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From Dyes to Digital: A Scientific Reconstruction of Early Colors

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Abstract

The growing interest in early films highlights the need for their preservation and digital restoration. Scientific methods are essential for analyzing historical coloring techniques and key characteristics for both physical conservation and digital reproduction.

This study applies colorimetric analysis to two early nitrate-based 35mm films—Voleurs de bijoux mystifiés (1906) and Satan fait la noce (1907)—to examine imbibition and au pochoir coloring methods. Spectral transmittance measurements enabled preliminary dye identification, while colorimetric data informed an accurate digital restoration.

This approach aims to (1) expand research on film dyes characterization and (2) establish a material-based method for digital color restoration. By reducing handling of analogue materials, it minimizes deterioration risks, ensuring long-term preservation while maintaining accessibility for study and appreciation.

Introduction

Cinema, with its multifaceted nature and relatively recent recognition as a cultural heritage, has gradually come to be regarded as deserving of preservation, restoration, and protection. For decades, photochemical restoration was the only available method for safeguarding films. However, with the advent of digital technologies, this practice was first complemented and eventually surpassed by digital restoration, marking a significant advancement in film preservation.

Film stock consists of a flexible, transparent, and durable strip of varying length and width, composed of a protective layer, a photosensitive emulsion where the image forms, a support base, and an anti-halation layer. The support layer, the thickest component, can be made of cellulose nitrate, cellulose (di- or tri-) acetate, or polyester. Cellulose nitrate, the earliest support material, was chosen for its flexibility, tensile strength, low water vapor permeability, and excellent mechanical properties. However, due to its flammability and explosive nature, it was replaced by cellulose triacetate, which was later supplanted by polyester in 1945, a material still in use today.

Since the earliest years of cinema, filmmakers have explored various ways to add color to film, either to reproduce the colors of reality or to use color as a narrative expedient. Among the most widespread methods were hand coloring, tinting, and toning (also known as *early cinema colors* or *early colors*). Briefly, tinting refers to the process of dyeing the entire film strip so that the lighter areas of the image take on a particular hue, often used to evoke mood or time of day (e.g., yellow for daylight scenes and blue for night scenes). Toning, on the other hand, involves chemically altering the darker areas (i.e., the silver) of the emulsion so they appear in a specific color, while leaving the lighter parts relatively unaffected (e.g., toning with Prussian blue). Hand coloring was a labor-intensive technique in which each frame was meticulously painted by hand, or using stencils (i.e., *au pochoir*, *stencil color*).

The first step in film preservation is the identification of materials. Film stocks can be identified and characterized primarily through the information printed along their edges, commonly referred to as edge codes. These markings provide crucial details such as the type of support material, manufacturer, production year, and emulsion number; data that are essential for film classification and preservation. In contemporary workflows, edge codes also play a key role in the restoration process: they help configure scanners for digitization, enable digital simulation of film characteristics, and inform decisions related to preservation protocols. However, edge codes and technical specifications are not always available, especially for historical film materials, making film identification a major challenge in early film restoration. For early color films, the identification of the dyes and pigments used in the coloring processes is often particularly challenging. The exact composition of these materials often remains unknown, as standardized references and detailed records are lacking. While historical sources, such as the Pathé coloring manuals [1] and the Mariani books [2], offer valuable insights into early tinting and toning processes, they frequently lack precise chemical correspondences to modern molecular classifications [3]. Many colorants in these sources are referenced using commercial or trade names, making direct correlation with specific chemical compounds difficult. As a result, scientific analysis, particularly spectrophotometry, is crucial in bridging this gap by enabling a more precise identification of materials and a deeper understanding of early cinema's color aesthetics and preservation requirements.

Inaccurate material characterization can have a cascading effect throughout the entire digital restoration workflow. Digital restoration involves converting analog film into a digital format to correct image degradation and encode it onto a viewing medium. One of its key advantages is that it allows the physical film to be safely archived without further handling, preventing additional deterioration. Moreover, it is a non-invasive, non-destructive, and reversible process that can either complement traditional physical restoration or serve as an alternative when the original material is too compromised for conventional methods. To ensure authenticity and avoid artificial alterations, digital restoration adheres to strict principles, including minimal intervention, reversibility, respect for aesthetic intent, and clear documentation of modifications. Achieving these standards requires interdisciplinary expertise to mitigate subjective interpretation. This challenge also extends to color restoration, where comparisons between analog and digital versions often rely on human perception, which is inherently variable due to environmental conditions, display settings, and individual interpretation. As a result, color fidelity is frequently compromised, making accurate reproduction of the film's original hues difficult to achieve.

