due to an optimistic view of one's research, as the effects of variables are inflated and given for universals (Elliot and Maier, 2014), color stimuli can also vary in terms of perceived typicality (the degree to which a color resembles a commonly seen representation of that color category). Thus, more rigorous experimental work addresses both the multidimensionality and perceived typicality of color stimuli in manipulations; most research has not addressed either simultaneously. All of these methodological problems have greatly hindered (rigorous) scientific progress in this area. Color control is typically improperly performed at the device level (rather than the spectral level), is impossible to implement (e.g., in web-based platform studies), or is ignored altogether. Color control is certainly difficult, as it requires technical equipment to evaluate and present color, as well as the experience to use it. However, careful color control is essential if systematic scientific work in this area is to be conducted. The results of uncontrolled research can be informative in initial explorations of color hypotheses, but such work is inherently fraught with interpretive ambiguity that must be subsequently addressed. The process of color perception is not only a function of hue (is "color's name", which represents a particular wavelength of visible light), lightness (represents the degree of reflected light), and chroma (refers to the intensity and purity of a hue), but also of factors such as viewing distance and angle, the amount and type of ambient light, and the presence of other colors in the immediate background and general surroundings (Fairchild, 2015). In basic scientific research on color, these factors are carefully specified and controlled to establish standardized viewing conditions for participants. These factors have been largely ignored and have allowed for variation in research on color and psychological functioning, with unknown consequences.

To date, most theories have focused on hue, one in particular, red, which is understandable given its importance in nature, body, and society (Changizi, 2009). However, other hues also carry important associations that undoubtedly have effects on psychological functions such as green and blue (Akers et al., 2012; Labrecque and Milne, 2012; Mammarella et al., 2016). But lightness and chroma also undoubtedly have implications for psychological functioning (Lee et al., 2013; Kareklas, Brunel and Coulter, 2014); lightness has received some attention within conceptual metaphor theory (Prado-León and Rosales-Cinco, 2011), but chroma has been almost entirely neglected, as has the problem of combinations of hue, lightness, and chroma. Finally, it is also likely that many situational (Bubl et al., 2010) and intrapersonal (Fetterman, Liu and Robinson, 2015) factors influence color perception such as the concept of color preference (Palmer and Schloss, 2010). The complexity of color as a stimulus capable of creating psychological effects needs more attention and further scientific research in this regard, for while much has been done just as much remains unexplored.

4. The lightness effect

The aim of this paper is to show the few studies on the subject of lightness, and to show how it may be of interest for future studies. On a physiological level, lightness of color influences the production and release of hormones. Color perception stimulates the neural portion of the optic pathway in the hypothalamic brain region and the pineal and pituitary glands, which control the entire endocrine system (Mahnke, 1996). Empirical work demonstrates the physiological effects of color in both animals and humans (Bellizzi, Crowley and Hasty, 1983), with physiological effects such as heart rate, respiratory rate, blood pressure, muscle activation, blinking, palmar conductance, and brain waves. In this paragraph we will focus on the importance of one of the fundamental dimensions of color, lightness, which is just as important, if not more so, than hue (Gorn et al., 1997; Labrecque and Milne, 2012). It has been known for many years that light directly influences physiology and increases arousal, but the effects of light can be non-visible and influence behaviour by modifying the biological state of the individual (Cajochen, 2007).

In the field of neuropsychology, cognitive performance refers to the ability of the human mind to acquire, store and process information, to solve problems of any kind, from the simplest ones, such as the needs of daily life, to others decidedly more complex to study, such as the level of subjective vigilance and the level of alertness that involve the brain, and in particular the attentional process. In this regard, color lightness can influence all these factors by modulating the cognitive performance of individuals (Rossi, 2019). There are non-visual effects of lightness that affect the human body through mechanisms other than melatonin regulation, through direct action on the human nervous system and with consequences that affect alertness level (or attentional process) (Cajochen, 2007) mood (or emotion) (Legates, Fernandez and Hattar, 2014) behavior (Chellappa et al., 2011), and other human physiological parameters such as heart rate and body temperature. All this effects can affect the cognitive performance in every behavioural choice. In general, light and lightness, represent the core of the process of visual perception, through transduction, the process by which the energy (light) of environmental stimuli is converted into neural activity. Leaving aside the difference between natural and artificial light, which have important differences between them (Jazizadeh and Wang, 2016), we will focus on the concept of lightness in general, without making this distinction. The effects of light on psychological components can be divided into several categories encompassing all human cognitive functions.

4.1. *The lightness effect on Emotion*

The human being is guided in his behavior by emotions and they are regulated by the context and experience (Mesquita, 2007). The emotions triggered by the external environment change the internal state of the individual going to affect the regulation of body temperature, mainly due to endogenous phenomena such as sweating and vasodilation. The ability to perform this regulation depends on the body surface involved and on the temperature difference with the external environment. In this regard, a study has analysed research that relates the amount of light to thermoregulation and the subjective feeling of thermal comfort. In some cases, light with color shades that turn toward red induces a feeling of greater environmental warmth than light that turns toward blue (Te Kulve et al., 2016, 2017). However, the results of the latter type of research are sometimes contradictory because the context, mode of experimentation, and detection of results differ. In this perspective, psychological factors may also come into play, leading to different results in different social and cultural contexts. A non-pathological condition, winter depression or seasonal affective disorder (SAD) is a disorder that affects people during the winter who are normally healthy during other seasons of the year (Targum and Rosenthal, 2008). The symptoms are those types of depression, such as lack of energy, tendency to sleep a lot, but also obesity, asthenia, insomnia, and difficulty in concentrating. It has also been observed that the same subjects in summer can show symptoms of intensified anxiety. For this reason, today this disease is no longer considered as an exclusive winter mood disorder, but as a disorder that can recur at different times of the year with different symptoms. Studies have shown that the likelihood of contracting this disease is greater with increasing latitude and particularly in Nordic countries, especially when exposed to solar radiation is lower (Rosenthal et al., 1988). How color lightness relates to emotions is the subject of much psychological research, but the results are difficult to assess for practical use, the reasons for this are both technical and conceptual. On the technical side, color-emotion data have been collected using experimental methods that vary widely in precision and scope, as described below.

To our knowledge, many of the studies on color and the relationship between color and emotion, to date have not used an objective method for studying color, not applying a correct description of color, without restrictions to specify the color (with a correct description of its characteristics) that best corresponds to a given emotional stimulus. These methodological problems make it very difficult to correctly study the physical characteristics of color such as lightness, which is a less studied characteristic than hue. If we wanted to list all the studies on the subject of colour associated with psychological characteristics, a review would not be sufficient, given the extensive literature on the subject. Our aim, in fact, is to analyse the psychological functions influenced by colour lightness. In this respect, it is important to emphasise the role of emotions in this interaction, as they are a ubiquitous aspect of human beings and which in turn influence the various human cognitive functions (Dolan, 2002), as we shall see in detail.

4.2. *The lightness effect on Attention*

Visual attention comprises a set of mechanisms that modulate sensory and cognitive processing to select the most behaviourally relevant stimuli for further limited-capacity processing. Which of the many retina-affecting stimuli will be selected is determined by both the task goals (top-down factors) (Folk, Remington and Johnston, 1992) and the current stimulus processing (bottom-up factors) (Itti and Koch, 2000). How top-down and bottom-up mechanisms interact in selection is still much debated (Beck and Kastner, 2009). The effects of light and lightness are visible in human behavior. These include behavioural changes throughout the day (circadian rhythm), in fact, the reaction times (in terms of behavioural response to any daily task) are generally longer in the early morning and decrease for the day only to increase again during the night and peak in the early morning (Posner and Petersen, 1990). These measures reflect other diurnal changes such as body temperature and cortisol secretion. This essentially modifies an attentional mechanism called “alertness” (Petersen and Posner, 2012); in this case there are at least two definitions of alertness, namely, the terms phasic and tonic alertness (Posner and Petersen, 1990). Phasic alertness refers to the orientation response (Sokolov, 1963) and tonic alertness will be used as a synonym for vigilance and sustained attention, these mechanisms can be influenced by colour lightness.

For example, the psychophysiological and behavioural effects mediated by light stimulation, this by assessing differences in illumination (Badia et al., 1991). The level of alertness, assessed with EEG through beta brain waves (14-30 hertz), showed a significant increase in the strong light condition, which also had the effect of decreasing drowsiness and increasing body temperature, going to modulate the alert attentional state. In another very relevant study (Cajochen et al., 2005) the focus was on the chromatic component of light (blue light with a peak at 460 nm and yellow light at 550 nm). In the blue light condition, in addition to observing a reduction in melatonin, there was an increase in body temperature, heart rate, and level of alertness of the subjects involved. This did not occur with exposure to yellow light. Similar results were also observed where participants were in a normal office setting (Smolders, de Kort and Cluitmans, 2012). The results showed that with the brighter lighting the subjects had shorter reaction times, higher alertness level, and increased heart rate, especially towards the end of the hour of exposure to the stronger light. These results would demonstrate that even under normal daytime conditions, not in the dark and temporally away from rest periods, i.e., under physiological conditions other than those in which melatonin regulation comes into play, brighter light can improve feelings of alertness and vitality, as well as subjective performance and level of physiological activation.

4.3. *The lightness effect on Memory*

Memory is now defined in psychology as the ability to encode, store, and retrieve information (Squire, 2009); focusing on these processes, one research study investigated the effects of different wavelengths of light on brain waves associated with memory processes (Okamoto and Nakagawa, 2016). Cortical activity was monitored using magnetoencephalography (MEG) The experiment was conducted by exposing subjects for 30 minutes (during the day) to two different lighting conditions, green light (with a peak wavelength of 520 nm) and blue light (with a peak wavelength of 470 nm). The results showed that blue light increased cortical activity related to active maintenance of working memory. Similar results were also observed in research in which, instead of monochromatic lights, they used two white lights 3,000 (warm light) and 5,000 K (cool light), noting that the 5,000 K light stimulates the central nervous system more (Noguchi and Sakaguchi, 1999). Working memory in the human cognitive system is a part of memory, with a time-limited capacity, that supports the temporary storage of information available for brain processing (Wynn and Coolidge, 2011). This cognitive structure is important in reasoning and in guiding decision-making and behavioral processes. It should not be confused with short-term memory, which simply stores information temporarily but is not directly related to the brain's processing of information (Cowan, 2009). Working memory is a central theoretical concept in cognitive psychology, neuropsychology, and neuroscience in general. it is essential for learning activities and problem-solving.

4.4. *The lightness effect on Memory*

A popular way to study decision-making is undoubtedly the studies on consumers going so in the field of marketing. Recent studies in this field are studies on cross-modal associations (two senses in one) (Spence and Parise, 2012) in this regard the lightness of the color is associated with characteristics such as hot-cold, or sad-happy (Kaya and Epps, 2004). The effects of the new correspondences between somatosensory and visual perceptions (warmth and color lightness) extend from capturing visual attention to preference formation, as well as on how attitudes toward sensory experiences (i.e., positive reactions to sensory experiences) play a critical role in preference formation. The results showed the existence of cross modal correspondences between the sensation of warm and light colors (Motoki et al., 2019). Thermal environment and product color are important considerations when designing marketing strategies for many business settings. Stores can usually control the ambient temperature using air conditioners, and light/dark colored products are displayed in such locations. Recognition of the impact of sensory experiences in natural shopping environments has led to increased attention to the effects of such experiences on consumer behavior (Krishna, Cian and Aydınoğlu, 2017). Still, other studies, show how the color of a dark (versus light) product encourages higher durability ratings but lower ease-of-use ratings (e.g., a PC) (Hagtvedt, 2020). Both of these influences are related to the impact of color brightness on perceived weight: darker (compared to lighter) colors cause objects to appear heavier (Sunaga, Park, & Spence, 2016). However, there is still little evidence in this area of study.