In this context, spectrophotometric techniques provide a significant advantage by offering objective, quantifiable color data, ensuring greater precision and consistency in film digitization and color correction. By integrating scientific analysis with colorimetric evaluation, this approach supports the preservation of the film's original aesthetic while minimizing the need for direct handling of fragile analog materials. This allows the physical copy to be stored under optimal conservation conditions, reducing the risk of deterioration.

Furthermore, colorimetric analysis standardizes color management, ensuring uniform reproduction across different viewing devices and eliminating distortions caused by variations in scanning, processing, and display technologies. Beyond technical accuracy, this method enhances our understanding of historical coloring techniques and their evolution over time, contributing valuable knowledge to both cultural heritage preservation and digital restoration.

In this study, we analyze two nitrate-based 35mm films to investigate their historical coloring techniques. Through spectrophotometric and colorimetric analysis, we identify some of the dyes used in the imbibition and au pochoir processes, and based on these objective color data, we propose a restoration method that ensures a faithful digital reproduction.

Materials and Methods

Film Materials

This study focuses on two early nitrate-based 35mm films that utilize historical coloring techniques such as tinting and au pochoir.

Voleurs de bijoux mystifiés (1906) was produced by Pathé Frères and has a length of 110 meters. Originally black and white, it was later tinted and colored au pochoir. The film tells the story of a gang of thieves who, using a clever trick, manage to infiltrate a train carriage and steal a chest of jewels. At the end of the journey, the owner discovers the theft and sets off in pursuit of the criminals on a bicycle. During the chase, the thieves accidentally drop the stolen jewels, giving the owner the opportunity to replace them with a bomb—ultimately catching the criminals by surprise.

Satan fait la noce (1907), directed by Louis Feuillade for Gaumont, extends 150 meters and was originally black and white, later enhanced with tinting. The film follows Satan, who falls in love with a woman and decides to leave the underworld to move with her to Paris. As they navigate the city's streets and its vibrant parties, they are relentlessly pursued by Satan’s jealous wife. With the help of two policemen, she ultimately succeeds in dragging him back to the underworld, separating him from his lover.

These films offer valuable insights into early cinematic color techniques, providing a rich foundation for the study of historical dyes and the development of accurate digital color restoration methods.

Spectrophotometric and Colorimetric Analysis

The frames of these films were analyzed using the X-Rite i1Basic spectrophotometer, connected to the i1Toolz software [4], to measure transmittance and perform a colorimetric analysis.

Transmittance spectra have been identified using the database [5]. In order to support the data from [5] in Table 1 we resume the historical dye name, the reference historical bibliography, the modern dye name and the reference database used to derive the absorbance/transmittance spectra used as reference. Here we report just the colorants relevant for the two case studies considered in this publication. The transmittance spectra were processed through colorimetric calculations, initially considering the D65 light source and then the A-type light source. For both illuminants, the XYZ colorimetric coordinates and xy chromaticity coordinates were determined, alongside the Adobe RGB 1998 and sRGB color spaces (10-bit) [6], to evaluate how colors can be accurately reproduced across different display devices during digital restoration and have a color reference for digital color correction.

Furthermore, by analyzing the differences in xy coordinates under the two light sources, the study underlines the importance of light conditions in digital restoration to preserve films’ color authenticity.

Table 1: Selected reference spectra

Historical Dye Name	Historical Reference	Modern dye name	Reference Database
Ponceau NR	Pathé coloring manuals [1]	Acid Red 26	Acid Red 26. PubChem. [7]
Vert Naphtol NB	Pathé coloring manuals [1]	Guinea Green B	Guinea green B. PubChem. [7]
/	/	Chrysodine	Chrysodine. PubChem. [7]
/	/	Methylene Blue	Methylene Blue. PubChem. [7]

Results and Discussion

The following sub-sections present the results of dye identification and colorimetric analysis conducted on two early color films: *Voleurs de bijoux mystifiés* and *Satan fait la noce*. For each title, spectrophotometric methods were used to compare the dyes present on the film with reference spectra from dye databases. These comparisons enabled preliminary hypotheses on the nature of the colorants used, particularly in tinting and pochoir processes.