4.5. *The lightness effect on Sleep*

Light and lightness affect the circadian rhythm by compromising sleep (Rossi, 2019). Many people suffer from sleep disorders, which can have different causes and different effects, even of a serious pathological nature, which hinder a healthy daily life both from a physiological and psychological point of view, interfering with emotional states and social relationships (Vgontzas et al., 1999). The most well-known disorder is that of insomnia, which occurs when the individual is unable to fall asleep despite being tired and having an actual physiological need to sleep (Lockley et al. 2008). The effects of insomnia also affect the quality of daily life, as affected individuals often have difficulty concentrating and learning, related to the malfunction of working memory, but also chronic fatigue and irritable mood. In general, the main discomforts, which occur in 40% of cases of people suffering from insomnia, are psychiatric disorders, particularly depression and anxiety (Roth, 2007). Another form of sleep disorder is nocturnal bruxism, which has very serious negative effects: erosion of the teeth down to the dentin, with an increased likelihood of fracture and of developing tooth decay and inflammation of the tongue. It can also induce headaches in the temporal areas, with possible ear discomfort caused by repeated nightly tension of the muscles acting on the jaw. This type of disorder results in restless sleep with nightmares, restless leg syndrome, increased heart rate, and various other types of disorders, including bruxism. It has been shown that approximately 86% of nocturnal bruxism episodes occur during restless sleep (Lavigne et al., 2007). These are some of the most well-known sleep disorders. In this field, some well-known research has shown that the use of bright light in the morning can help with typical sleep disturbances with subjects with an unbalanced circadian rhythm (Figueiro and Rea, 2016), while strong lighting (2,500 lx) after 8:00 pm can help reset the circadian rhythm and alleviate the typical disturbances (Lack and Wright, 2007). A review of the literature examined 21 research studies that investigated the use of light as a therapy for sleep disturbances, such disturbances being much more common in the elderly population. The elements that were considered were the amount of light, spectral power distribution (SPD) of the light, time of exposure to light, duration of exposure, and direction of light (Sloane et al. 2008). The positive effects of light on proper sleep timing and quality have been verified, several effects of light wavelengths have in this context have been highlighted (Figueiro and Rea, 2016). Thus, excluding the need for excessively bright (annoying) lighting that is not applicable in the design reality, and instead of using normal comfortable lighting systems with white light and adequate content of short wavelengths (blue). There is now broad scientific consensus that light can be used as a therapy to improve sleep quality for all individuals (Figueiro and Overington, 2016).

5. Conclusion

The effects of light are varied, and are not limited only to the effects we have mentioned above; in fact, we can go on to say that the effects that light and lightness can have on learning environments have been a topic of research for some time. For example, three studies conducted in Sweden (Küller and Lindsten, 1992) and the USA (Heschong, Wright and Okura, 2002) have demonstrated the importance of the presence of windows and natural light on students' psychophysiological well-being and performance. Two of them also demonstrated that these positive psychophysiological and performance effects are absent in windowless classrooms. We could go on describing other effects of light and lightness on cognitive performance, but while it is true that much has been done so far, it is also true that not enough has been done, due to the experimental limitations outlined above, with the lax way of conducting such research in the field being most to blame. Moreover, the study of psychological effects related to color is a very hot topic, and one should approach it more cautiously without drawing hasty and universal conclusions. Color is too complex a phenomenon or concept to "take lightly" its study, then associated with cognitive functions is an even more difficult task because of the many variables involved. Just think of the physical characteristics related to color and how difficult it can be to study them rigorously if you then have the "scientific presumption" to associate them to psychological characteristics without taking into account variables such as context and individual variables (just to mention a few) you fall into error. This work shows various limits of research in this field, it is hoped that this overview will let us think about the complexity of the stimulus and the importance of its correct decomposition into physical characteristics. Perhaps by studying these characteristics individually, giving them all the right importance, it will be possible to obtain a more accurate result than those obtained so far; it is hoped that the focus of research will also shift to color characteristics such as lightness because, as shown, it matters a lot and its effects are visible.

6. Future directions

On the subject of the psychology of color (in all its parts) and its effect on emotions, there has been an exponential growth in the number of scientific publications in the last twenty years. Being the topic of interest for several disciplines it is easy to think that the growth of publications will not stop in the recent future. Technological advances have allowed other disciplines, such as neuroscience, psychophysics, visual cognition, and biology, to gain new insights into understanding the complexities of color perception using new populations and/or new methods such as neuroimaging (e.g. fMRI, ERP, MEG), eye-tracking or modeling (computational or mathematical) (Shevell and Kingdom, 2008). The hope is that along with basic research, the results obtained from them can be made applicable.

7. Conflict of interest declaration

The authors declare that no conflict of interest, real or potential, including financial or personal links with other persons or organizations.

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Colour measurement and documentation in historical buildings: the case study of the Kirna Manor House in Estonia

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ABSTRACT

Historical buildings and their decorative apparatus have a key role in the transmission of national and local traditions, requiring careful conservation of these structures and their overlapping decorative layers, mostly made up of stuccos and coatings. Unfortunately, the procedures and methodologies for both documenting and preserving such cultural heritage are not clearly standardised in Estonia, where most historic manor houses are managed by private owners who have no precise guidelines to follow during the restoration of such complex structures. To amend this issue, the Estonian Academy of Arts (EKA) organised an international workshop on “Colour Measurement and Documentation in Architectural Paint Research” with the aim to bring together several experts, techniques and tools from different countries in order to define, optimise and modernise the methodologies employed for the identification, documentation and preservation of historical painted interiors and colours. In addition to a theoretical session, the workshop held in October 2019 entailed practical work at the Kirna Manor House, analysing the entrance hall of the building. The paper presents the results of the research and the discussion between international experts.