In parallel, a colorimetric analysis was performed using xy chromaticity coordinates and standardized RGB color spaces to evaluate how the original colors are reproduced on modern digital displays and to guide the color correction strategy adopted during restoration. The detailed results are discussed in the subsections below.

Voleurs de bijoux mystifies: dyes identification

In Figure 1, the similar trend observed between the transmittance spectrum of the dye Acid Red 26 and those of the measured samples suggests the use of this dye on the film. This hypothesis is further supported by the fact that Acid Red 26 is also known as Ponceau NR, a name mentioned in the tinting recipes recorded in [1].

The green dye used for the jewelry exhibits similarities to Guinea Green B; however, the correspondence is not well-defined. In the tinting recipes listed in the book [1], the green dye is referred to as Vert Naphtol NB, which is also known as Guinea Green B. This correspondence provides additional evidence supporting the dye identification hypothesis. Nevertheless, further analysis is necessary to confirm this identification, as discrepancies in the spectra could result from aging effects, such as yellowing, or from dilution or modification of the dye.

Satan fait la noce: dyes identification

To identify the dyes used, the transmittance spectra from the database [5] were compared with those acquired using the i1Basic instrument.

Figure 2 shows that the transmittance spectrum of the orange sample appears consistent with Chrysodine, although the dataset includes a limited selection of orange dyes, and the hue could also result from a mixture of colorants. The transmittance spectrum of blue tinting points closely resembles that of Methylene Blue. In all cases, degradation and aging may have altered the dyes on the film; however, the identifications appear reasonably accurate. Also, in this case, red tinting has been identified as Acid Red 26.

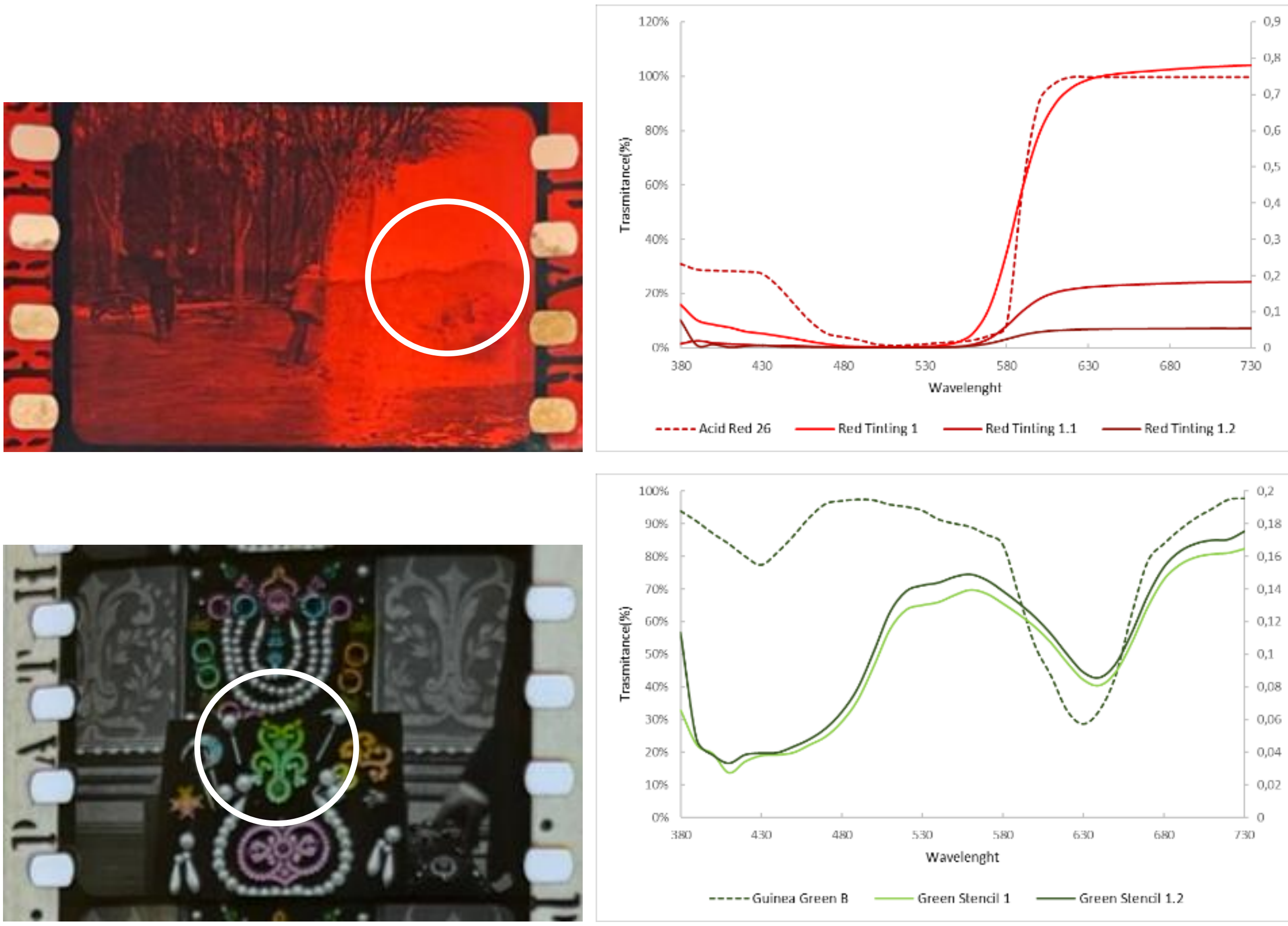

Figure 1. *On the left, the measured area on some reference frames "Red Tinting 1" and "Green Stencil 1" from Voleurs de bijoux mystifiés (1906). On the right, the comparisons of the acquired spectra with some references.*