KEYWORDS Colour measurement, Colour documentation, Colour vision, Architectural paint research, Historical interior restoration, Estonian manor house, Estonian Academy of Arts

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1. Introduction

The conservation of historical buildings and their ornaments is paramount for preserving national and local architectural traditions. Within this context, understanding the perception of colours and their use on original building decor constitutes a research topic which is relatively understudied. Furthermore, in many countries, including Estonia, the guidelines for standard procedures for colour determination and documentation in architectural paint research are not entirely clear or even unavailable. Nowadays in Estonia, as in several other countries, visual comparison using colour charts/fan decks is the main approach for colour determination in architectural frameworks. The current regulations set by the National Heritage Board of Estonia recommend studying colours using this method, without the mention of scientific measurement devices (appendix to the *Heritage Conservation Act*, 2019). The multitude of methods and the lack of specific instructions cause confusion among researchers, conservators and building owners, as the possibility of subjectivity leading to inaccurate colour determination remains.

In order to improve this issue, the Estonian Academy of Arts (EKA) organised an international workshop "Colour Measurement and Documentation in Architectural Paint Research", held in Tallinn (Estonia) on October 22–25, 2019. Conservators, art historians, specialists in colorimetry and digital reconstruction involved in paint research and conservation from 6 countries gathered to share expertise and gain international consensus on documenting, interpreting and visualising the colour information of historical buildings.

The workshop was organised in two parts: the first was a theoretical session with keynote lectures about the best practices in participating countries followed by a discussion; the second part was practical and carried out *in situ* in the historical interior of the Kirna Manor House (in Järva County, *ca* 100 km from Tallinn, Estonia). In the latter part, research teams were formed and assigned leaders who developed workflows for the identification of historical colour schemes, colour measurement and documentation. For the data acquisition, several systems were used, e.g. colorimeters, a spectrophotometer, colour charts and digital photographic equipment.

The use of various techniques allowed participants to learn from international expertise, compare different methodologies and eventually discuss how to optimise and modernise the identification, documentation and preservation of historical colour information on architectural surfaces in Estonia and abroad (Carbonell Rivera, Montalvá España and Lerma García, 2016; Giannattasio, 2019; Guarneri *et al.*, 2019; Verweij, Schade and Kutzke, 2019). Simultaneously with the paint research, a colour vision experiment was conducted with the workshop participants to test the accuracy of human colour perception. In the final roundtable discussion, practical solutions were suggested, which could be developed into a pipeline including both scientific measurements and historical/visual evaluations.

2. Aims of the workshop

The purposes of the workshop were: 1) to experiment with various paint research methods on the finishes of the entrance hall's vaults and their adjacent architectural features; 2) to test both destructive and non-destructive colour measuring techniques and tools; 3) to identify and date the paint layer stratigraphy, colour schemes, and the ambiguous constructional stages and additions in the hall; 4) to revise the adopted workflow and define the best practice in light of the workshop results.

The practical investigation was organised in five teams, each led by an international expert who instructed their team members according to the prevalent architectural paint research methods in their respective country. The results were documented separately by each team in the form of reports and paint exposure charts compiled by a student of the Department of Cultural Heritage and Conservation (Valge *et al.,* 2020). Finally, the teams engaged in constructive interaction, comparing their results to share reflections and proposals for research improvement.

2.1. *Historical overview of the Kirna Manor House*

The Kirna manor estate and the first wooden manor house were established in the 17th century by the Baltic German nobleman Hans von Fersen, whose family would keep ruling the estate for nearly 150 years (Maiste, 1985). The existing Neo-Palladian building was probably erected between 1760 and 1780 by Otto Wilhelm von Fersen, with Neo-Classical alterations having been made in the early 1800s by the new owner Carl Magnus von der Osten-Sacken (Danil *et al.*, 1985; Parek, 1973). Gothic Revival elements were added to the building in the mid-to-late 19th century when the manor belonged to the Pilar von Pilchau family. The manor estate has a long history of owners, uses and renovations, which is why many overlapping layers of architectural and decorative details and their finishes have been preserved.

The investigation was focussed on the central entrance hall of the building (Fig. 1), which has been extensively modified throughout centuries.

Fig. 1. The entrance hall of the Kirna Manor House, Järva County, Estonia (https://www.puhkaeestis.ee/et/kirna-mois).

3. Experimental methodology

The experimental part of the workshop consisted of: 1) general research documentation; 2) identification and dating of layers under the current finishes; 3) characterisation of the pigments and components used in the plasters and finishes; 4) colour measurements on the preserved paint layers; 5) an experiment for testing the accuracy of human colour vision.

3.1. *General documentation*

The documentation has been carried out mainly producing drawings/notes and photographic material before, during and after destructive exposures and samples. Data gathering dealt with capturing digital images with different devices (smartphones, compact cameras, DSLRs), adding a ruler for size reference and an X-Rite ColorChecker Classic/ Passport Photo 2 for colour reference. One team experimented with a more detailed system for storing image metadata and best quality data such as 1) shooting in RAW format to gather uncompressed data, 2) converting images into lossless compressed formats, 3) processing images, balancing colour and storing useful data for further digital processing (Gaiani *et al.*, 2016; Ramanath *et al.*, 2005).

3.2. *Analysis of hidden layers*

The study of the complex chromatic stratigraphy of the entrance hall was firstly analysed examining the existing photographic material starting from the early 20th century, which, albeit mostly in black-and-white (Fig. 2), helped to clarify some historical decoration stages and colour schemes.

Secondly, small mechanical paint exposures were conducted in strategic areas (i.e. where colour changes were detected in historical images), such as walls, pillars and pilasters, window and door openings, the stucco decor on the vaults. Although the latter is a relatively destructive technique, paint exposures proved essential in discovering previous decorative phases and paint colours. The revealed layers were identified with a shared indication system, numbered in chronological order starting from the oldest and compared in various areas to verify the layer order and chromo-chronology (Fig. 3).