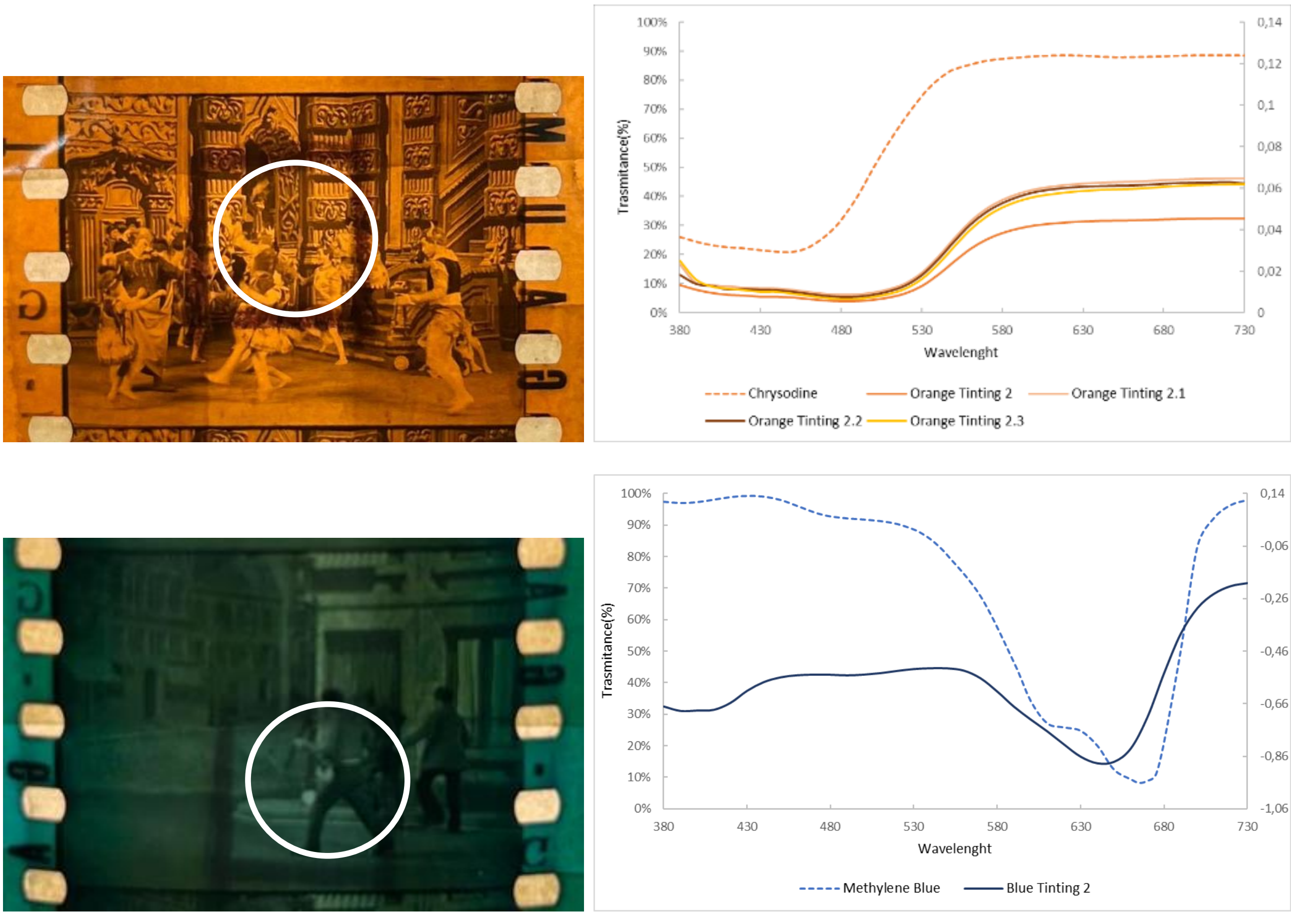

Figure 2. *On the left, the measured area on some reference frames "Orange Tinting 2" and "Blue Tinting 2" from Satan fait la noce (1907). On the right, the comparisons of the acquired spectra with some references.*

Colorimetric analysis

The xy chromaticity coordinates, together with the AdobeRGB 1998 and sRGB color spaces, enabled a detailed analysis of how the original film colors are reproduced on modern display devices. These standardized color spaces provided a framework for evaluating the chromatic fidelity of the scanned material and for guiding the digital color correction process. AdobeRGB 1998 was used as a secondary reference space to evaluate whether a wider gamut might be necessary, given its extensive use in color reproduction. sRGB was selected for the correction process due to its close similarity to Rec.709, the color space adopted as a standard within the film archive's restoration workflow and thus served as the primary working color space throughout the project. In Figure 3 and 4 are represented the xy chromaticities in relation with the chosen color spaces.

For the actual color correction phase, RGB coordinates derived from the xy values were imported into DaVinci Resolve, where they were used to adjust the color balance of the digitized frames. This step was crucial for achieving a more faithful correspondence between the colors of the digital files and those of the original analog frames. The use of 10-bit sRGB values further enhanced the precision of tonal adjustments, allowing for smoother gradients and more accurate color rendition. Overall, this integrated workflow ensured that the final digital restoration maintained a good degree of visual consistency with the historical source material.

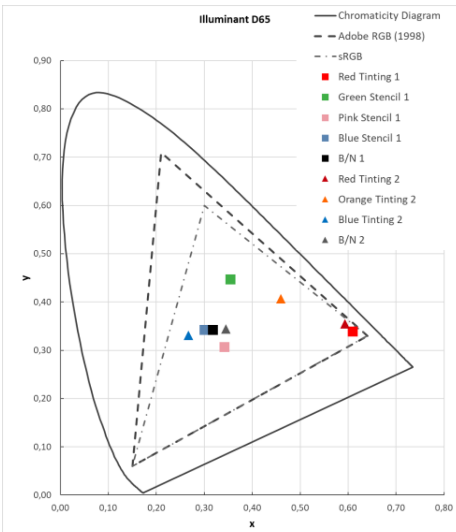

Figure 3. *Chromaticity Diagram – Illuminant D65.*

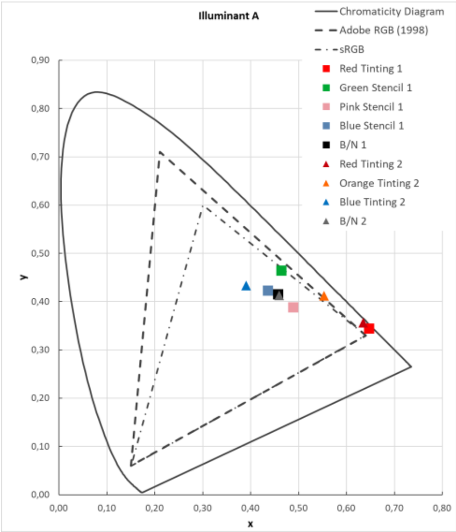

Figure 4. *Chromaticity Diagram – Illuminant A.*

Voleurs de bijoux mystifies: color restoration

The following section presents selected examples of color restoration for the film *Voleurs de bijoux mystifiés*, developed on the basis of the colorimetric analyses previously described.

These examples illustrate how the chromatic data, extracted from the original film elements and interpreted within standardized color spaces, guided the digital correction process.

The goal was to achieve a faithful visual correspondence between the digitized frames and the original analog appearance, while respecting both the historical color aesthetics and the technical constraints of the digital workflow (see Figure 5 and Figure 6).

Figure 5. *On the left, frame before the restoration. On the right, frame after the restoration.*

Figure 6. *On the left, frame before the restoration. On the right, frame after the restoration.*

Satan fait la noce: color restoration

In this section, examples of the color restoration process for *Satan fait la noce* are presented, highlighting how the results of the colorimetric analysis informed the digital adjustments. The restoration aimed to recover the visual character of the original film colors as closely as possible, using chromatic references derived from the scanned material. These guided interventions ensured coherence between the analog source and its digital representation, within the framework of the archive's standardized color workflow (see Figure 7, 8 and 9).

Figure 7. *On the left, frame before the restoration. On the right, frame after the restoration.*

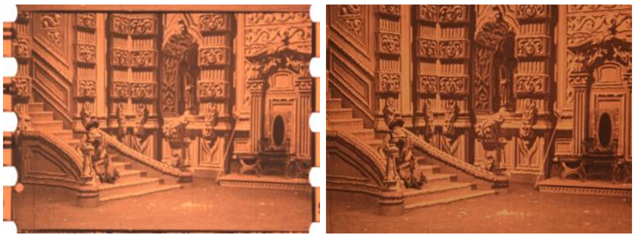

Figure 8. *On the left, frame before the restoration. On the right, frame after the restoration.*

Figure 9. *On the left, frame before the restoration. On the right, frame after the restoration.*

Discussion and Conclusion

This study demonstrates how the integration of spectrophotometric and colorimetric analysis into the digital restoration process can significantly improve the accuracy and consistency of color reconstruction in early films. Through the analysis of *Voleurs de bijoux mystifiés* (1906) and *Satan fait la noce* (1907), we were able to formulate preliminary hypotheses on the dyes used in historical coloring techniques such as tinting and pochoir, and to apply these findings to guide the digital correction process.

One of the key outcomes of this research is the potential to build structured databases based on the characterization of dyes and film materials. Identifying the molecular composition of early film colorants not only supports more faithful reconstructions but also lays the groundwork for creating comparative frameworks, such as color palettes associated with specific production houses or time periods. In the future, this could enable systematic studies on the aging and stability of similar dyes across different films, or more in-depth analyses of historical coloring techniques and their evolution.

Moreover, the objectivity provided by spectrophotometric and colorimetric data offers a concrete advantage in overcoming the subjectivity typically involved in visual color matching. While current methodologies can only reconstruct the color as it has reached us, subject to the effects of time and degradation, the quantification of chromatic values opens the door to future research into unfading techniques. In this perspective, further developments may include predictive models of chemical alteration or the integration of spectral data directly into digital editing software. This would allow real-time adjustments and automated color referencing during restoration, making the workflow faster and more reliable.

Importantly, this case study highlights how the correlation between material analysis and digital restoration is not only feasible but also highly effective when embedded into archival workflows. The use of accessible tools, such as the X-Rite i1Basic spectrophotometer, and integration with industry-standard software like DaVinci Resolve demonstrates that this methodology is scalable and adaptable to various institutional contexts. By streamlining the restoration process while maintaining a strong link to the material evidence, archives can pursue more philologically-informed, consistent, and efficient digital reconstructions.

Ultimately, this approach contributes to both the preservation of film as a physical object and the safeguarding of its visual and cultural identity, enhancing accessibility for future generations of researchers, restorers, and viewers.

Aknowledgements

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Chiara Campagnari has a master degree in Conservation and Restoration of cultural heritage at Università degli Studi di Milano (2024). In 2023/2024 she did your internship at the Cineteca Milano for Image Digitization, and Digital restoration of cinematic films. In 2021/2022 she carried out an internship at the Benedetto Marcello Conservatorio in Venezia for the digitization of paper documents of musical scores degraded by interaction with water and incorrect environmental conditions. She is now working at the Colzani organi snc company (Bulgarograsso, Como) as a restorer of metal organ pipes.

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