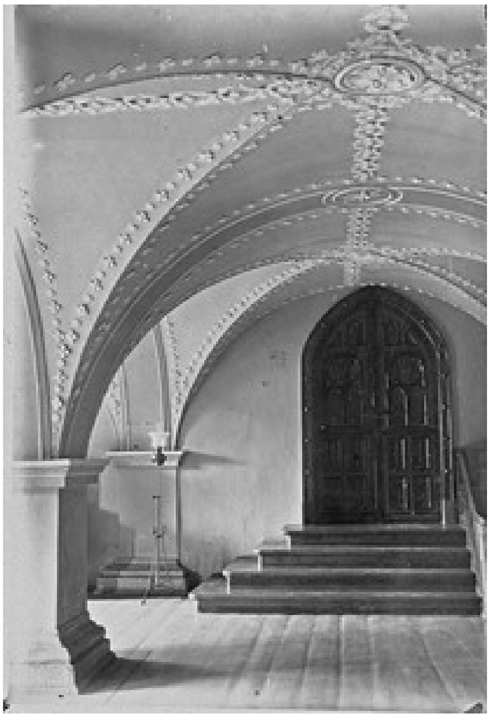

Fig. 2. One of the earliest photos of the entrance hall, ca 1910 (Estonian National Museum, https://www.muis.ee/museaalview/666779).

Fig. 3. A paint exposure with the finishes chronologically numbered.

3.3. *Analysis of hidden layers*

In addition to on-sight evaluations of the paint ingredients, paint cross-sections detached with scalpels were examined in the laboratory under a microscope under visible and ultraviolet light, and scanned with an electron microscope (SEM), which enabled to correctly identify the paint stratigraphy and some pigments (Fig. 4).

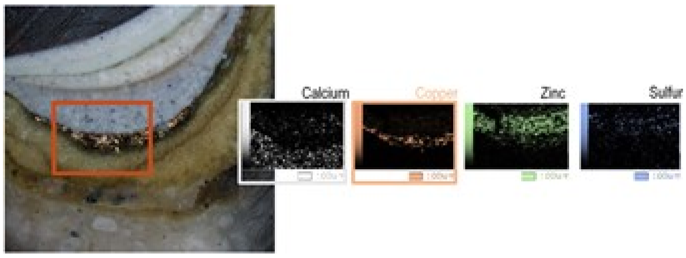

Fig. 4. The SEM analysis detected the presence of copper and zinc in a metallic paint layer uncovered on the decorative piping on the vault arch edges, which implies it is brass paint or gilding.

3.4. *Colour determination*

Different approaches were used for the colour determination in the entrance hall: a) colour measuring devices; b) image and colour processing software; c) naked eye perception which was mostly assisted by specific colour charts. The paint layers were examined using both daylight and controlled flicker-free artificial LED-lighting (Yongnou Digital YN1200, CRI>95+) given their indoor location.

a) The portable tools used for measuring colours were a Konica Minolta Spectrophotometer (CM 2300d) and colorimeters NCS Colourpin SE and NCS Colour Scan 1.0 (RM200). The systems use two different measurements methods: the spectrophotometer provides a spectral response of the colour to light stimulation, translated into physical colour space coordinates, CIE L*a*b* in this case, The operating range of wavelengths of the spectrophotometer is between 360 nm to 740 nm. This type of instrumentation is often used for quick analysis *in situ* or when moving an artwork is impossible (Sanderson, 2015; Ceccarelli *et al*., 2021). The colorimeters give a direct translation into the closest NCS notation and index (perceptive colour) along with related CMYK, RGB, L*a*b*; meaning that it represents the closest match to an existing colour in the NCS chart with its coded name (Kahu *et a*l., 2018).

b) Various pipelines have been developed by researchers for balancing captured images and specific software can be used to process images for documenting colours (Rieger *et al.*, 2016; Gaiani and Ballabeni, 2018). E.g., Adobe Camera RAW allows white balancing images captured with the colour reference X-Rite ColorChecker Classic or Portable; ProfileMaker Professional 5.0 can be used to create an ICC profile assigned to the images; Imatest Master 5.2.4 allows testing the colour fidelity between the reference ColorChecker patch and its radiometrically calibrated image in terms of the mean camera chroma relative to the mean ideal chroma in the CIE colour metric (ΔE^*_{ab}) to estimate perceptibility tolerance of colour quality (Mokrzycki *et al.*, 2011; Gaiani *et al.*, 2019);

c) Visual colour determination using side-by-side comparison with colour charts/fan decks helped to define the closest colours to the historical paints.

Although much more accessible and affordable than colour measurement tools, this vision-based technique is reliant on the researcher's individual colour perception, colour differentiation expertise, lighting conditions and other factors.

The colour charts used were the NCS - Natural Colour System INDEX 1950 colour chart; the NCS colour chart *Kulturkulör för linoljefärg*, developed in collaboration with the Swedish National Heritage Board, which contains 300 colour samples with traditional pigments historically used in linseed-oil paint; and the Caparol 3D system Plus, a more affordable colour chart with a limited selection of samples which resemble historical colours. Alternatively to the use of colour charts, some experts mix a similar colour to the historical paint on site for illustrating it in research documentation, which, however, lacks standard classification.

3.5. *Colour vision experiment*

In the first part of the experiment, the 27 test subjects were asked to describe and determine the colour of two different historical paint layers uncovered on a window scuncheon in two lighting conditions (daylight and spotlight, see Fig. 5) using the NCS INDEX 1950 colour chart. Later, the colours were measured with the colorimeters NCS Colourpin SE and NCS Colour Scan 1.0 RM200, as well as the Konica Minolta Spectrophotometer CM 2300d. In the second part, the test subjects took the colour blindness test developed by Jean Jouannic and the X-Rite hue test online (see references) to evaluate their general colour perception and the ability to differentiate similar hues. Finally, the results of the colour vision tests were compared with the colour determination experiment to evaluate the potential correlation.

Fig. 5. The participants determining the colours of the paint patches in a) daylight and b) under a spotlight.

4. Results

4.1. *Architectural paint analysis*

During the two-day paint investigation, at least eight historical colour schemes (Fig. 6) were discovered in the entrance hall. The earliest pastel scheme probably dates from the Neo-Palladian remodelling conducted shortly after 1804. Another important discovery was that the pointed groin vaults of the room are an essential structure erected simultaneously with the late 18th-c building rather than a decorative form added during the Gothic Revival period. Meanwhile, the plastered surfaces as well as the stucco decor probably date from the early 19th-c Neo-Palladian modernisation of the building. Judging by the paint stratigraphy, the later added pointed doors and windows most likely originate from the mid-to-late 19th century.

Nevertheless, due to the limited time of the workshop, all preliminary findings presented in this section need to be confirmed and elaborated on with further research.

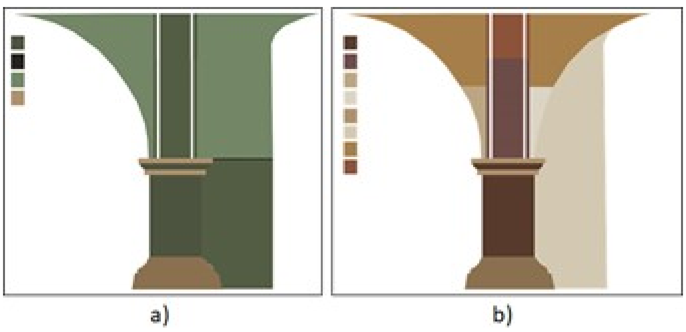

Fig. 6. Visualisation of two relatively recent colour schemes illustrated with the NCS values acquired on the exposures: a) ca 1960s; b) current state of the room.

4.2. *Outcomes of the colour vision test*

19 out of 27 test subjects determined colour matches which were noticeably dissimilar with the most common results of the NCS colour chart determination and colour measurement devices. The colour measurements carried out with three instruments were relatively similar yet visually differentiable, which implies that colorimetric results do not only vary across devices but are also heavily dependent on the specific measuring area.

The two spectrophotometer results for the first dark green colour were also identified by the participants in 14 instances (Fig. 7a). Meanwhile, none of the colorimetric results coincided with each other nor with the colour codes determined by the participants for the second lighter yellowish colour (Fig. 7b). However, the same NCS notation was identified by the test subjects in 24 instances out of 50. This suggests that while human colour vision is fallible and varies, it is still surprisingly similar considering how the results of precise colour measurement devices also differ. Another observation was that participants found it more difficult to identify the darker colour in insufficient natural light, which means ample lighting is paramount for more accurate visual colour determination.

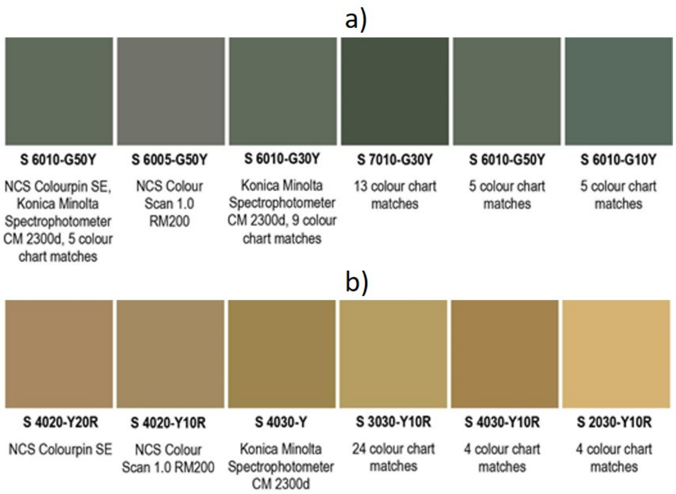

Fig. 7. The results of the colour measurement devices and the most common NCS matches determined by the test subjects for a) the first dark green colour and b) the second lighter yellowish colour.

All but a few test subjects had faultless results in the Jouannic test for general colour blindness while slightly less than half made a few mistakes in the X-Rite hue test. Most commonly, the test subjects had colour vision issues in the turquoise/green area of the spectrum. These results are consistent with the most common form of colour blindness, deuteranomaly (reduced sensitivity to green light; a milder form of deuteranopia, commonly known as daltonism) which effects 5% of males and 0.4% of females (Kalloniatis *et al.*, 2007). The fact that the results for the green colour varied much more also validated the hypothesis that it would be more difficult to ascertain the green colour than the yellowish one. This reflects the studies which have shown that colour blind people mostly retain blue–yellow discrimination, and most colour-blind individuals have limited discrimination along the red–green axis of colour space, with their ability to separate colours in this dimension being reduced (Sembulingam *et al.*, 2012).

4.3. *Colour measurement devices versus visual comparison*

Colour measurement devices enable to quickly and very accurately ascertain colour, although the results can still be dependent on lighting. However, since the historical paint on architectural surfaces is mostly unsmooth, faded, discoloured or cracked, the precision of the measurements depends far more on the measured spot than the specific device used. With instruments like the NCS Colourpin SE it is very difficult to locate an ideal measuring spot due to the lack of a viewing port. The human eye is hence a more precise tool for determining the exact area where the paint is most vibrantly (accurately) preserved. Moreover, while the colour measuring devices can only focus on a very small surface area at a time, our eyes can generalize, evening out the patchy colour of the historical paint surface more adequately. This skill is especially useful for identifying the colours of less opaque paint layers, which have previous layers showing through. Regardless, visual colour determination is still extremely dependent on surrounding lighting, personal colour perception and colour differentiation experience as the results of this experiment clearly showcase. Furthermore, commercial fan decks can be unsustainable due to being discontinued, and the inferior convertibility of the results. On the other hand, although the L*a*b* spectral data received with a spectrophotometer allows to preserve the most accurate and reproducible information about historical paint colours. In conservation practice (e.g. repainting) it is still usually necessary to convert this data into commercially used colour systems like NCS, which potentially causes slight conversion inaccuracies as seen in Fig. 8, which summarizes the colorimetric data acquired in several points.

However, colour charts also have a limited selection of colours, allowing room for imprecision. Still, they are accessible and cost-effective tools for most paint researchers, whereas spectrophotometers can be too costly and require consistent maintenance and re-calibration.

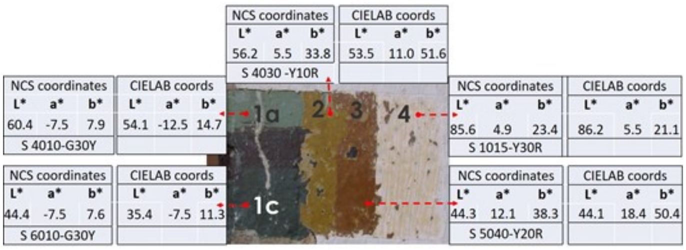

*Fig. 8. NCS and CIE L*a*b* coordinates for the 5 paint layers of an exposure.*

5. Conclusions

The workshop was a successful first attempt at determining the correlation and the differences between colour measurements obtained with visual, digital and spectrophotometric analyses. Additionally, the interdisciplinarity of the workshop participants provided a diversified viewpoint on the subject matter as well as reaching novel and insightful perspectives through international collaboration and expertise. The debate about the pros and cons of various colour measurement and documentation techniques and methodologies is not only applicable to this case study but also generally to the usual workflow adopted by experts with limited time and budget for paint research prior to restoration. The workshop also yielded tangible results in the architectural paint investigation carried out in the Kirna Manor House entrance hall, where many historical colour schemes were discovered.

In general, it should be taken into account that there is no absolute truth in determining the colour of historical paint due to it having been discoloured through time to begin with (see e.g. Krotzer, 2008, Van Velzen, 2018). However, it would be beneficial to implement precise colour measurement devices in architectural paint research more often, while acknowledging that it still requires a trained eye and good colour perception to see where to take the measurements from. Still, they are accessible and cost-effective tools for most paint researchers, whereas spectrophotometers can be too costly and require consistent maintenance and re-calibration. The use of portable and quick-capturing colorimeters could easily be adopted by researchers without excessive costs or added expertise.

Colour charts also remain essential tools because they display painted colours much more realistically than digital screens, thus enabling to directly compare a physical colour sample with the painted architectural surface. Even though colorimetric tools are more accurate than the average human eye, colour charts remain useful for cross-checking the results *in situ*.

Colour measurement devices enable to improve the speed and accuracy of colour measuring and obtain more objective and reproducible data, which can easily be preserved in online databases for subsequent in-depth analysis. Ultimately, visual colour identification and the use of colorimetric instruments are complementary methods which should be utilised in parallel to receive the most comprehensive and accurate results.

The results of the workshop are now used in the Department of Cultural Heritage and Conservation at the Estonian Academy of Arts for the development of a digital documentation system related to colour data collecting and presentation, with the aim of its future application to the restoration of other Estonian historical buildings and potentially also to international case studies.

6. Conflict of interest declaration

Authors declare no conflict of interest.

7. Funding source declaration

Funding of the workshop was provided by the Estonian Academy of Arts and the European Regional Development Fund.

8. Acknowledgment

The authors would like to thank the Estonian Academy of Arts, the organising committee and all the workshop participants for the rewarding experience and productive discussion about different research approaches. Acknowledgements go to Taavi Tiidor for taking the photos included in this paper. Particular gratitude is extended to the owners of Kirna Manor House for hosting the practical part of the workshop.

12. Short biography of the author(s)

Claudia Valge - MA student in Cultural Heritage and Conservation and a lecturer on architectural paint research at the Estonian Academy of Arts. She has supervised several extensive paint research projects on historical wooden houses, carried out paint investigation in various other historical buildings, and was the main organizer of the international colour measurement workshop conducted in Estonia in 2019.

Sofia Ceccarelli - Conservation Scientist, PhD student in the Industrial Engineering Department at the University of Rome Tor Vergata with a thesis on the characterisation of hygroscopic painted supports in Cultural Heritage with non-destructive infrared imaging techniques. She has worked on the high-resolution 3D digitalisation of artworks, colorimetric studies on Cultural Heritage and the development of a web-based platform for sharing metadata in regional projects.

Silvia Bertacchi - Architect, PhD in Survey and Representation of Architecture and Environment at the University of Florence, Research fellow at the Department of Architecture of the University of Bologna. She is expert in 3D survey, photogrammetry, reality-based modelling and optimization for documenting and disseminating Cultural Heritage, including both shape and reliable colours. She is the author of several scientific papers on digitization of Architectural Heritage.

Andres Uueni - Estonian Academy of Arts. Andres has worked in different memory institutions, designing, developing information systems and led many cultural heritage digitisation and documentation projects, focusing on high-resolution imaging technologies. In 2014 Andres was a co-founder of Archaeovision LLC and he has also started a PhD program with the Estonian Academy of Arts which focuses on cultural heritage 3D documentation and multi-spectral imaging.

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BOOK REVIEW: Light - the color of desire

Renata Pompas

Andrea dall'Asta: Light - the color of desire, Ancora Editrice, Milan, 2021.

In this second book dedicated to light in art, Andrea Dall'Asta tackles modernity, after analysing its presence in antiquity in: "The light splendour of truth" (see: Color Culture and Science, nm. 10 - December 2018).
The author, continuing the path of analysis and research on the tension towards light, asks himself whether in contemporary art light is symbolic, physical, or simply functional, and answers in seven chapters: seven interdisciplinary paths starting from Impressionism to monochromy, through the icon-works of some artists, including at the end of the book, also sacred architecture, photography and cinema.

Chapter I - **The Light of Impressionism: completion of a Western journey?**

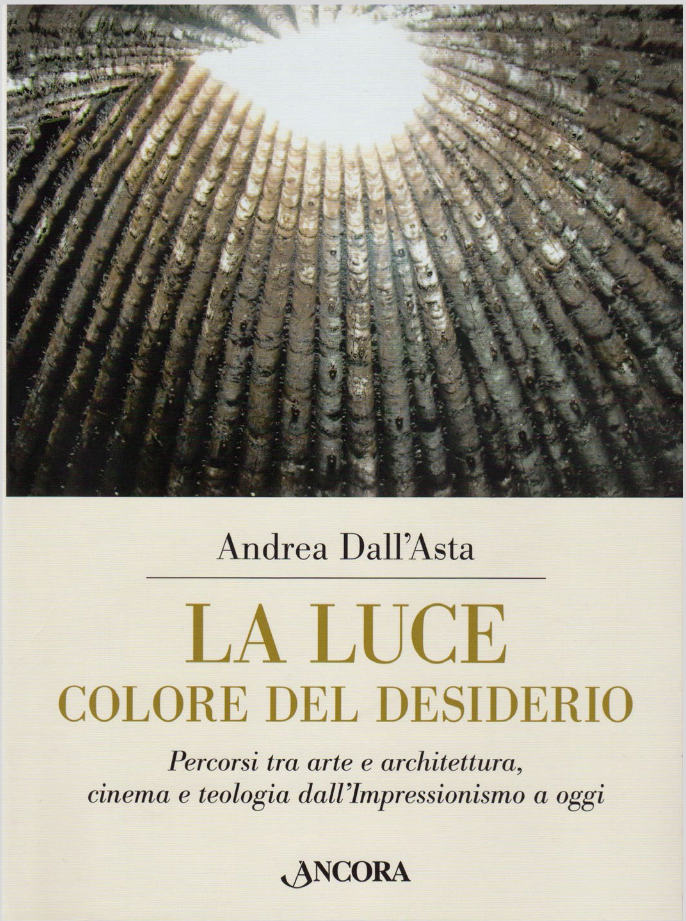
The 19th century ends with Monet's color, who in the landscape in "Impression, sunrise" shows a phenomenological vision of light (1872); with Seurat's color, who in "A Sunday afternoon on the island of Grande-Jatte" shows a system of optical rules (1884); and with Cézanne's color, to whom the author dedicates intense pages, who in "Still life with peaches and pears" (1889) revolutionises the representation of light in the image, in fact: "from within the thing comes a light, as if it were its splendour, its *éclat*".

Chapter II - **The twentieth century: the dissolution of the 'realm' of representation**

In the new century, philosophy rethinks itself, aesthetics and the function of art, which the author compares.

Chapter III - **The modern icon and the spiritual power of color**

The 20th century opened with the renewal of oriental spirituality of Byzantine origin, led by two Russians: Kazimir Malevich and Wassilji Kandinsky, the former with his radical rejection of all representativeness that in the painting "Black Square on a White Background" (1915) partially hides the light of the cosmic white background with the black of alchemic lead and the latter, as a true synesthete, creating the structure of a metaphysics of colors, based on the construction of a sound symphony: a music of the celestial spheres.



Chapter IV - **A journey into the beyond. Beyond the perception**

After the Second World War, research into color and light in art achieved results on the borderline between aesthetics and mysticism.
Yves Klein's radiant colors, reach the limits of visibility through luminous blue; Mark Rothko's colors "create the sensation of an evanescent movement of matter" in which color becomes light, atmosphere, even in the very dark tones of the Rothko Chapel, where they "shine a kind of black light".
The American Barnett Newman vertically crosses his monochromes with zips as rhythm, separation, wound.

Chapter V - **Light is the material of the work!**

There are beautiful the pages dedicated to Lucio Fontana and his relationship between light/space/time and to the spirituality inherent in his works, where the holes and cuts show a further space that "is neither physical nor

perspective, but cosmic, infinite, illuminated by the light that enters and spreads", or to the installations with neon light or Wood's light, where the spectator loses his bearings and feels disoriented.
He describes Nanda Vigo's immateriality of the play of reflections and light; of James Turrell and Irwin's Ganzfeld, the a-directional immersive spaces that seem to be a journey through a giant three-dimensional monochrome; of Dan Flavin's the environments enveloped in the intensity of light-color energy. Then he describes contemporary research on monochrome: the changing colors of David Simpson's canvases, the RGB LED projections of Pietro Mega's "Blue Church", the constant and elusive flow of light in Shay Frisch's modular elements, the meditation on light in Ettore Frani's works.

Chapter VI - **Light in sacred architecture**

In contemporary sacred architecture it is emptiness that dictates the spatial and functional relationships, and light is a protagonist: now purely functional, now symbolic. Dall'Asta looks for the most spiritual expressions, from the beginning of the 20th century to the present day.
The beautiful pages devoted to the chapel in Vence (France) created by Henri Matisse (1949-1951), focus on the warm light of Provence that illuminates the chromatic symphony of the pure colours of the partly transparent and partly frosted stained glass windows. Are at the opposite the 104 aniconic stained-glass windows by Pierre Soulage in Conques (France, 1994) and the Gerard Richter's abstract stained-glass windows in Cologne (Germany, 2007). Tadao Ando's Church of Light in Ibakiri (Japan, 1989) pierces the deep darkness of the ascetic, bare chapel with a cross-shaped slit in the solid concrete walls. Also are described the Friedrich F. Haindl's church in Munich (Germany, 2000), the Peter Zumthor's extraordinary chapel built like "a cave dug into the belly of the world" in Wachendorf (2001). Among the Italians, Mario Botta's churches and the mystical chapel of Villa Serena (2017) by Ettore Spalletti, drowned in the metaphysical silence of its blue hues.

Chapter VII - **Photography and cinema: the landing of a long journey?**

Since photography, as the term itself composed of *phòs-photòs* (light) and *graphé* (writing) says, is "a writing of light", as is cinema, to which movement and time are added, Dall'Asta traces a brief history of the two arts, in which photography and cinema are seamlessly intertwined.

ConclusionsVII

An exciting, well-documented, original and unmissable book for all those who are passionate about art, light and colour.